BIOL 4640 Study Guide for Exam 2 (Wed 10/28/26): Lecture 20 Internal Structures and Cell Division

Source: Dr. Rowen's lecture slides, in the order of the 2025 Exam 2 study guide outline.
Slide blanks still empty in the notes are filled from the textbook and marked "textbook".
Tags like [L16 p08] give the source page of each line.
Textbook to read (Slonczewski 6e, Textbook page on the site): 3.1 The Bacterial Cell: An Overview; part of 3.3 on the cytoskeleton (Bacterial Cytoskeleton); part of 3.6 on thylakoids, carboxysomes and storage granules; 7.2 Genome Organization (nucleoid and DNA packing); the posted source Bacterial Intracellular Structures. **Also useful:** 3.4 Bacterial Cell Division and 3.5 Cell Asymmetry, Membrane Vesicles, and Extensions (cell division, named on the slides); 4.6 Cell Differentiation (endospores, akinetes, myxospores; not assigned).
(teal italics) = plain meaning of the word before it. ⚠ **Do not mix up = a look-alike pair to keep apart.**

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D. Bacterial Internal Structures (Chapter 3): know types of structures seen in bacteria

Book: 3.1 The Bacterial Cell: An Overview, Model of a Bacterial Cell (chapter 3 PDF, p. 7).

Internal structures outline

Internal structure outline: cytoplasm *(jelly inside the cell membrane)*, ribosomes *(protein building machine)*, cytoskeleton *(inner scaffold of the cell)*, nucleoid *(DNA region without a membrane)*, compartments, inclusions *(clumps of protein and other material)* and granules, endospores *(tough dormant survival form)*. [L20 p03]

Surface and wall

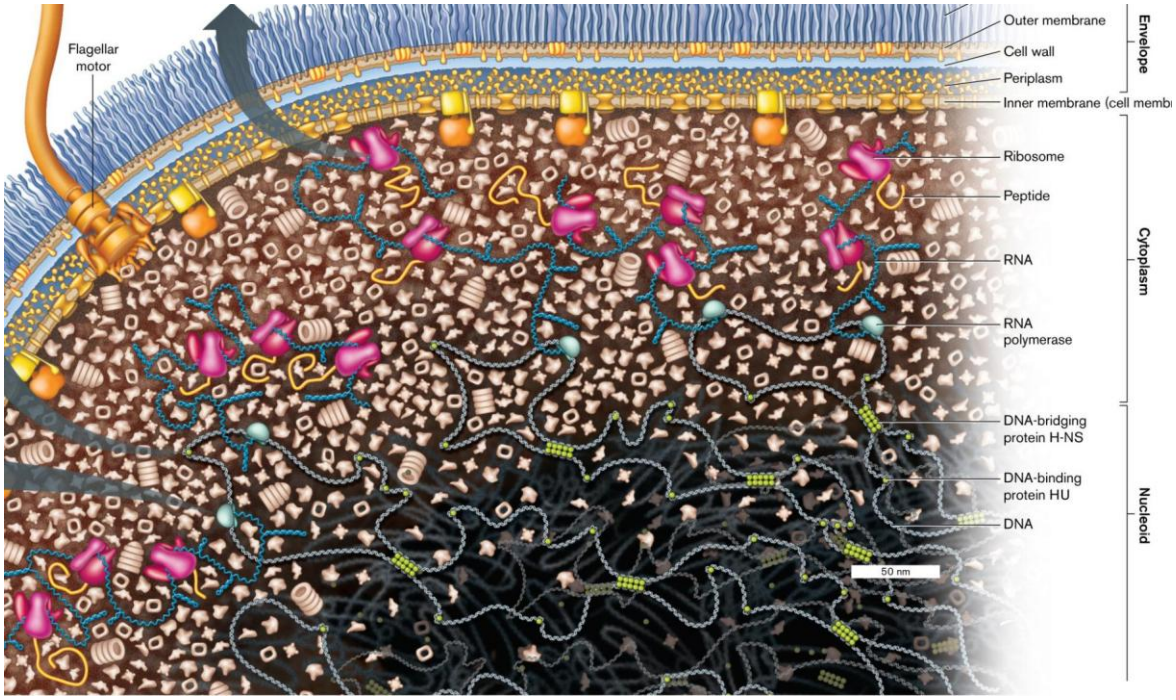
Appendages *(parts that stick out from the surface)* of a **prokaryotic** cell: flagella *(whip tails that spin)*, pili *(thin hairs on the cell)* and **fimbriae** *(short sticky hairs)*. [L20 p04]

Glycocalyx *(sticky coat outside the wall)*: the capsule *(firm sugar coat outside the cell)* and the **slime layer** *(loose sticky coat outside)*. [L20 p04]

Peptidoglycan *(sugar and peptide mesh of the wall)* of an E. coli cell: the murein *(another name for peptidoglycan)* **sacculus** *(bag)*. [L20 p07]

Sacculus: **1 molecule**, **0.8** percent of total weight. [L20 p07]

Cytoplasm contents



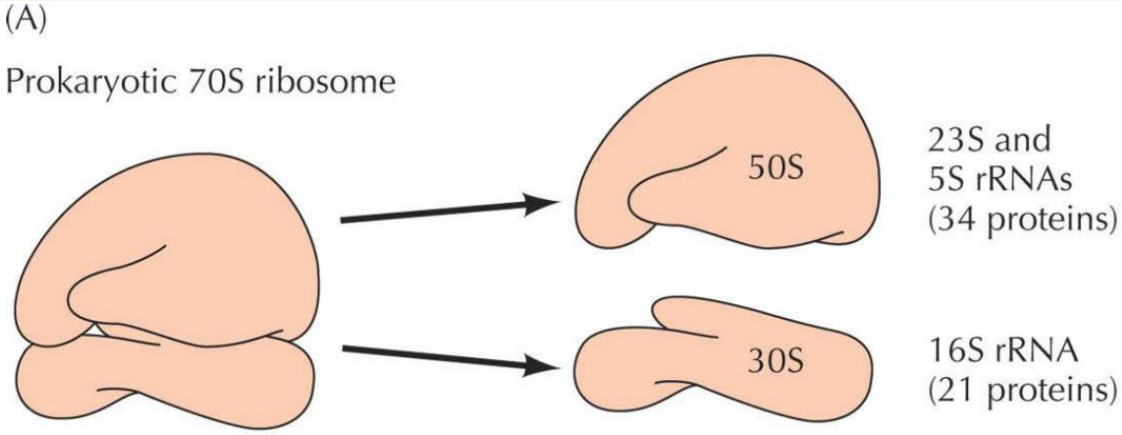
Cytoplasm contents: ribosomes, peptides, RNA and RNA polymerase in the E. coli cell [L20 p06]

On the figure: ribosomes · peptide · RNA · RNA polymerase

Cytoplasm contents: ribosome, **peptide** *(short chain of amino acids)*, **RNA** and **RNA polymerase** *(enzyme copying DNA into RNA)*. [L20 p06]

Polyamines *(small charged helper molecules)* in E. coli: mainly putrescine and **spermidine**. [L20 p07]

Ribosome and inhibitors



Prokaryotic 70S ribosome split into 50S and 30S subunits with their rRNAs [L20 p09]

On the figure: 50S · 23S · 5S · 34 proteins · ribosomes

Large subunit (50S) of the **prokaryotic** ribosome: **23S** and **5S** rRNAs plus **34 proteins**. [L20 p09]

Chloramphenicol inhibits **peptidyl transferase** *(enzyme that joins amino acids)* on the **prokaryotic** large subunit. [L20 p10]

Cycloheximide *(drug blocking eukaryotic peptide bonds)* inhibits peptidyl transferase on the **eukaryotic** *(cells with a nucleus)* large subunit. [L20 p10]

Paromomycin increases the ribosomal *(about protein building machines)* error rate. [L20 p10]

3. Cytoskeleton: types found and roles

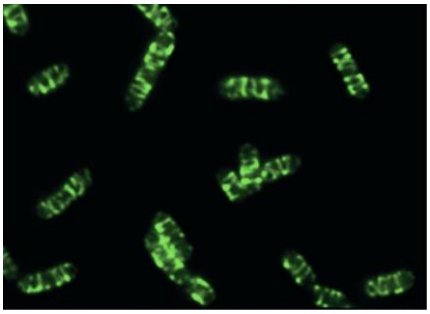
Book: 3.3 The Envelope and Cytoskeleton, Bacterial Cytoskeleton (chapter 3 PDF, p. 67).

⚠ **Do not mix up: Bacteria DO have a cytoskeleton *(inner scaffold of the cell)*: homologs of all three types of eukaryotic *(cells with a nucleus)* cytoskeletal proteins.** [L20 p11]

Cytoskeleton: bacteria have homologs *(related proteins)* of all three types of **eukaryotic** cytoskeletal proteins. [L20 p11]

Roles: cell division, cell polarity *(which end is which)*, cell shape regulation, plasmid *(small extra DNA circle)* partition and other functions. [L20 p11]

Stained actin *(protein of eukaryote thin filaments)* **fibers** show as green bands along rod-shaped cells. [L20 p11]

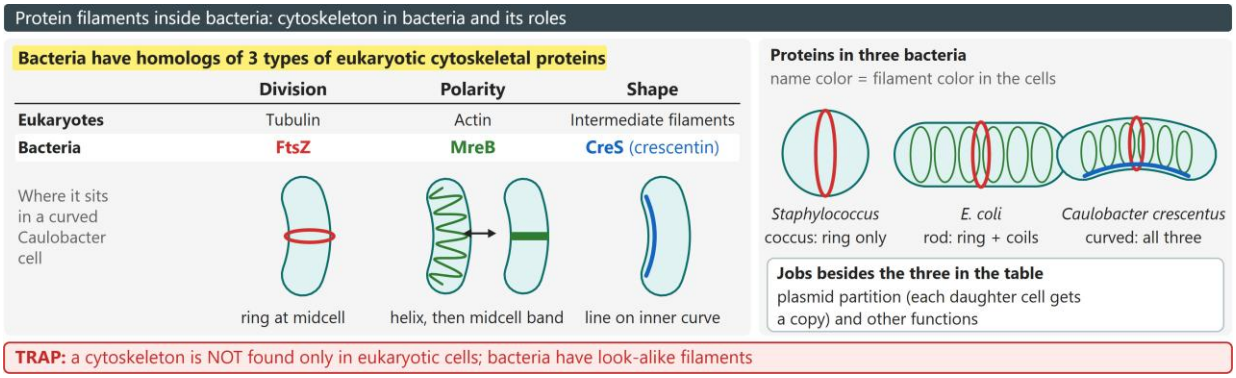


Bacterial cells with green stained actin fiber bands [L20 p11]

FtsZ, MreB and crescentin (CreS): which eukaryotic protein each is like and its role

Book: 3.3 The Envelope and Cytoskeleton, Bacterial Cytoskeleton (chapter 3 PDF, p. 67).

⚠ **Do not mix up: FtsZ *(protein ring for cell splitting)* is like tubulin (division); MreB is like actin (polarity). Do not swap them.** [L20 p11, L20 p12]



FtsZ ring, MreB helix then band, and crescentin line in a curved Caulobacter cell [L20 p11]

On the figure: tubulin · actin · intermediate filaments · FtsZ · MreB · Crescentin · Caulobacter

The three filaments

All 3 types of cytoskeletal filaments play a role in cell shape and cell division. [L20 p12]

FtsZ of the Z ring: similar to **tubulin**. [L20 p12]

The **Z-ring** determines cell diameter and manages growth of the septum *(cross wall)*, the dividing partition (textbook).

MreB:

> Similar to **actin**. [L20 p12]
>
> Travels in a helical arc beneath the cell membrane *(thin skin around the cell)*, guiding peptidoglycan *(sugar and peptide mesh of the wall)* elongation (textbook).
>
> Forms a **helix** *(spiral coil)* along the cell first, then gathers as a band at midcell. [L20 p11]

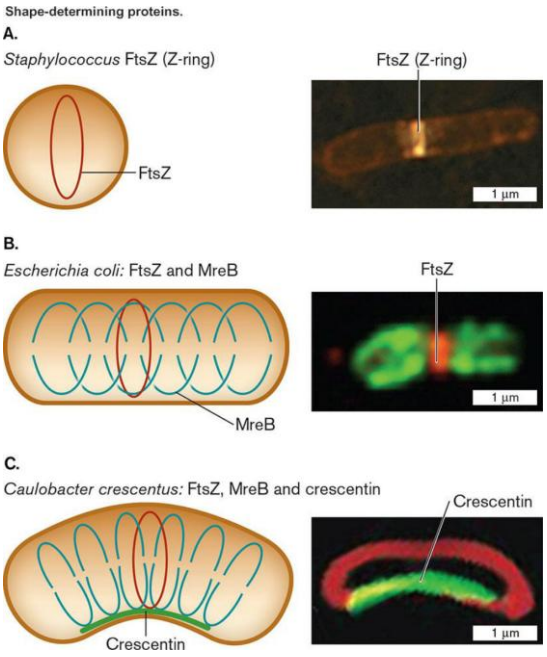
Crescentin *(protein that keeps the cell curved)*: similar to **intermediate filaments** *(rope-like eukaryote filaments)*. [L20 p12]

Shape-determining proteins

Staphylococcus (a coccus): FtsZ forms the Z ring around the middle of the cell. [L20 p12]

E. coli (a rod): an FtsZ ring at midcell plus **MreB** helices along the cell. [L20 p12]

Caulobacter crescentus (curved): FtsZ midcell ring, MreB helices, crescentin along the inner curve. [L20 p12]



FtsZ in a coccus; FtsZ and MreB in E. coli; plus crescentin in Caulobacter [L20 p12]

On the figure: FtsZ · MreB · Crescentin · Staphylococcus · E. coli · Caulobacter crescentus

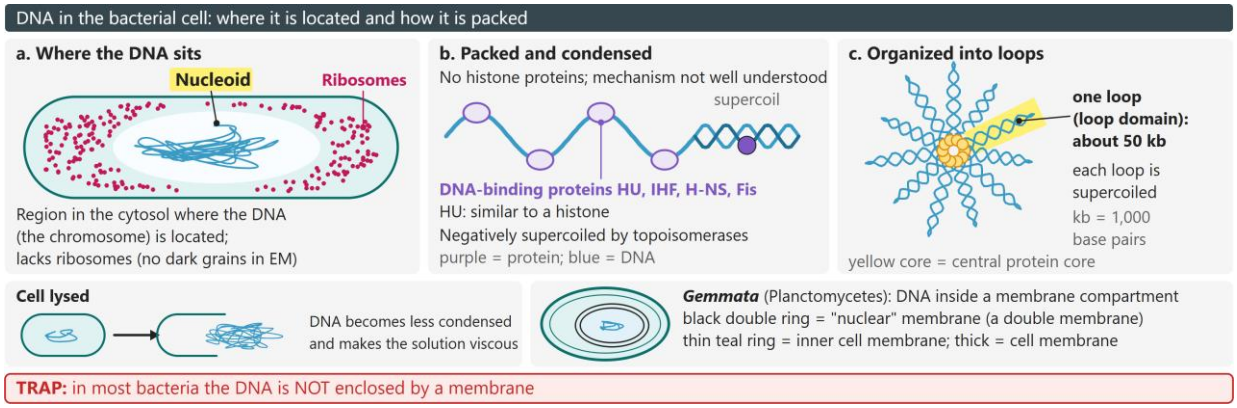
Cytoskeleton proteins: eukaryote vs bacteria

Role	Eukaryotic protein	Bacterial homolog	Caulobacter localization
Division	Tubulin	FtsZ (Z ring)	Ring at midcell
Polarity	Actin	MreB	Helix along the cell, then a band at midcell
Shape	Intermediate filaments	CreS (crescentin)	Line along the inner curve

Table source: [L20 p11, L20 p12]

4. Nucleoid: DNA and packing proteins

Book: 7.2 Genome Organization, Bacterial Chromosomes Are Compacted into a Nucleoid (chapter 7 PDF, p. 21); 3.4 Bacterial Cell Division, DNA Is Organized in the Nucleoid (chapter 3 PDF, p. 81).



Where the DNA sits, how it is packed, loop domain and the Gemmata membranes [L20 p13]

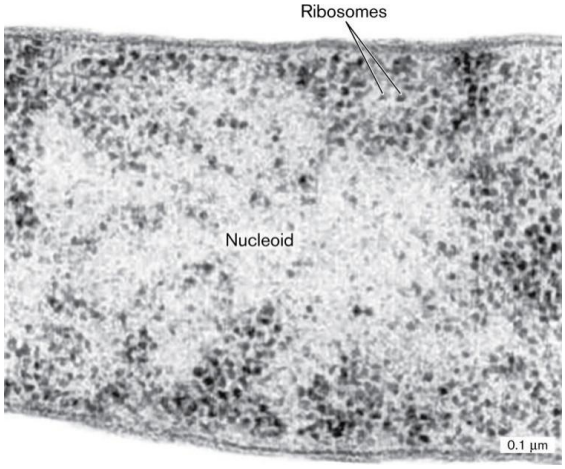
On the figure: Nucleoid · loop domains · Gemmata

> **Nucleoid** *(the cell DNA region)* topics: DNA *(cell genetic instruction molecule)* location, DNA packing, **loop domains**, a membrane *(thin lipid layer)* compartment. [L20 p13, L20 p15, L20 p17, L20 p18]

a. Nucleoid region: where the DNA is located

Book: 3.4 Bacterial Cell Division, DNA Is Organized in the Nucleoid (chapter 3 PDF, p. 81); 7.2 Genome Organization, Bacterial Chromosomes Are Compacted into a Nucleoid (chapter 7 PDF, p. 21).

⚠ **Do not mix up: The nucleoid *(the cell DNA region)* is the area WITHOUT ribosomes *(protein building machine)*; the dark grains around it are ribosomes.** [L20 p13]



Electron micrograph: pale nucleoid region without ribosomes, dark ribosome grains around it [L20 p13]

On the figure: nucleoid · ribosomes

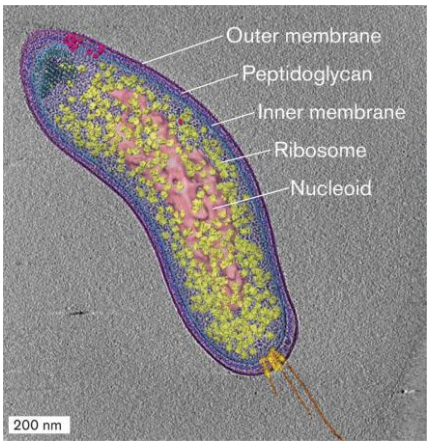
Nucleoid: region in the cytosol *(liquid part of the cytoplasm)* where chromosomal DNA *(cell genetic instruction molecule)* is located. [L20 p13]

Lacks ribosomes: in an electron micrograph, ribosomes are the black dots or grains. [L20 p13]

In an electron micrograph the nucleoid is the lighter area; ribosome-filled cytoplasm *(jelly inside the cell membrane)* is darker. [L20 p13]

Bdellovibrio bacteriovorus: colorized cryo-electron tomograph *(3D electron microscope picture)* of one cell. [L20 p14]

Bdellovibrio tomograph: outer membrane *(extra membrane outside the wall)*, peptidoglycan *(sugar and peptide mesh of the wall)*, inner membrane *(the skin around the cytoplasm)*, ribosome and nucleoid. [L20 p14]



Cryo-electron tomograph of one Bdellovibrio cell with its membranes, ribosomes and nucleoid [L20 p14]

On the figure: outer membrane · peptidoglycan · inner membrane · ribosomes · nucleoid

b. How bacterial DNA is packed: no histones, DNA binding proteins, supercoiling

Book: 7.2 Genome Organization, DNA Supercoiling Compacts the Chromosome (chapter 7 PDF, p. 24); 7.2 Genome Organization, Topoisomerases Supercoil DNA (chapter 7 PDF, p. 33).

⚠ **Do not mix up: Bacteria have NO histones *(eukaryote protein that DNA winds around)*; HU *(DNA binding protein)* is only similar to a histone.** [L20 p15]

Packing basics

Bacterial DNA *(cell genetic instruction molecule)* **is packed and condensed**; the mechanism is not well understood. [L20 p15]

No histone proteins in bacteria. [L20 p15]

DNA binding proteins

Proteins that bind DNA: HU, IHF, H-NS *(DNA bridging protein)* and Fis help pack it, in part. [L20 p15]

These proteins bind DNA but with low sequence specificity *(not tied to one exact DNA sequence)*. [L20 p15]

HU is similar to a histone protein. [L20 p15]

Supercoiling and loops

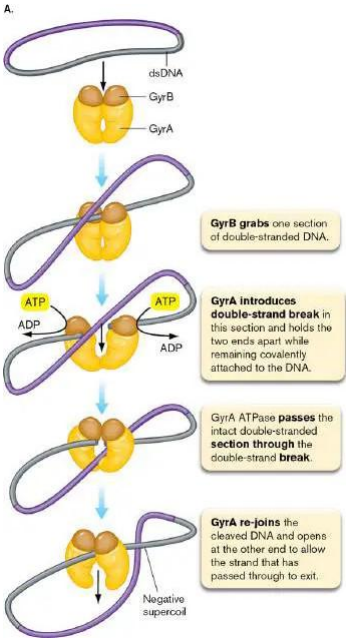
Supercoiling: the DNA is negatively supercoiled *(underwound, then twisted into coils)* by topoisomerases *(enzymes that twist or untwist DNA)*. [L20 p15]

DNA gyrase *(enzyme that coils DNA)*, a type II topoisomerase, introduces **negative supercoils** and uses **ATP** (textbook).

In loops: the packed DNA is arranged in loops. [L20 p15]

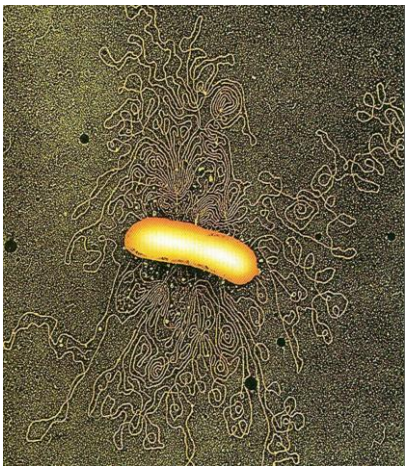
After the cell is lysed

After the cell is lysed *(broken open)* the DNA becomes less condensed. [L20 p16]



DNA gyrase makes a negative supercoil using ATP [textbook 7.10]

On the figure: ATP · negative supercoils



Uncondensed DNA spread around one lysed bacterial cell [L20 p16]

Released DNA can make the solution viscous *(thick)*. [L20 p16]

Uncondensed DNA released from one bacterial cell spreads all around it. [L20 p16]

c. Loop domains of about 50 kB

Book: 7.2 Genome Organization, DNA Supercoiling Compacts the Chromosome (chapter 7 PDF, p. 24).

⚠ **Do not mix up: Not 1,000 nm loops: each loop holds about 50 kB; 1,000 nm is the whole structure.** [L20 p17]

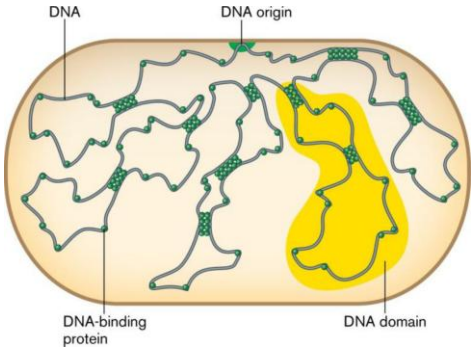
What loop domains are

Loop domains: DNA *(cell genetic instruction molecule)* is organized into loops of about **50** kB and supercoiled *(twisted into coils)*. [L20 p17]

Attachment points: the chromosome *(one long DNA molecule)* attaches to itself about once every **50** kb, forming a loop. [L20 p17]

DNA-binding proteins hold the loops; one loop is a DNA domain. [L20 p17]

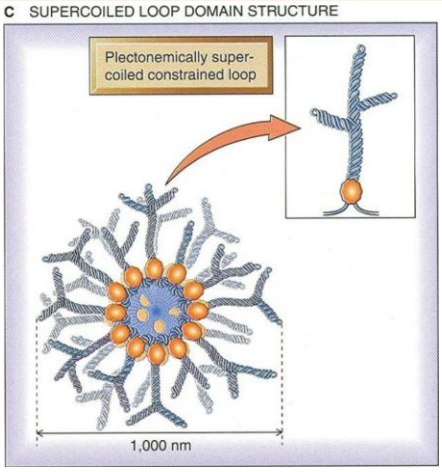
The DNA origin sits at the cell envelope *(layers wrapped around the cell)*. [L20 p17]



Chromosome loops held by DNA-binding proteins; one loop is a DNA domain [L20 p17]

On the figure: DNA-binding proteins · DNA domain · DNA

Supercoiled loops



Supercoiled loop domain structure, about 1,000 nm across, with one constrained loop [L20 p17]

On the figure: supercoiled loop domain structure · 1,000 nm · plectonemically · constrained

Supercoiled: the looped DNA is also supercoiled. [L20 p17]

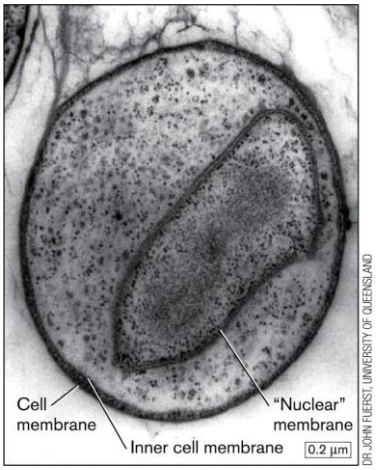
Each loop is a **plectonemically** *(twisted around itself like a coiled phone cord)* supercoiled **constrained** loop. [L20 p17]

Supercoiled loop domain structure: about 1,000 nm across. [L20 p17]

d. DNA inside a membrane compartment (Gemmata, Planctomycetes)

Book: Not in the assigned textbook sections; see the posted source "Bacterial Intracellular Structures".

⚠ **Do not mix up: The chromosome *(one long DNA molecule)* sits inside TWO membranes *(thin lipid layer)*: the double nuclear membrane and the inner cell membrane *(membrane that lies inside another membrane)*.** [L20 p18]



Gemmata: cell membrane, inner cell membrane and nuclear membrane around the chromosome [L20 p18]

On the figure: cell membrane · inner cell membrane · nuclear membrane

One type of bacterium (Planctomycetes): DNA *(cell genetic instruction molecule)* appears to sit inside a membrane compartment. [L20 p18]

Gemmata is that bacterium. [L20 p18]

Chromosome inside two membranes: the nuclear membrane (a double membrane) and the inner cell membrane. [L20 p18]

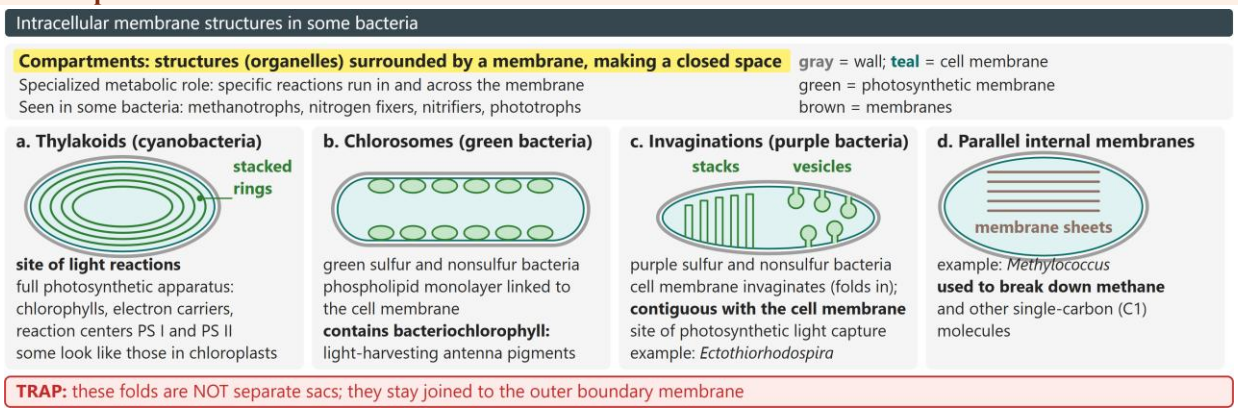
Gemmata membranes: the cell membrane *(thin skin around the cell)*, the inner cell membrane and the nuclear membrane. [L20 p18]

5. Compartments: intracellular membrane structures (know some examples and their role)

Book: 3.6 Specialized Structures, Thylakoids, Carboxysomes, and Storage Granules (chapter 3 PDF, p. 119).

⚠ **Do not mix up: Compartments are surrounded by a lipid membrane *(thin fat skin)*; gas vesicles *(gas filled floating bubbles)* and carboxysomes *(protein-shell bodies that fix carbon dioxide)* have a protein shell.** [L20 p19, L20 p30, L20 p31]

What compartments are



Membrane compartments: thylakoids, chlorosomes, invaginations and methanotroph membranes [L20 p23]

On the figure: Compartments · methanotrophs · nitrogen fixers · nitrifiers · phototrophs · thylakoids

Compartments: structures (organelles) surrounded by a lipid membrane, thus making a compartment. [L20 p19]

Seen in some bacteria: methanotrophs *(bacteria that use methane)*, nitrogen fixers, nitrifiers *(bacteria that turn ammonia into nitrate)*, phototrophs *(organisms that use light for energy)*. [L20 p19]

Specialized physiological role *(a special job in the cell)*: they carry out specific metabolic reactions in and across the membrane. [L20 p19]

Photosynthesis example

Example: photosynthesis. [L20 p19]

Phototroph *(organism that uses light for energy)* **examples**: **thylakoids** *(membrane sacs for photosynthesis)* and tubular, vesicular and lamellar *(in flat sheets)* internal membranes in phototrophic bacteria. [L20 p20, L20 p21]

Intracellular membrane structures are found in many types of phototrophic bacteria. [L20 p20, L20 p21]

Intracellular membrane structures

Membrane structure	Found in	Built how	Role
Thylakoids	Cyanobacteria	Stacked membranes with full lipid bilayers, some like chloroplast thylakoids	Site of light harvesting reactions
Chlorosomes	Green sulfur and nonsulfur bacteria	Single phospholipid monolayer linked to the cell membrane	Contain light harvesting pigments
Invaginations	Purple sulfur and nonsulfur bacteria	Cell membrane folds inward and stays contiguous with it	Photosynthetic light capture reactions
Membrane compartments	Methanotrophs (Methylococcus)	Stacks of internal membranes	Breakdown of methane and other one carbon molecules

Table source: [L20 p23, L20 p25, L20 p26, L20 p27, L20 p28]

a. Thylakoids in cyanobacteria

Book: 3.6 Specialized Structures, Thylakoids, Carboxysomes, and Storage Granules (chapter 3 PDF, p. 119).

⚠ **Do not mix up: Thylakoids *(membrane sacs for photosynthesis)* = cyanobacteria; chlorosomes *(light catching sacs)* = green bacteria; invaginations *(inward folds)* = purple bacteria.** [L20 p21, L20 p24, L20 p26]

What thylakoids are

Thylakoids *(flat membrane sacs for photosynthesis)*: found in cyanobacteria. [L20 p21, L20 p22]

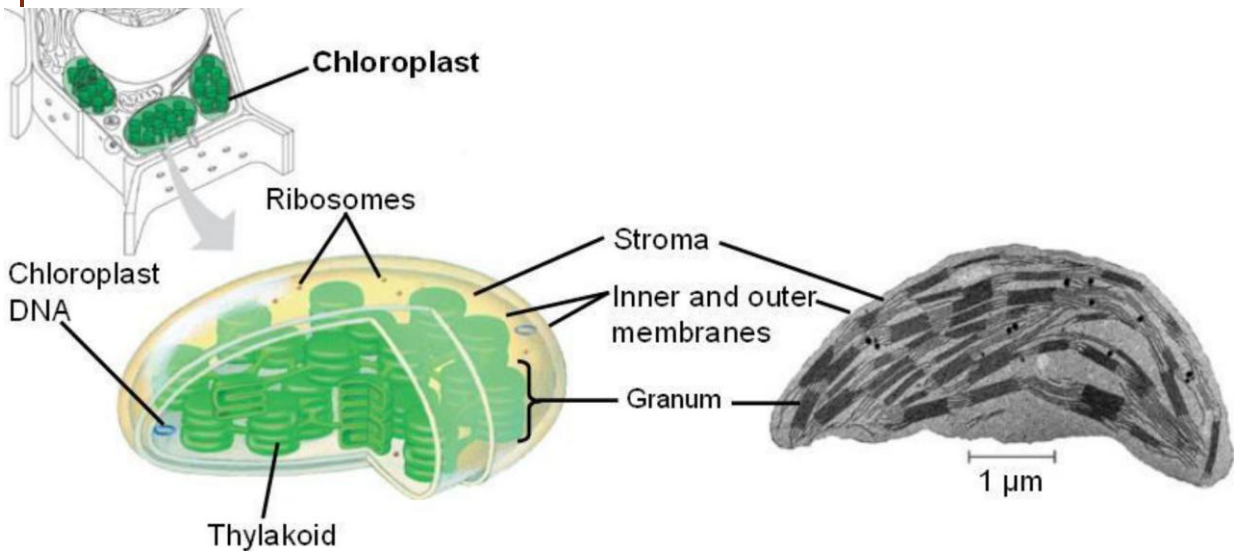
Thylakoids are the site of light harvesting reactions. [L20 p23]

Thylakoid membranes *(thin lipid layer)* have full lipid bilayers *(two-layer membranes, like a normal membrane)*. [L20 p23]

Compared with chloroplasts

Some are similar to the thylakoids in chloroplasts *(plant part that does photosynthesis)*: stacked thylakoid membranes. [L20 p21, L20 p22]

Chloroplast parts: stroma, inner and outer membranes *(extra membrane outside the wall)*, **granum** and thylakoid. [L20 p22]



Chloroplast parts: stroma, inner and outer membranes, granum and thylakoid [L20 p22]

On the figure: chloroplasts · stroma · inner and outer membranes · granum · Thylakoids

Cyanobacteria and examples

Cyanobacteria with oxygen: oxygenic *(gives off oxygen)* phototrophy; chlorophyll *(green light-catching pigment)* a/b in **thylakoids**. [L20 p21]

Cyanobacteria without oxygen (-O2): photolithoautotrophy on reduced sulfur. [L20 p21]

Cyanobacteria reaction centers: PS I and PS II. [L20 p21]

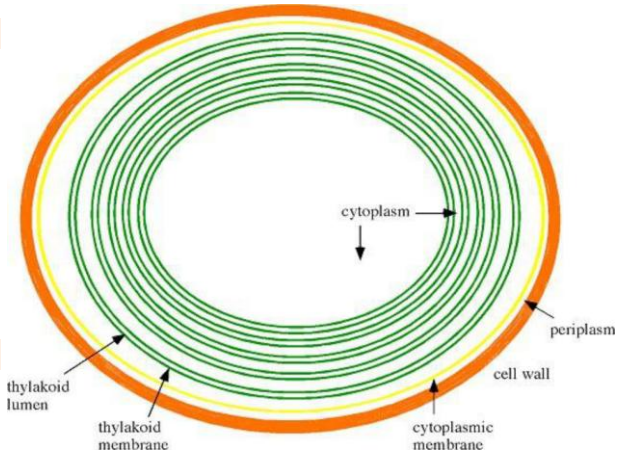
Example: the cyanobacteria example is **Anabaena**. [L20 p21]

Prochlorococcus

Prochlorococcus, a marine phototroph *(organism that uses light for energy)*: concentric thylakoid layers, carboxysomes *(protein-shell bodies that fix carbon dioxide)* in the center. [L20 p23]

Prochlorococcus cell layers: **periplasm** *(space between the two membranes)*, **cell wall** *(stiff layer around the cell membrane)*, **cytoplasmic** membrane, thylakoid membrane and thylakoid **lumen** *(inner space)*. [L20 p23]

The thylakoid membrane surrounds the lumen. [L20 p23]



Prochlorococcus cell layers: periplasm, cell wall, cytoplasmic membrane, thylakoid membrane, lumen [L20 p23]

On the figure: periplasm · cell wall · Thylakoid membranes · lumen

b. Chlorosomes in green bacteria

Book: Not in the assigned textbook sections; see the posted source "Bacterial Intracellular Structures".

⚠ **Do not mix up: A chlorosome has a SINGLE phospholipid *(membrane fat with a charged head)* monolayer *(one layer)*, not a bilayer *(two layers)*, linked to the cell membrane *(thin skin around the cell)*.** [L20 p25]

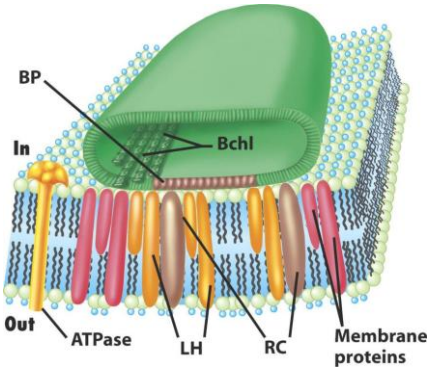
Chlorosome structure

Chlorosomes *(light catching sacs)*: found in green sulfur and green nonsulfur phototrophic bacteria. [L20 p24, L20 p25]

Chlorosome membrane: a single phospholipid monolayer linked to the cell membrane. [L20 p24, L20 p25]

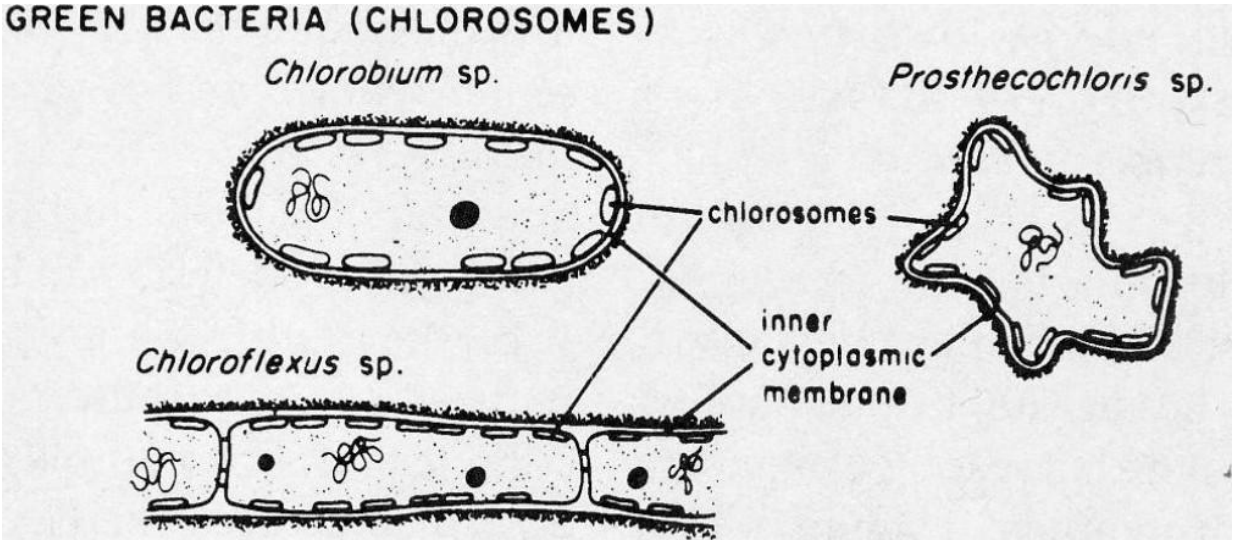
Contains light harvesting pigments *(pigments that catch light)*. [L20 p24, L20 p25]

Chlorosome: it sits on the cell membrane on the baseplate (**BP**); bacteriochlorophyll (**Bchl**) is inside it. [L20 p25]



Chlorosome on the baseplate BP with bacteriochlorophyll inside, sitting on the membrane [L20 p25]

On the figure: BP · Bchl



Chlorosomes along the inner cytoplasmic membrane in Chlorobium, Prosthecochloris and Chloroflexus [L20 p25]

On the figure: Chlorosomes · Chlorobium · Prosthecochloris · Chloroflexus · inner cytoplasmic membrane

> **Chlorosomes** in **Chlorobium**, **Prosthecochloris** and **Chloroflexus** lie along the **inner cytoplasmic membrane**. [L20 p25]

Green nonsulfur bacteria

> **Chloroflexi** (green nonsulfur) have chlorosomes with BChl c/d, reaction center PS II. [L20 p24]
>
> **Chloroflexus** with oxygen uses **heterotrophy** *(food from ready-made organic matter)*; without oxygen it does photoheterotrophy or uses reduced sulfur. [L20 p21, L20 p24]

Green sulfur bacteria

> **Chlorobi** (green sulfur):
>
> > Chlorosomes with BChl c/d/e, reaction center PS I.
> >
> > Live **only** without oxygen (-O2 **only**): photolithoautotrophy on reduced sulfur. [L20 p24]

Example names

> **Chlorobium** is the green sulfur example; **Chloroflexus** is the green nonsulfur example. [L20 p24]

c. Membrane invaginations in purple bacteria

Book: Not in the assigned textbook sections; see the posted source "Bacterial Intracellular Structures".

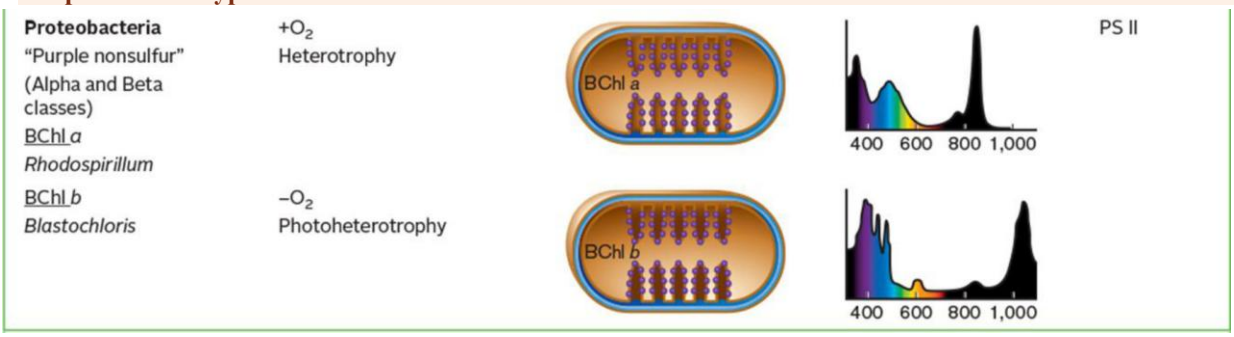
⚠ **Do not mix up: In purple bacteria the cell membrane *(thin skin around the cell)* folds inward; the folds stay CONTIGUOUS *(still joined)* with it.** [L20 p26, L20 p27]

Membrane folds inward

> **Purple sulfur and nonsulfur bacteria**: the cell membrane folds inward (invaginations). [L20 p26, L20 p27]
>
> **Contiguous with the cell membrane**, but the site of photosynthetic reactions. [L20 p26, L20 p27]

Invaginated membrane becomes the site of photosynthetic light capture reactions. [L20 p26, L20 p27]

Purple bacteria types



Purple nonsulfur Proteobacteria: BChl a or b, heterotrophy with oxygen, photoheterotrophy without [L20 p26]

On the figure: BChl a · heterotrophy · photoheterotrophy · PS II

Purple bacteria use **BChl a** or b, reaction center **PS II**. [L20 p26]

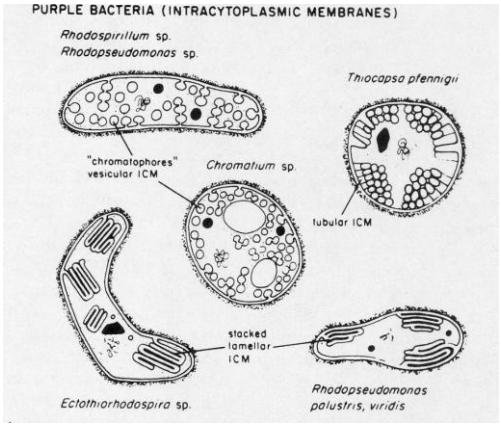
Purple nonsulfur bacteria (Alpha and Beta classes): **heterotrophy** with oxygen, **photoheterotrophy** *(light for energy, ready-made organic food for carbon)* without oxygen. [L20 p26]

Purple sulfur bacteria (Gamma class): the example is **Chromatium**. [L20 p26]

Membrane shapes

Purple bacteria membrane types: **vesicular chromatophores**, **tubular** (Thiocapsa pfennigii) and **stacked lamellar** *(in flat sheets)* membranes. [L20 p27]

Ectothiorhodospira: a curved cell packed with stacked membranes. [L20 p27]



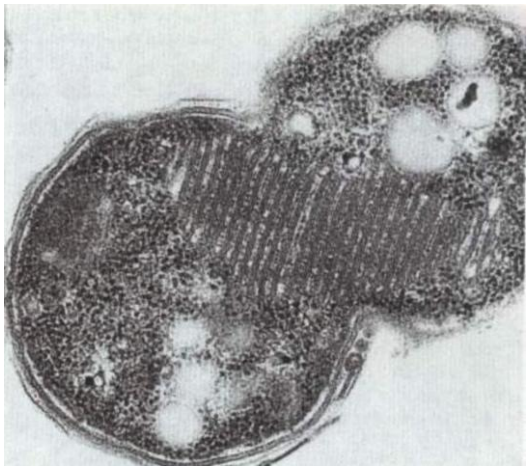
Purple bacteria membranes: vesicular chromatophores, tubular and stacked lamellar [L20 p27]

On the figure: vesicular · tubular · stacked lamellar · Ectothiorhodospira · chromatophores

d. Membrane compartments in methanotrophs

Book: Not in the assigned textbook sections; see the posted source "Bacterial Intracellular Structures".

⚠ **Do not mix up: Methanotroph *(bacterium that uses methane)* internal membranes *(stacked lipid layers)* break down methane; purple bacteria membranes capture light.** [L20 p28, L20 p27]



Methylococcus: a stack of parallel internal membranes across the cell [L20 p28]

Methanotrophs *(bacteria that use methane)*: have membrane compartments. [L20 p28]

Role: breakdown of methane and other one carbon molecules. [L20 p28]

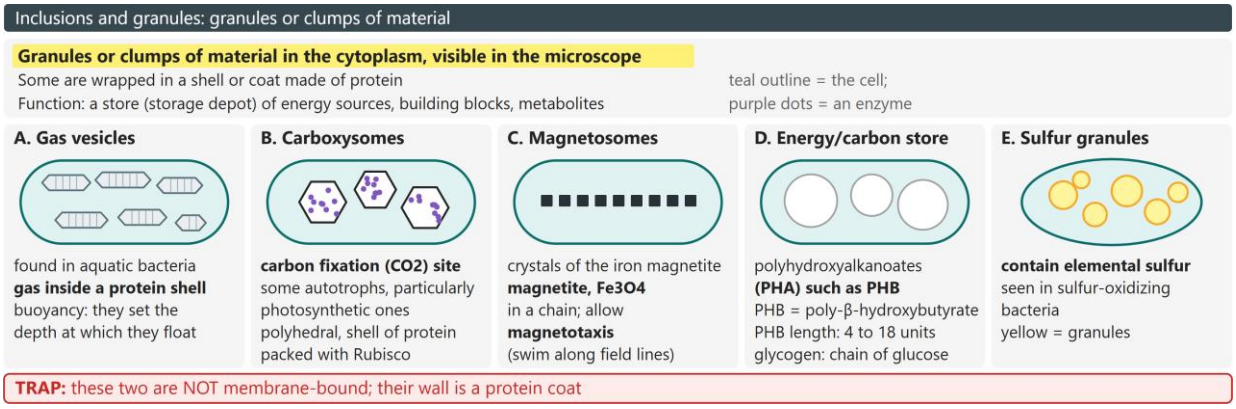
Methylococcus: a large stack of parallel internal membranes across the cell. [L20 p28]

6. Inclusions and granules (gas vesicles, carboxysomes, energy and carbon storage polymers, sulfur granules)

Book: 3.6 Specialized Structures, Thylakoids, Carboxysomes, and Storage Granules (chapter 3 PDF, p. 119).

⚠ **Do not mix up: Inclusions *(clumps of protein and other material)* are granules or clumps in the cytoplasm *(jelly inside the cell membrane)*; compartments are surrounded by a membrane *(thin lipid skin)*.** [L20 p29, L20 p19]

What inclusions are



Inclusions and granules: gas vesicles, carboxysomes, magnetosomes, storage and sulfur granules [L20 p30]

On the figure: Inclusions and granules · gas vesicles · carboxysomes · protein

Inclusions and granules: granules or clumps of material in the cytoplasm. [L20 p29]

Visible in the microscope. [L20 p29]

Some have a shell or coat of **protein** or a single monolayer *(one layer)* of lipids. [L20 p29]

Function: a store of energy sources, building blocks and metabolites *(small working molecules of the cell)*. [L20 p29]

Not membrane compartments

Gas vesicles *(gas filled floating bubbles)* **and carboxysomes** *(protein-shell bodies that fix carbon dioxide)* are classed as inclusions. [L20 p30, L20 p31]

Both have a protein shell, not a membrane. [L20 p19, L20 p30, L20 p31]

Watch out: both enclose a space, but their wall is a protein shell, not a membrane. [L20 p29, L20 p31]

Inclusions and granules

Inclusion	What it is	Role or where found
Gas vesicles	Gas stored inside a protein shell	Aquatic bacteria; buoyancy to control the depth they float at
Carboxysomes	Polyhedral structures with a protein shell	Site of carbon fixing (CO2) in some autotrophs, especially photosynthetic ones
Magnetosomes	Crystal of iron magnetite, Fe3O4	Magnetotaxis
Energy and carbon storage granules	PHA such as poly-beta-hydroxybutyrate; glycogen, a chain of glucose	Store energy and carbon
Sulfur granules	Elemental sulfur	Sulfur oxidizing bacteria

Table source: [L20 p30, L20 p31, L20 p32, L20 p33, L20 p34]

A. Gas vesicles

Book: 3.6 Specialized Structures, Thylakoids, Carboxysomes, and Storage Granules (chapter 3 PDF, p. 119).

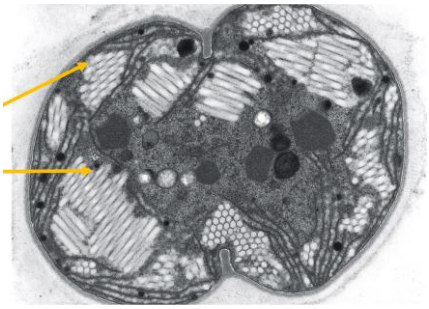
⚠ **Do not mix up: The gas vesicle wall is a protein shell, NOT a lipid membrane *(thin fat layer)*.** [L20 p30]

Gas vesicles *(gas filled floating bubbles)*:

> Store gases within a protein shell.
>
> Are packed in bundles inside the cell. [L20 p30]

Found in aquatic bacteria: they confer buoyancy *(ability to float)*. [L20 p30]

Buoyancy lets the cell control the depth at which it floats. [L20 p30]



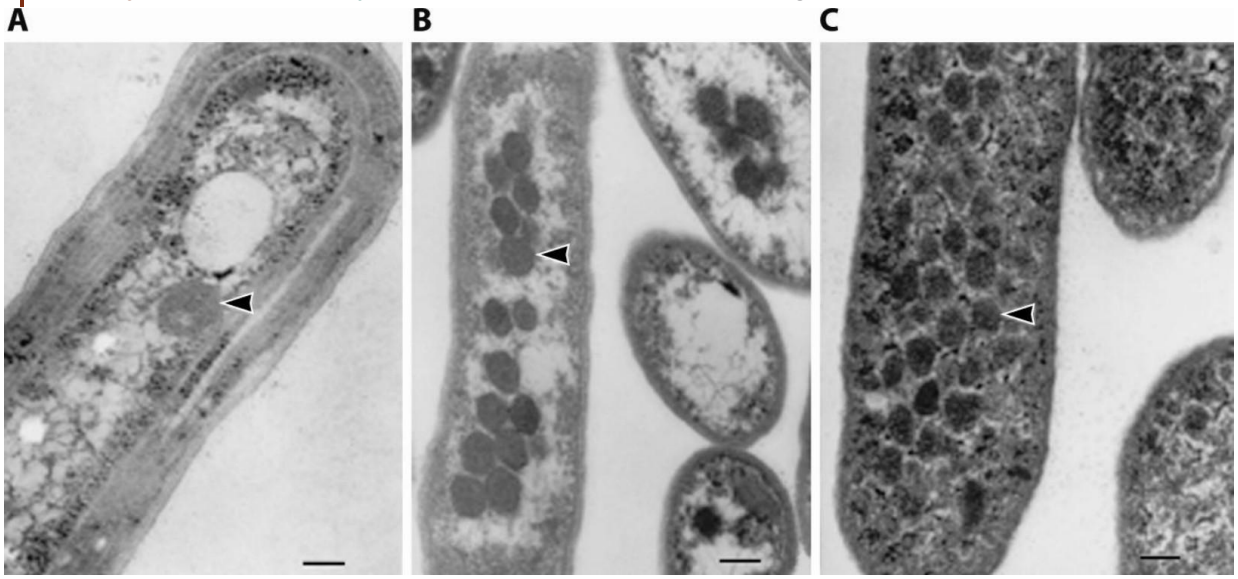
Gas vesicle bundles in a cell; arrows point to them [L20 p30]

B. Carboxysomes

Book: 3.6 Specialized Structures, Thylakoids, Carboxysomes, and Storage Granules (chapter 3 PDF, p. 119).

⚠ **Do not mix up: Carboxysomes *(protein-shell bodies that fix carbon dioxide)* are the site of carbon fixing (CO_2); gas vesicles *(gas filled floating bubbles)* store gases. Both have protein shells.** [L20 p31, L20 p30]

Carboxysomes *(bodies that fix carbon dioxide)*: site of carbon fixing (CO_2). [L20 p31]



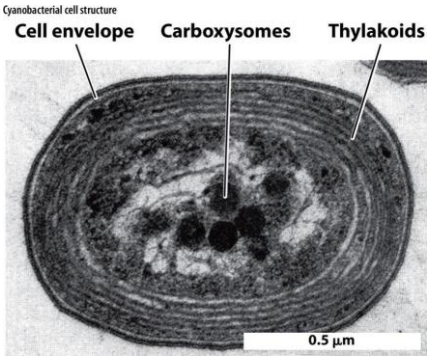
Carboxysomes: dark polyhedral bodies at the arrowheads [L20 p31]

Polyhedral structures with a protein shell. [L20 p31]

Associated with autotrophs *(organisms that make food from CO_2)*. [L20 p31]

Found in some autotrophic bacteria (use CO_2), particularly photosynthetic ones. [L20 p31]

Prochlorococcus has **carboxysomes** in the cell center, inside the **thylakoid** rings. [L20 p23]



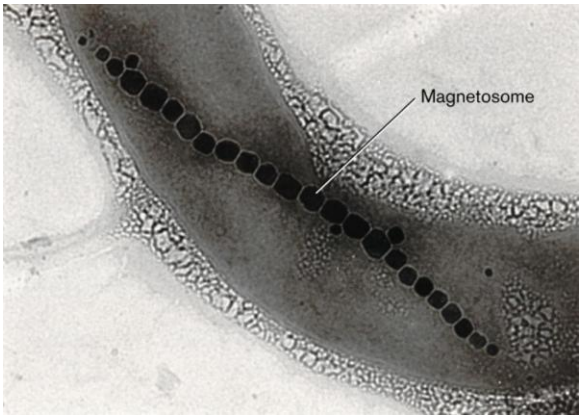
Cyanobacterial cell: carboxysomes in the center inside the thylakoid rings [L20 p23]

On the figure: Carboxysomes · thylakoid

C. Magnetosomes

Book: Not in the assigned textbook sections; see the posted source "Bacterial Intracellular Structures".

⚠ **Do not mix up: Magnetosomes give magnetotaxis *(moving along magnetic field lines)*; gas vesicles *(gas filled floating bubbles)* give buoyancy *(ability to float)*.** [L20 p32, L20 p30]



A chain of dark magnetite crystals along the cell [L20 p32]
On the figure: Magnetosomes

- **Magnetosomes**:
  - A crystal of iron magnetite *(magnetic iron mineral)*, Fe3O4.
  - Form a chain of dark magnetite crystals along the cell. [L20 p32]
- **Magnetite**, Fe3O4, is an **iron oxide** *(iron bound to oxygen)*. [L20 p32]
- **Allow magnetotaxis** *(moving along magnetic field lines)*. [L20 p32]

D. Energy and carbon storage granules (PHA, glycogen)

Book: 3.6 Specialized Structures, Thylakoids, Carboxysomes, and Storage Granules (chapter 3 PDF, p. 119).

⚠ **Do not mix up: Glycogen *(stored chain of glucose)* is a chain of glucose; PHA such as poly-beta-hydroxybutyrate is a different polymer.** [L20 p33]

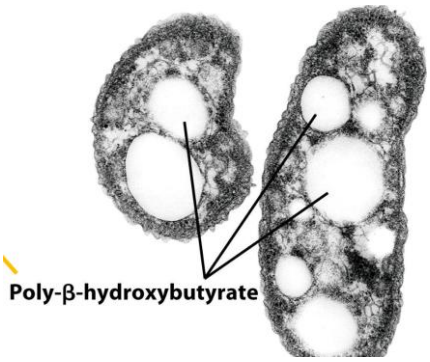
Energy and carbon storage granules: two kinds, PHA and glycogen. [L20 p33]

Polyhydroxyalkanoates (PHA), such as **poly-beta-hydroxybutyrate**. [L20 p33]

Poly-beta-hydroxybutyrate chain length: **4** to **18** units. [L20 p33]

Poly-beta-hydroxybutyrate granules are large and light, filling the cells. [L20 p33]

Glycogen: a chain of glucose. [L20 p33]

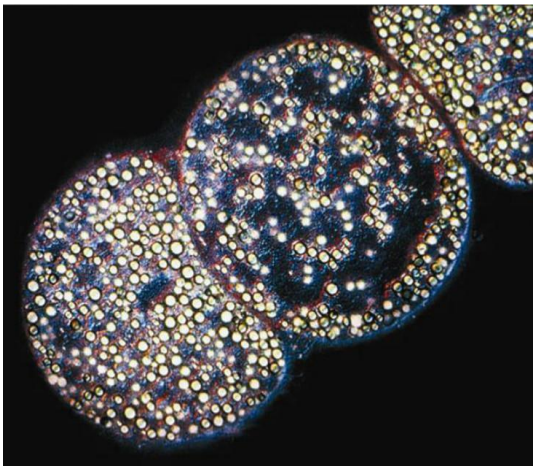


Poly-beta-hydroxybutyrate granules filling the cells [L20 p33]
On the figure: poly-beta-hydroxybutyrate

E. Sulfur granules

Book: 3.6 Specialized Structures, Thylakoids, Carboxysomes, and Storage Granules (chapter 3 PDF, p. 119).

⚠ **Do not mix up: Sulfur granules hold elemental sulfur; magnetosomes hold iron magnetite *(magnetic iron mineral)* crystals.** [L20 p34, L20 p32]



Bright sulfur granules packing large round cells [L20 p34]

> **Sulfur granules**: contain elemental sulfur. [L20 p34]
> **Seen in** sulfur oxidizing bacteria. [L20 p34]
> **Sulfur granules** are bright and pack large round cells. [L20 p34]

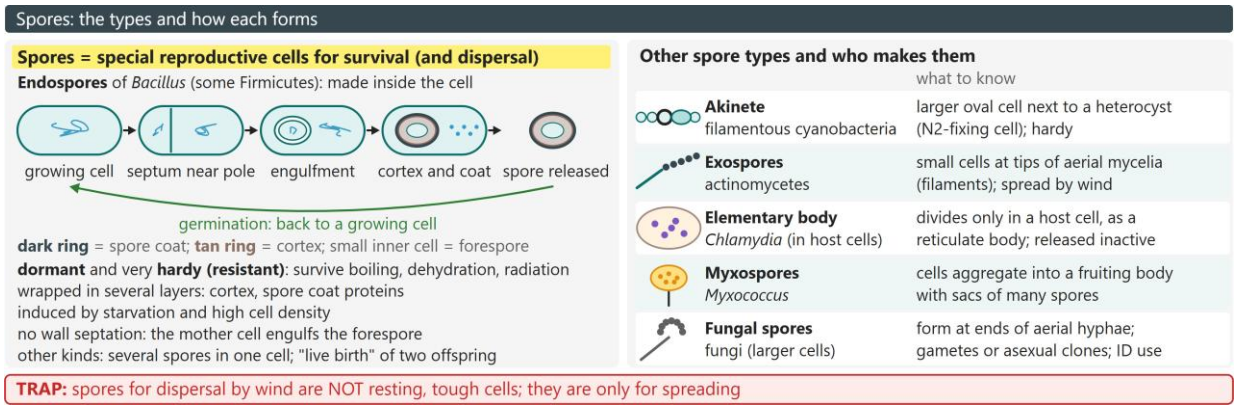
7. Endospore: what they are

Book: 3.5 Cell Asymmetry, Membrane Vesicles, and Extensions, Growth Asymmetry and Polar Aging (chapter 3 PDF, p. 103).

⚠ **Do not mix up: Endospores *(tough dormant survival form)* form INSIDE the cell; exospores form at the tips of aerial mycelia *(mats of filaments)*.** [L20 p35, L20 p45]

Spores and their types

Spores are special reproductive cells for survival or dispersal. [L20 p35]



Spore types and who makes them, and endospore formation inside the cell [L20 p35]

On the figure: akinete · elementary body · Endospores · myxospore · forespore · mother cell

> **Spore types in bacteria**: **akinete** *(hardy resting cell)*, arthrospore (exospore), **elementary body**, endospore, **myxospore**. [L20 p35]

Endospores

> **Endospores**:
>> A few bacteria form spores inside the cell.
>> Made by Firmicutes *(Gram positive group that includes Bacillus)*. [L20 p35]
>
> **Endospore triggers**: carbon, nitrogen or phosphate *(a mineral nutrient)* starvation, low pH, peptide *(short chain of amino acids)* antibiotics. [L20 p35]
>
> **Endospore formation**: **mother cell** and **forespore** *(the part that becomes the spore)*; coat reinforced by keratin and calcium dipicolinate. [L20 p35]
>
> **Endospore properties**: highly heat and desiccation *(drying out)* resistant; viable for centuries, possibly thousands of years. [L20 p35]

Endospores of Bacillus: features and the stages of formation

Book: Not in the assigned sections (endospore stages are in 4.6, not assigned).

⚠ **Do not mix up: Cortex *(thick spore wall layer)* peptidoglycan *(sugar and peptide mesh of the wall)* comes in Stage V; dipicolinic acid *(heat-protecting spore chemical)* and calcium come in Stage VI.** [L20 p36]

Features

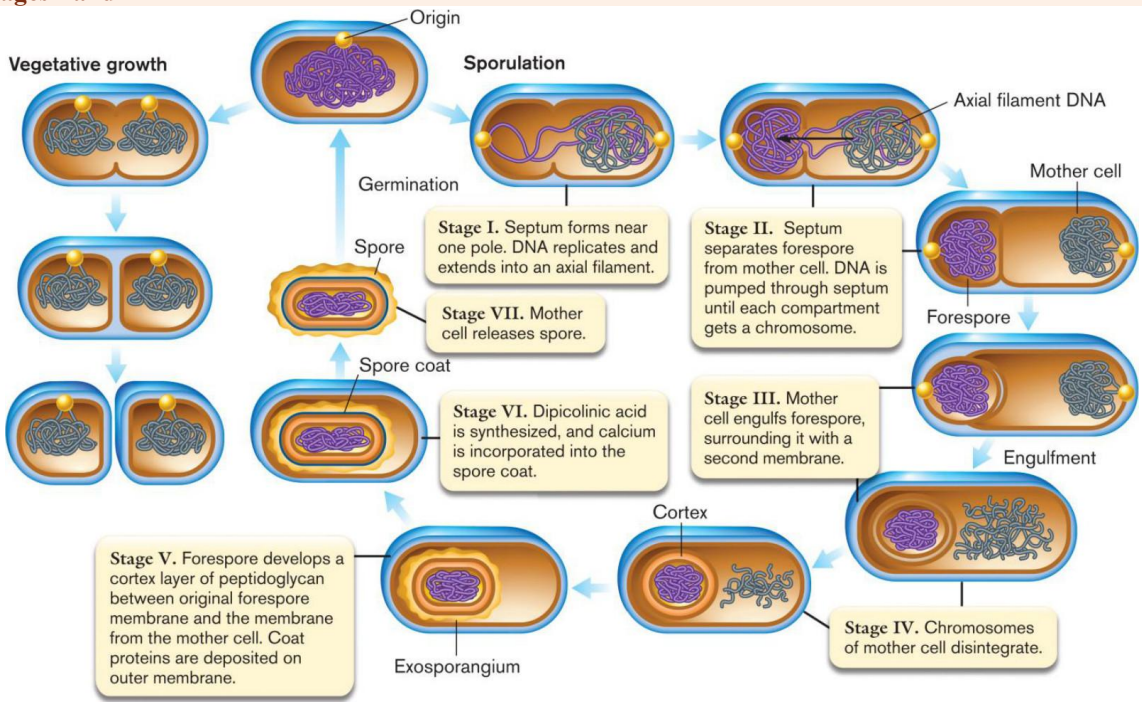
Endospores *(tough dormant survival form)* **of Bacillus** are dormant *(inactive, not growing)* and very hardy. [L20 p36]

They survive boiling, dehydration and radiation. [L20 p36]

Wrapped in several coats. [L20 p36]

Induced by starvation and high cell density. [L20 p36]

Stages I and II



Seven stages of endospore formation with mother cell, forespore, cortex and exosporangium [L20 p36]

On the figure: mother cell · forespore · axial filament · Cortex · Exosporangium · Stage VI

Stage I: septum *(cross wall)* forms near one pole; DNA *(cell genetic instruction molecule)* replicates, extends into an **axial filament** *(stretched-out DNA strand)*. [L20 p36]

Stage II: septum separates **forespore** *(the part that becomes the spore)* from **mother cell**; DNA is pumped through the septum. [L20 p36]

Stage II, also: pumping continues until each compartment gets a chromosome *(one long DNA molecule)*. [L20 p36]

Stages III to V

Stage III: mother cell engulfs forespore; a second membrane (from the mother cell) surrounds it. [L20 p36]

Stage IV: chromosomes of the mother cell disintegrate. [L20 p36]

Stage V: forespore develops a **cortex** of peptidoglycan between its two membranes. [L20 p36]

Stage V, also: coat proteins are deposited on the outer membrane (from the mother cell). [L20 p36]

Exosporangium: named at Stage V, when coat proteins are deposited on the outer membrane. [L20 p36]

Stages VI and VII

Stage VI: dipicolinic acid is made; calcium is incorporated into the spore coat. [L20 p36]

Stage VII: mother cell releases the spore; it can germinate back into a vegetative cell *(normal growing cell)*. [L20 p36]

E. Cell division and Differentiation (sections 3.4, 3.5 and posted article)

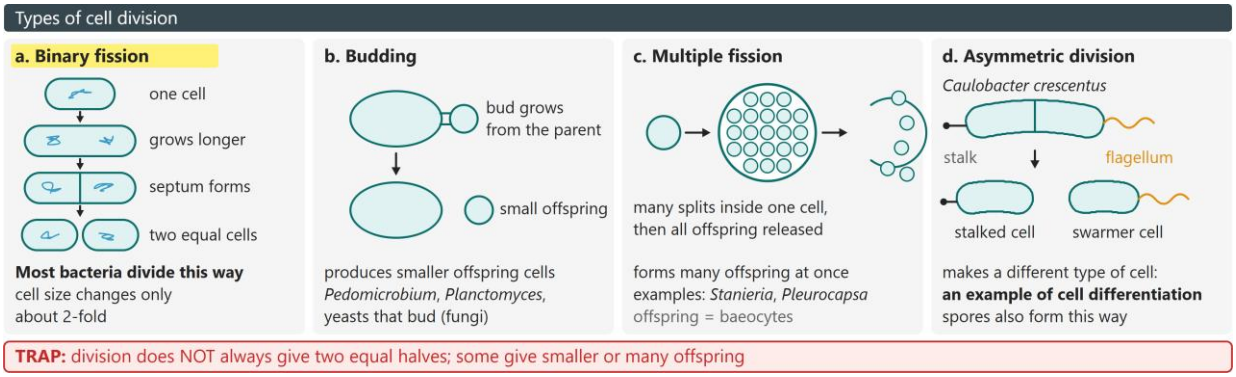
Book: 3.4 Bacterial Cell Division (chapter 3 PDF, p. 78); 3.5 Cell Asymmetry, Membrane Vesicles, and Extensions (chapter 3 PDF, p. 99).

Cell division topics: types, steps, mechanism, cell polarity *(which end is which)* after division, and division proteins. [L20 p37, L20 p38]

1. Features and Types of Cell division in bacteria

Book: 3.4 Bacterial Cell Division (chapter 3 PDF, p. 78).

⚠ **Do not mix up: Budding gives SMALLER offspring; binary fission gives two equal cells.** [L20 p39, L20 p40]



Binary fission, budding, multiple fission and asymmetric division [L20 p39]

On the figure: binary fission · Budding · multiple fission · Caulobacter crescentus

Four types: binary fission, budding, multiple fission, asymmetric cell division. [L20 p39, L20 p42]

Asymmetric division gives examples of cell differentiation *(becoming a different cell type)*: stalked cells of Caulobacter crescentus, and spores. [L20 p39, L20 p42]

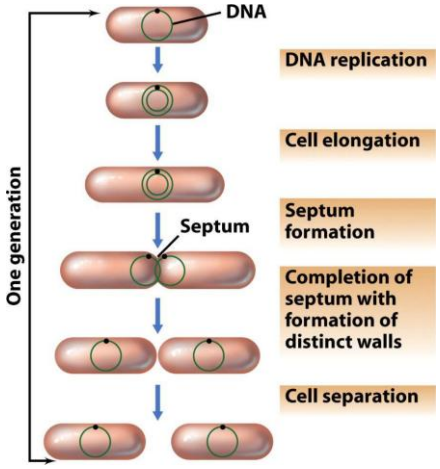
Types of cell division

Type	Offspring	Examples
Binary fission	Two cells; usually **only** a small change in cell size (**2** fold)	Most bacteria
Budding	Smaller offspring cells	Pedomicrobium, Planctomyces, budding yeast (fungi)
Multiple fission	Multiple offspring by multiple fission events, usually in a sac	Stanieria, Pleurocapsa
Asymmetric cell division	A different type of cell	Caulobacter stalked and swarmer cells; spores

Table source: [L20 p39, L20 p40, L20 p41, L20 p42]

a. Binary fission

Book: 3.4 Bacterial Cell Division (chapter 3 PDF, p. 78); 3.4 Bacterial Cell Division, Cell Division by Septation (chapter 3 PDF, p. 78).



One generation of binary fission: replication, elongation, septum, walls, separation [L20 p39]

On the figure: DNA replication · cell elongation · septum formation · distinct walls

Most bacteria divide by binary fission: usually **only** a small change in cell size (**2** fold). [L20 p39]

One generation: DNA *(cell genetic instruction molecule)* replication, **cell elongation**, septum *(cross wall)* formation. [L20 p39]

Then the septum is completed with **distinct walls**, then the cells separate. [L20 p39]

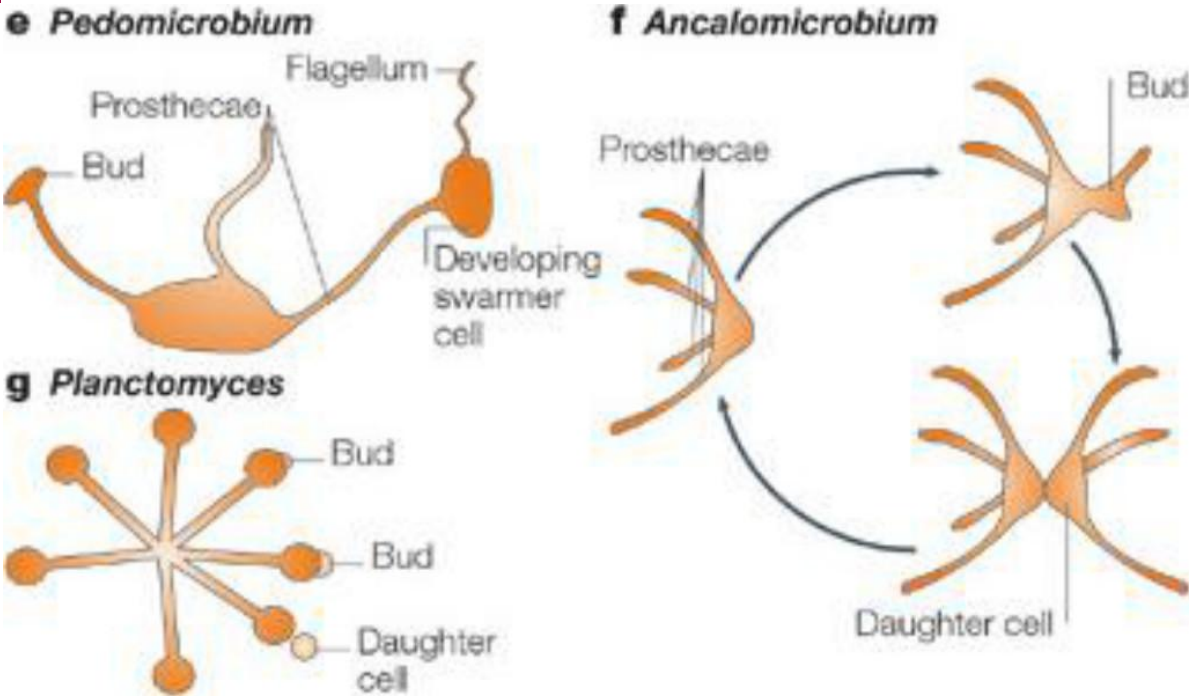
b. Budding

Book: Not in the assigned sections.

Budding:

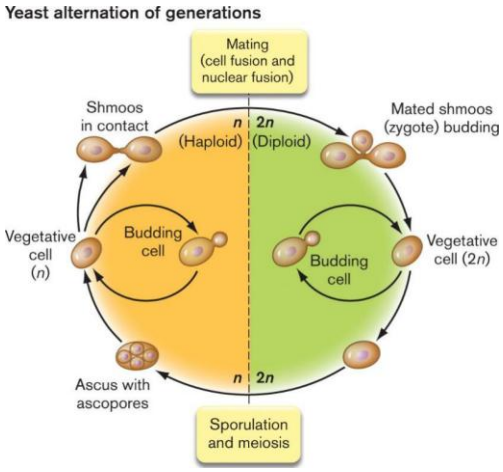
- Produces smaller offspring cells.
- Produces a **bud** that becomes a smaller offspring (daughter) cell. [L20 p40]

Examples: Pedomicrobium, Planctomyces, budding yeast (fungi). [L20 p40]



Pedomicrobium, Ancalomicrobium and Planctomyces budding [L20 p40]

On the figure: Pedomicrobium · prosthecae · bud · flagellum · developing swarmer cell · Ancalomicrobium · daughter cell



Budding yeast cycle: shmoos, mating, sporulation and meiosis, ascus with ascospores [L20 p40]

Pedomicrobium parts: **prosthecae** *(thin cell extensions)*, **bud**, **flagellum** *(whip tail that spins)*, developing swarmer *(swimming daughter cell)* cell; **Ancalomicrobium**: prosthecae, bud, **daughter cell**. [L20 p40]

Budding yeast cycle	What happens
Haploid cells in contact before mating	shmoos
Mating	Cell fusion and nuclear fusion give a diploid zygote (mated shmoos) that buds
Sporulation and meiosis	Make an ascus with ascospores

Table source: [L20 p40]

c. Multiple fission

Book: 3.6 Specialized Structures, How Do a Hundred Cells Divide at Once? (chapter 3 PDF, p. 139).

⚠ **Do not mix up: Multiple fission gives MULTIPLE offspring, usually in a SAC; budding gives smaller offspring.** [L20 p41, L20 p40]

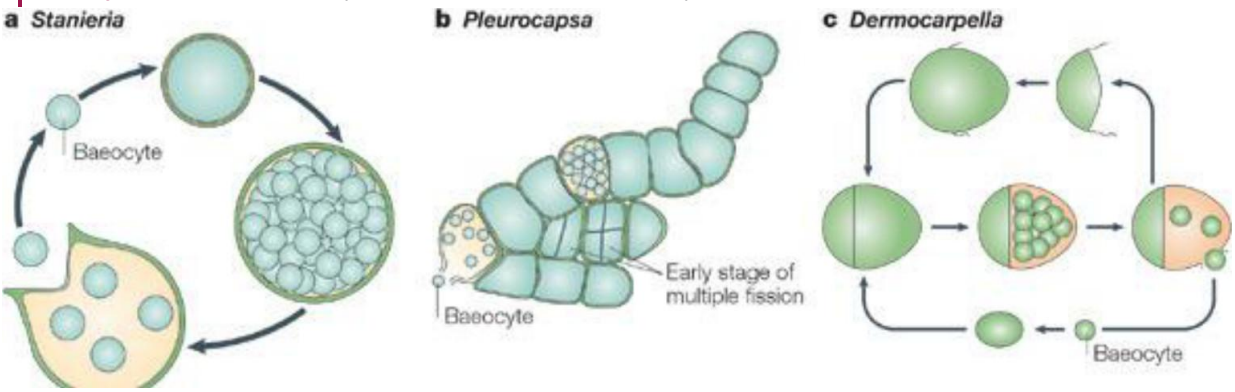
What multiple fission is

Multiple fission: some form multiple offspring by multiple fission events. [L20 p41]

Usually in a sac *(a closed pouch)*. [L20 p41]

Examples

Examples: Stanieria (also spelled Stanleria) and Pleurocapsa. [L20 p41]

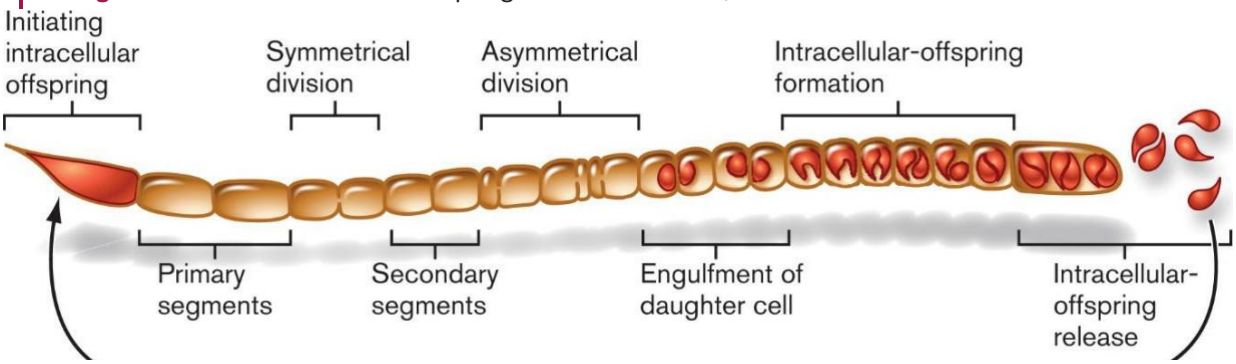


Baeocytes released in Stanieria; early multiple fission in Pleurocapsa [L20 p41]

On the figure: Stanieria · Pleurocapsa · baeocytes · Multiple fission

Stanieria: the cell enlarges, fills with many **baeocytes** *(small offspring cells)*, then releases them. [L20 p41]

Savagella: a filament that forms offspring inside its cells. [L20 p41]



Savagella filament: primary and secondary segments, engulfment of daughter cell, offspring release [L20 p41]

On the figure: primary segments · secondary segments · engulfment of daughter cell

Savagella parts: **primary segments**, **secondary segments**, **engulfment of daughter cell** and intracellular offspring **release**. [L20 p41]

d. Asymmetric cell division and differentiation

Book: 3.5 Cell Asymmetry, Membrane Vesicles, and Extensions, Bacterial Cell Differentiation (chapter 3 PDF, p. 99).

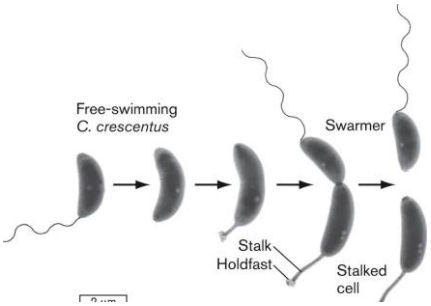
⚠ **Do not mix up: Caulobacter: the STALKED cell divides into a swarmer *(swimming daughter cell)* cell and a stalked cell.** [L20 p42]

Asymmetrical cell division: produces a different type of cell. [L20 p42]

Examples of cell differentiation *(becoming a different cell type)*: **stalked cells** of Caulobacter crescentus, and spores. [L20 p42]

Caulobacter: a **free-swimming** cell loses its flagellum *(whip tail that spins)* and grows a **stalk** *(stem that anchors the cell)* with a **holdfast** *(sticky foot at the stalk tip)*. [L20 p42]

The stalked cell divides into a flagellated **swarmer** cell and a stalked cell. [L20 p42]



Caulobacter crescentus: free-swimming cell, stalk, holdfast, swarmer and stalked cell [L20 p42]

On the figure: **free-swimming** · **stalk** · **holdfast** · **swarmer** · **stalked cells**

▸ **Spore types: akinetes, exospores, Chlamydia elementary bodies, endospores, myxospores, fungal spores**

Book: Not in the assigned sections (akinetes and myxospores are in 4.6, not assigned).

⚠ **Do not mix up: Exospores are NOT dormant *(inactive, not growing)* or hardy (wind dispersal); endospores *(tough dormant survival form)* are dormant and very hardy.** [L20 p45, L20 p36]

Spores in general

Spores: several types of bacteria form spores, special reproductive cells for survival or dispersal. [L20 p43]

Some spores are dormant. [L20 p43]

Akinetes

Akinete *(hardy resting cell)*: a larger, oval cell near a heterocyst *(nitrogen-fixing cell)* in a chain of vegetative cells *(normal growing cell)*. [L20 p44]

Akinetes form in response to stress; akinetes are hardy. [L20 p44]

Akinete triggers: light limitation, cold, phosphate *(a mineral nutrient)* starvation; viable for decades. [L20 p35, L20 p43]

Heterocyst cells fix nitrogen. [L20 p44]

Anabaena solitaria: a filament with a heterocyst and an akinete. [L20 p44]

Exospores

Exospores: smaller spore cells at the end of aerial mycelia *(filaments)*, like fungal spores. [L20 p45]

Exospore triggers: carbon and phosphate starvation. [L20 p45]

Tip cells of an aerial mycelium undergo vegetative division and pinch off as arthrospores. [L20 p45]

Exospores are NOT dormant or hardy: they are just for dispersal by wind. [L20 p45]

Watch out: arthrospores are listed as desiccation *(drying out)* and heat resistant. [L20 p35]

Yet exospores are also called not dormant or hardy, just for dispersal by wind. [L20 p45]

Chlamydia elementary bodies

Chlamydia: obligate intracellular parasite; its life cycle is similar to viruses. [L20 p46]

Elementary bodies *(infectious resting form outside the host cell)* are inactive spores with cross-linked outer membrane *(extra membrane outside the wall)* proteins. [L20 p46]

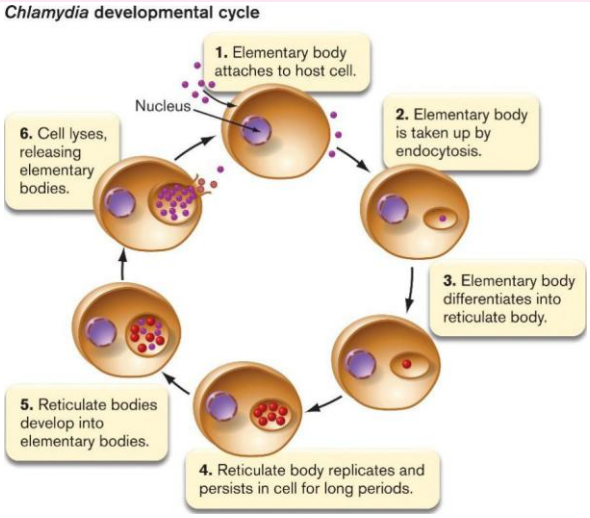
Elementary body formation starts when the intracellular life cycle is complete. [L20 p46]

Chlamydia divides only inside a host cell, as reticulate bodies *(dividing form inside the host)*. [L20 p46]

Chlamydia cycle: elementary body attaches, enters by **endocytosis**, becomes a **reticulate body**. [L20 p46]

Cycle, continued: the reticulate body replicates and persists in the cell for long periods. [L20 p46]

Then reticulate bodies develop into elementary bodies; the cell **lyses** and releases them. [L20 p46]



Chlamydia cycle: elementary body attaches, endocytosis, reticulate body replicates, cell lyses [L20 p46]

On the figure: **elementary body** · **reticulate body** · **endocytosis** · **lyses**

Endospores

Endospores: some Firmicutes *(Gram positive group that includes Bacillus)* form them. [L20 p47]

Endospore division: the cell divides, but with no septation *(building the cross wall)* of the cell wall *(stiff layer around the cell membrane)*. [L20 p47]

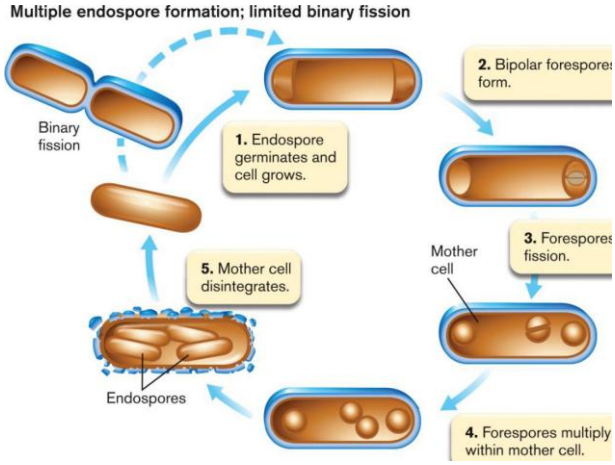
Watch out: in the endospore stages a septum *(cross wall)* near one pole separates forespore *(the part that becomes the spore)* and **mother cell**. [L20 p47]

One cell is engulfed and then develops into a hardy spore. [L20 p47]

Multiple endospores

Multiple endospores:

> One type forms multiple **endospores** inside the cell.
>
> **Bipolar** **forespores** form, fission, then **multiply** within the mother cell, which **disintegrates**. [L20 p48]



Multiple endospore formation: bipolar forespores form, fission, multiply, mother cell disintegrates [L20 p48]

On the figure: **endospores** · **bipolar** · **forespores** · **mother cell** · **disintegrates**

Live birth

Live birth:

> One type does live births; two offspring emerge from the mother cell.
>
> **bipolar** *(at both ends)* division gives two offspring. [L20 p48]

Offspring grow through the length of the mother cell; no binary fission. [L20 p48]

Myxospores

Myxococcus: cells aggregate and form a fruiting body *(raised clump of cells that holds spores)* with sacs of many myxospores. [L20 p49]

Myxospore cycle: free-living cells, starvation, aggregation *(clumping together)*, fruiting body, myxospore dispersal. [L20 p49]

Myxospore triggers: nutrient starvation, heat shock, glycerol *(three carbon fat backbone)* and dimethyl **sulfoxide**. [L20 p35]

Fungal spores

Fungi: most grow as filaments (hyphae). [L20 p50, L20 p51]

Fungal spores form at the end of aerial hyphae *(fungal filaments)*. [L20 p50, L20 p51]

Fungal spores can be gametes or asexual clones. [L20 p50, L20 p51]

Fungal cells are larger than bacteria. [L20 p50, L20 p51]

Spore-forming structures vary in shape and features; they are used for identification. [L20 p50, L20 p51]

Examples: sporangiospores in a sporangium; conidia such as arthrospores, chlamydospores, phialospores. [L20 p50, L20 p51]

Spore types

Spore type	Made by	How it forms	Dormant and hardy?
Akinete	Filamentous cyanobacteria (Anabaena)	Larger oval cell near a heterocyst, in response to stress	Hardy
Exospore (arthrospore)	Actinomycetes	Smaller spore cells at the end of aerial mycelia, like fungal spores	**NOT** dormant or hardy; for dispersal by wind (also listed as desiccation and heat resistant)
Elementary body	Chlamydia	Reticulate bodies divide in a host cell, then become elementary bodies	Inactive spores; survive outside the host; desiccation resistant
Endospore	Some Firmicutes (Bacillus)	Cell division with no wall septation; one cell is engulfed and becomes the spore	Dormant and very hardy
Myxospore	Myxococcus	Cells aggregate into a fruiting body with sacs of many myxospores	Desiccation and UV resistant
Fungal spores	Fungi	At the end of aerial hyphae; gametes or asexual clones	Not stated

Table source: [L20 p43, L20 p44, L20 p45, L20 p46, L20 p47, L20 p49, L20 p50]

Actinomycete life cycle	What happens
Favorable conditions	One or two germ tubes emerge from a spore and make the substrate mycelium
Nutrient depletion	After **48** to **72** hours, bld genes are expressed and make aerial hyphae (aerial mycelia)
Growth stops	The compartment segments of the aerial hyphae (this requires the whi genes) change shape and thicken the wall to become desiccation resistant spores
Glucose drops	Nonbranching exploratory cells develop to find new nutrients and form mycelia

Table source: [L20 p45]

Fungal structure	Name
Root-like structures at the base of the reproductive hyphae	rhizoids
What a germinating fungal spore sends out; it becomes a hypha	germ tube
Inside the sporangium, which sits on the sporangiophore	columella
Between the conidiophore and the phialospores	sterigma
Other conidia besides arthrospores, chlamydospores, blastospores, macroconidia and microconidia	porospore

Table source: [L20 p50, L20 p51]

2. Basic Steps in process: Replication, cytokinesis, septation, separation

Book: 3.4 Bacterial Cell Division, DNA Replication Regulates Cell Division (chapter 3 PDF, p. 85); 3.4 Bacterial Cell Division, Cell Division by Septation (chapter 3 PDF, p. 78).

⚠ Do not mix up: Cytokinesis *(splitting the cell in two)*: splitting into two cells, each with its own cell membrane *(thin skin around the cell)*. Septation *(building the cross wall)*: envelope *(layers wrapped around the cell)* partition. Separation: detachment. [L20 p53]

The four steps

Four steps: replication and segregation of chromosomes *(one long DNA molecule)*, cytokinesis, septation, separation of the cell. [L20 p52]

The replicating chromosome has an **origin of replication** and a **terminator sequence** *(the DNA site where copying ends)*. [L20 p52]

Watch out: in Staphylococcus the septum *(cross wall)* furrow *(groove)* grows in first; cytokinesis happens when furrows meet. [L20 p58]

Replication and segregation

Replication: the origin replicates and migrates; **replication continues bidirectionally**. [L20 p52]

After the DNA *(cell genetic instruction molecule)* **origin replicates and migrates**, two **replisomes** *(DNA copying machines)* are present. [L20 p52]

Segregation *(copies pulled apart)*: the two copies of the DNA origin move apart as the cell expands. [L20 p52]

Replication of the DNA termination site triggers proteins to form the divisome (textbook).

The divisome manages assembly of the septum (textbook).

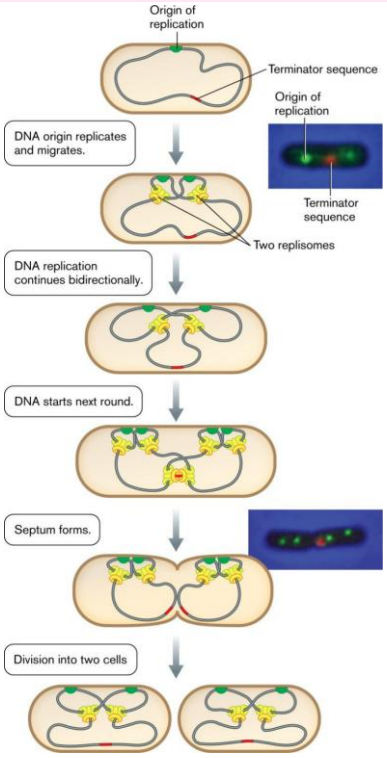
Division follows

Then DNA starts the next round, the **septum forms**, and the cell divides into two. [L20 p52]

FtsN, a divisome part, helps time septum constriction (textbook).

Cells lacking FtsN balloon out at the septum (textbook).

Staphylococcus: septum grows in, two partitions complete, then the cells peel apart. [L20 p53]



Origin replicates and migrates, two replisomes, septum forms, division into two cells [L20 p52]

On the figure: replisomes · DNA origin replicates and migrates · replication continues bidirectionally · septum forms

Steps in cell division

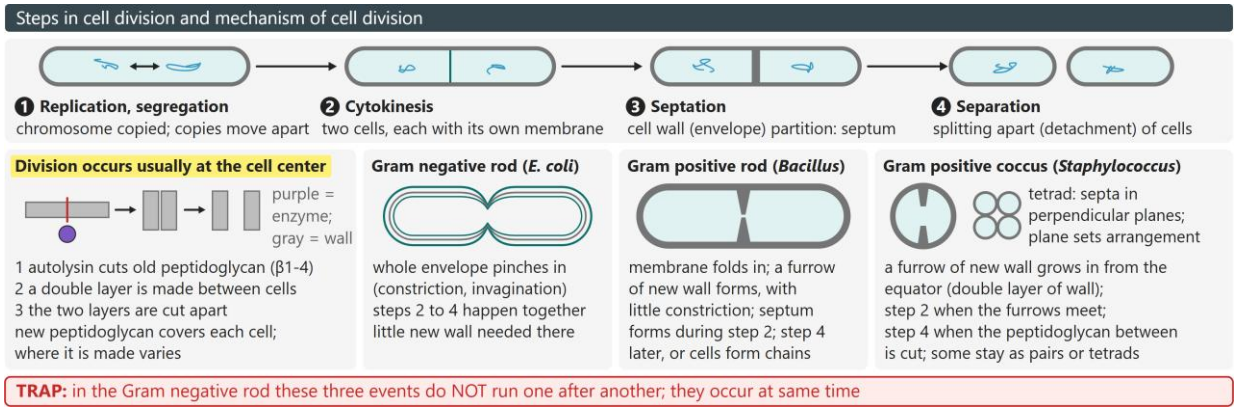
Step	Meaning
Cytokinesis	Splitting of the cell to form two cells, each surrounded by its own cell membrane
Septation	Formation of an envelope partition (septum) between dividing cells
Separation	Detachment of the two cells

Table source: [L20 p53]

3. Mechanism of cell division: how it differs between cell types

Book: 3.4 Bacterial Cell Division, Cell Division by Septation (chapter 3 PDF, p. 78).

⚠ Do not mix up: E. coli: all three steps at the same time; Bacillus: separation may come later. [L20 p56, L20 p57]



Division in E. coli, Bacillus and Staphylococcus compared [L20 p56]

On the figure: Gram negative rod · Gram positive rod · E. coli · Bacillus · Staphylococcus

Mechanism varies: cytokinesis *(splitting the cell in two)*, septation *(building the cross wall)* and separation differ between bacteria. [L20 p54]

Location: division usually occurs in the center of most cells. [L20 p54]

Division mechanism in three cell types

	Gram negative rod (E. coli)	Gram positive rod (Bacillus)	Gram positive cocci (Staphylococcus)
What you see	Constriction and inward fold of the entire envelope in the middle	Membrane invaginates in the middle; a furrow of new wall forms, little constriction	A furrow of new wall forms at the equator and grows inward
Timing	Cytokinesis, septation and separation at the same time	Septum forms with cytokinesis; separation may occur later	Cytokinesis when the septa furrows meet; separation when the peptidoglycan between cells is cut
New wall at the division site	Little needed	A furrow of new cell wall	A double layer of cell wall
Afterward	The two cells are already separate (separation happens with cytokinesis)	Often stay attached as a chain or filament	Some stay as pairs or tetrads

Table source: [L20 p56, L20 p57, L20 p58, L20 p59]

Autolysins and new peptidoglycan at the division site

Book: 3.4 Bacterial Cell Division, Cell Division by Septation (chapter 3 PDF, p. 78).

⚠ **Do not mix up: Autolysin *(wall-cutting enzyme made by the bacterium itself)* CUTS old peptidoglycan (beta 1-4 linkage); it does not build new wall.** [L20 p54]

Three steps at the septum

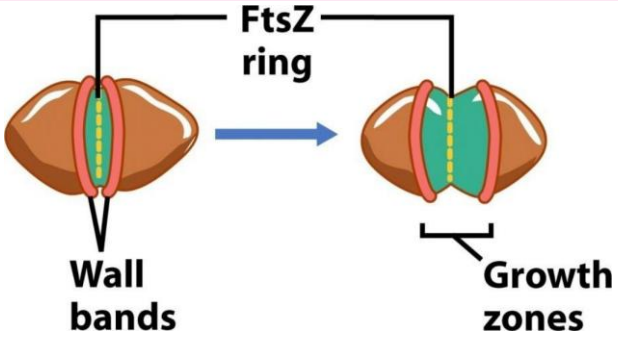
Basic steps, step **1**: autolysin enzyme cuts old peptidoglycan (beta **1**-**4** linkage). [L20 p54]

Step 2: synthesize a double layer between the cells. [L20 p54]

Step 3: then cut the two layers apart. [L20 p54]

Dividing coccus

Dividing coccus: FtsZ *(protein ring for cell splitting)* ring at the equator, **wall bands**, new wall from **growth zones**. [L20 p54]

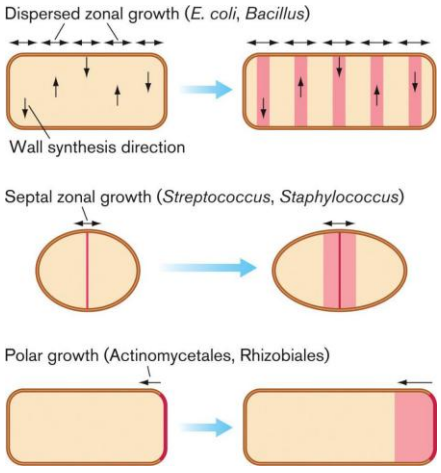


Dividing coccus: FtsZ ring, wall bands and growth zones [L20 p54]

On the figure: FtsZ ring · wall bands · growth zones

New peptidoglycan

New peptidoglycan must be made so each cell is covered when separation occurs. [L20 p55]



Dispersed zonal, septal zonal and polar wall growth patterns [L20 p55]

Location of new peptidoglycan synthesis varies. [L20 p55]

Where new wall is made

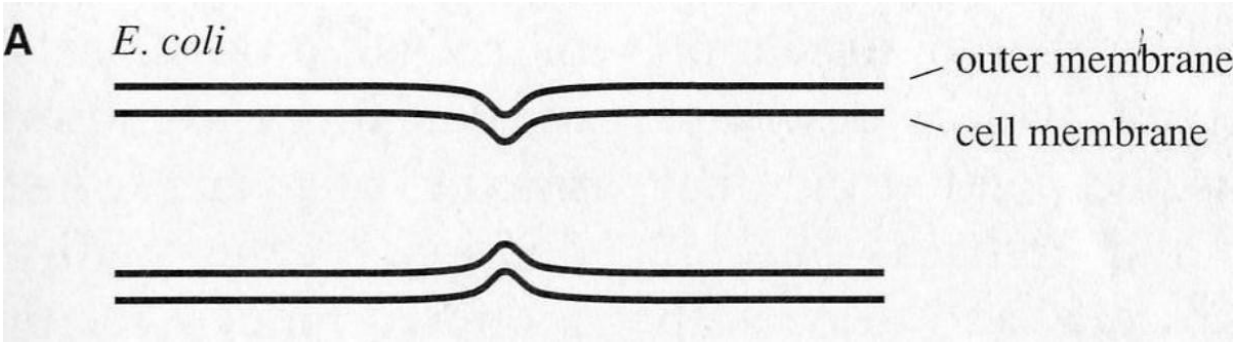
Growth pattern	Where new wall is made	Examples
Dispersed zonal growth	Many bands along the rod	E. coli, Bacillus
Septal zonal growth	At the septum	Streptococcus, Staphylococcus
Polar growth	At one pole	Actinomycetales (actinomycetes), Rhizobiales

Table source: [L20 p55]

a. Gram negative rod (E. coli)

Book: 3.4 Bacterial Cell Division, Cell Division by Septation (chapter 3 PDF, p. 78).

⚠ **Do not mix up: E. coli pinches the whole envelope *(layers wrapped around the cell)* inward; little new wall is made at the division site.** [L20 p56]



E. coli: outer membrane and cell membrane fold inward together [L20 p56]

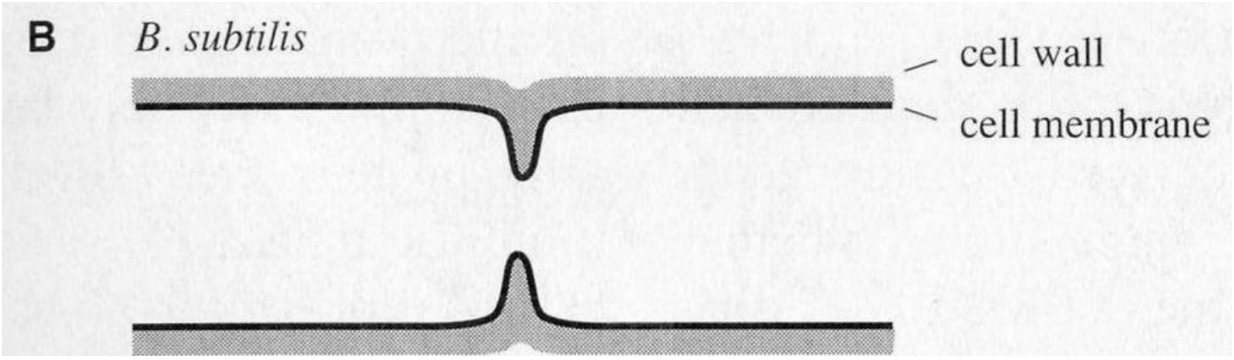
On the figure: E. coli · Outer membrane · cell membrane

> **E. coli (Gram negative rod)**: the entire envelope constricts *(pinches in)* and folds inward (invaginates) in the middle. [L20 p56]
>
> **Outer membrane** *(extra membrane outside the wall)* **and cell membrane** *(thin skin around the cell)* pinch inward together. [L20 p56]
>
> **Cytokinesis** *(splitting the cell in two)*, **septation** *(building the cross wall)* **and separation** occur at the same time. [L20 p56]
>
> **Little new cell wall** *(stiff layer around the cell membrane)* **synthesis** is needed at the division site. [L20 p56]

b. Gram positive rod (Bacillus)

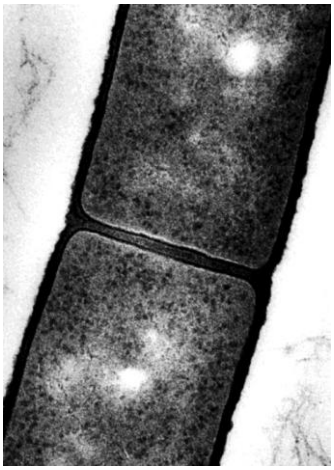
Book: 3.4 Bacterial Cell Division, Cell Division by Septation (chapter 3 PDF, p. 78).

⚠ **Do not mix up: Bacillus *(rod shaped cell)*: little constriction and late separation (chains); E. coli: constriction, all at once.** [L20 p57, L20 p56]



B. subtilis: cell membrane invaginates with a furrow of cell wall [L20 p57]

On the figure: cell wall · membrane



Two Bacillus cells joined by a straight cross wall [L20 p57]

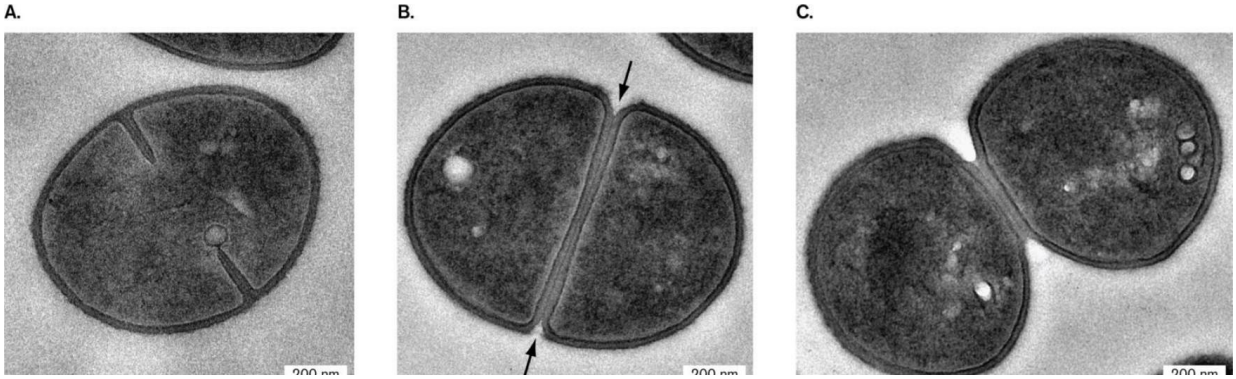
> **Gram positive** *(thick wall, stains purple)* **rod (Bacillus)**: the **membrane** *(thin lipid layer)* invaginates *(folds inward)* in the middle. [L20 p57]
>
> **A furrow** *(groove)* **of new cell wall** *(stiff layer around the cell membrane)* forms there, with little constriction. [L20 p57]
>
> **Septum** *(cross wall)* **forms** between the cells with cytokinesis *(splitting the cell in two)*. [L20 p57]
>
> **Bacillus**: two cells joined by a straight cross wall in a chain. [L20 p57]
>
> **Separation may occur later**; cells often stay attached as a chain or filament. [L20 p57]

c. Gram positive cocci (Staphylococcus): septum, planes and arrangements

Book: 3.4 Bacterial Cell Division, Cell Division by Septation (chapter 3 PDF, p. 78).

⚠ **Do not mix up: Pairs or tetrads** ***(two or four cells left stuck together)*** **stay attached; tetrads** ***(groups of four cells)*** **need septation** ***(building the cross wall)*** **in PERPENDICULAR** ***(at right angles)*** **planes.** [L20 p59]

Furrow and septum



Staphylococcus division: septum furrow, completed septum, cells peeling apart [L20 p58]

On the figure: furrows · septa

Gram positive *(thick wall, stains purple)* **cocci (Staphylococcus)**: a furrow *(groove)* of new wall forms at the equator and expands inward. [L20 p58]

This forms a double layer of cell wall *(stiff layer around the cell membrane)*. [L20 p58]

When the septa furrows meet, cytokinesis *(splitting the cell in two)* occurs. [L20 p58]

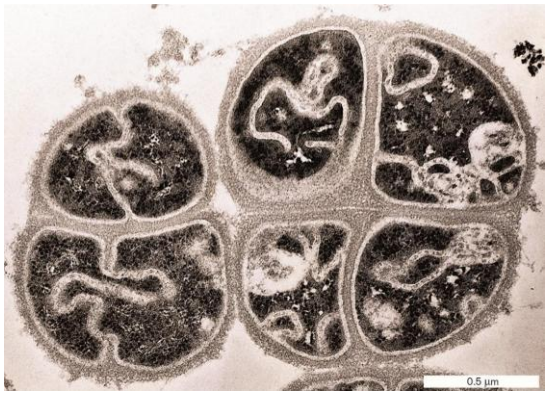
Cell separation occurs when the peptidoglycan *(sugar and peptide mesh of the wall)* between the cells is cut. [L20 p58]

Arrangements

Some do not separate: they remain as pairs or tetrads. [L20 p59]

The plane used for septation can determine the arrangement afterward. [L20 p59]

Tetrads: septation uses perpendicular planes. [L20 p59]



Tetrad of cocci separated by septa in perpendicular planes [L20 p59]

On the figure: septation · Arrangements