BIOL 4640 Study Guide for Exam 2 (Wed 10/28/26): Lecture 19 Internal Structures, Cytoplasm and Ribosomes

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): 27.1, 27.2 and 27.3 (antimicrobial therapy); 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; the posted source Bacterial Intracellular Structures.
(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); 3.6 Specialized Structures, Thylakoids, Carboxysomes, and Storage Granules (chapter 3 PDF, p. 119).

⚠ **Do not mix up: Bacterial DNA *(cell genetic instruction molecule)* is folded by proteins, but NOT wrapped around an octamer of histones *(eukaryote protein that DNA winds around)***.

Cell envelopes

Major styles of cell envelope *(layers wrapped around the cell)*: **Gram-positive** *(thick wall, stains purple)*; mycobacterial (Gm+ **actinomycete** *(a type of Gram-positive bacterium)*), **acid-fast** *(holds dye despite acid wash)*; **Gram-negative** *(thin wall plus outer membrane)*; Mollicutes (Mycoplasma) with no cell wall *(stiff layer around the cell membrane)*; archaeal *(of archaea)*. [L19 p03]

Peptidoglycan *(sugar and peptide mesh of the wall)* **synthesis** is **unique** to bacteria; many antibacterial drugs (antibiotics) interfere with or inhibit it, and antibiotics inhibit **different** steps. [L19 p04]

Enzymes that cleave peptidoglycan: lysozyme (a defensive enzyme of our body) and autolysin (produced by bacteria). [L19 p04, L19 p16]

New peptidoglycan is needed for growth and division and for repair and replacement. [L19 p05]

Dividing cell: FtsZ *(protein ring for cell splitting)* ring, wall bands and growth zones (where the new peptidoglycan is). [L19 p05]

Site of new peptidoglycan synthesis varies: it can occur in the middle, at one end or **dispersed**. [L19 p06]

Peptidoglycan synthesis overview

Overview step 1: make the two sugar units (NAG and NAM), with a peptide *(short chain of amino acids)* off NAM *(the other wall sugar)*. [L19 p07]

Overview step 2: add the **2** sugar unit to an **existing** chain. [L19 p07]

Overview step 3: form a **crosslink** to the peptide in a different chain. [L19 p07]

The peptide off NAM in the cross-linked **Gram negative** wall is L-Ala, D-Glu *(D form of glutamic acid)*, m-diaminopimelic acid and D-Ala *(D form of alanine amino acid)*; the terminal (fifth) D-Ala was released. [L19 p07]

The peptide cross-bridge forms with release of **D-alanine**; penicillin blocks this step. [L19 p07]

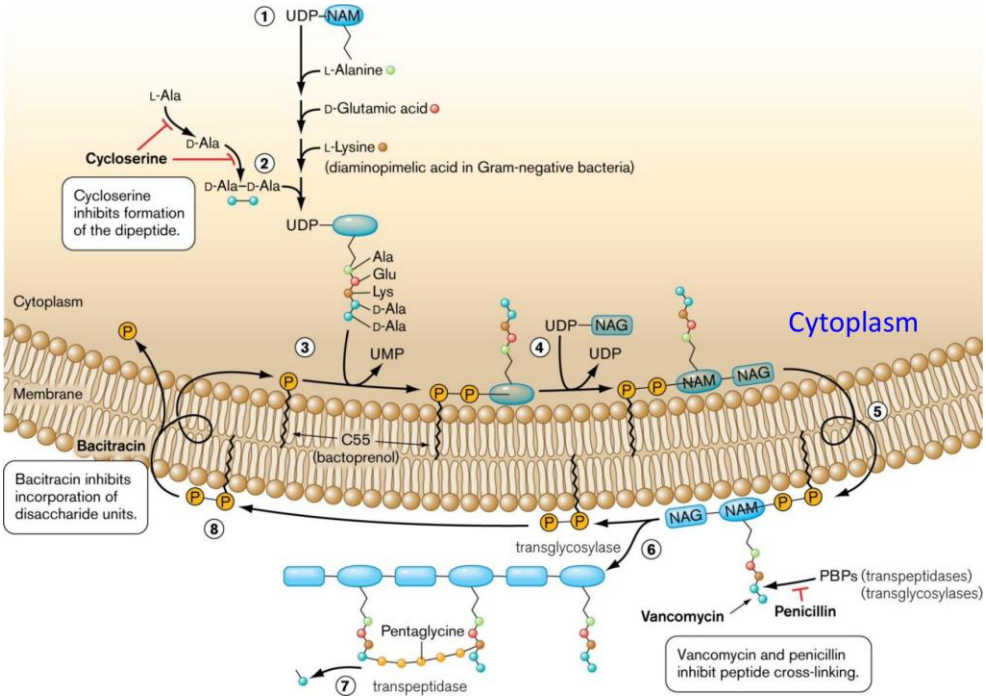
Vancomycin *(drug blocking wall building)* binds D-Ala-D-Ala and blocks cross-bridge formation. [L19 p07]

Vancomycin binds the D-Ala-D-Ala terminal end of the disaccharide unit and prevents transglycosylase and transpeptidase *(enzyme making wall cross bridges)* action (textbook).

Synthesis steps in order

Where it happens: in a **Gram-positive** bacterium. [L19 p10]

Gram-negatives are similar, but some steps occur in the periplasm *(space between the two membranes)* between the membranes *(thin lipid layer)*. [L19 p10]



Peptidoglycan synthesis steps with the points where each antibiotic blocks [L19 p10]

On the figure: UDP · UMP · bactoprenol · Cycloserine · bacitracin · Vancomycin · penicillin · transpeptidase

Step 1: make the sugar precursors (NAM and NAG). Both come from **fructose-6-P** in the cytosol *(liquid part of the cytoplasm)*, and the sugars are first attached to **UDP**. [L19 p09]

Sugar names: NAG *(one wall sugar)* is also written **GlcNAc** or G, and NAM is written **MurNAc** or M. [L19 p09]

Sugar precursors, step 2: add an acetyl group from **acetyl-CoA** (CoA is released). [L19 p09]

Step 2: add **3** amino acids to UDP-NAM to begin the peptide: L-alanine, D-glutamic acid, then L-lysine (**diaminopimelic acid** *(DAP, the third amino acid in Gram-negatives)* instead of lysine in **Gram-negative** bacteria). [L19 p10, L19 p11]

Step 3: add a dipeptide of **2 D-alanine** amino acids to the peptide. [L19 p11]

Step 4: transfer the NAM-pentapeptide to **bactoprenol** (C55) in the cell membrane *(thin skin around the cell)*; **UMP** is released. [L19 p10, L19 p11]

Step 5: link NAG to NAM (UDP is released). [L19 p10, L19 p11]

Step 6: **flip** the **2** sugar unit to the other side of the bilayer *(two layers)*. [L19 p11]

Step 7: transglycosylation *(joining sugar chains longer)*, linking sugars to a glycan *(sugar chain)* chain. [L19 p11]

Step 8: **transpeptidase**, forming the cross link. [L19 p11]

Step 9: regenerate bactoprenol-P by cleaving off a phosphate *(PO4 group)* group. [L19 p11]

Bactoprenol, flippase and crosslinking

Bactoprenol *(undecaprenyl, a large isoprenoid phosphate with 55 carbons)* helps carry peptidoglycan units, LPS *(outer membrane sugar and fat coat)* and **teichoic acid** *(charged chains in Gram positive wall)* through the cell membrane; the sugar is attached via phosphate. [L19 p12]

MurJ *(flipper protein for wall units)* is a transmembrane protein (flippase) that flips the sugars to the other side. [L19 p12]

Transpeptidation *(making peptide bridges between chains)* **reaction**: in **Gram-negative**s, DAP *(special amino acid in wall peptide)* in the 3rd position attacks D-Ala in the 4th position and displaces D-Ala in the 5th position. [L19 p14]

Drugs that block wall synthesis

Antibiotics that interfere with peptidoglycan synthesis: the **penicillin** (beta-lactam) family, cephalosporins *(penicillin like wall blocking drugs)*, **vancomycin**, **bacitracin** *(drug blocking carrier recycling)* and D-cycloserine *(drug blocking D alanine steps)*. [L19 p16]

Cycloserine inhibits formation of the **dipeptide** (the D-Ala-D-Ala pair). [L19 p10]

Bacitracin inhibits incorporation of disaccharide units. [L19 p10]

Bacitracin binds bactoprenol and blocks its dephosphorylation, so the carrier cannot accept a new unit of UDP-NAM (textbook).

Antibiotics in general

Most antibacterial drugs target unique features of bacteria; most inhibit an **enzyme** involved in biosynthesis, the synthesis of a cell component. [L19 p17, L19 p18]

Cidal *(kills the germs)* drugs kill bacteria; **static** *(only stops germ growth)* drugs inhibit growth. [L19 p17]

Most antibiotics block synthesis of new: proteins, cell wall, **nucleic acids** (DNA or RNA) or metabolites *(small working molecules of the cell)*. [L19 p19]

Folic acid pathway: folic acid is made from **PABA**; sulfonamides and trimethoprim inhibit folic acid metabolism. [L19 p20]

Sulfa drugs bind and inhibit the enzyme that converts PABA to folic acid; humans do not synthesize folic acid (textbook).

Antibiotic resistance

Microbial drug resistance: pathogenic strains evolve resistance to one or more drugs. [L19 p21]

It is a growing, worldwide, complex problem that may lead to untreatable infections. [L19 p21]

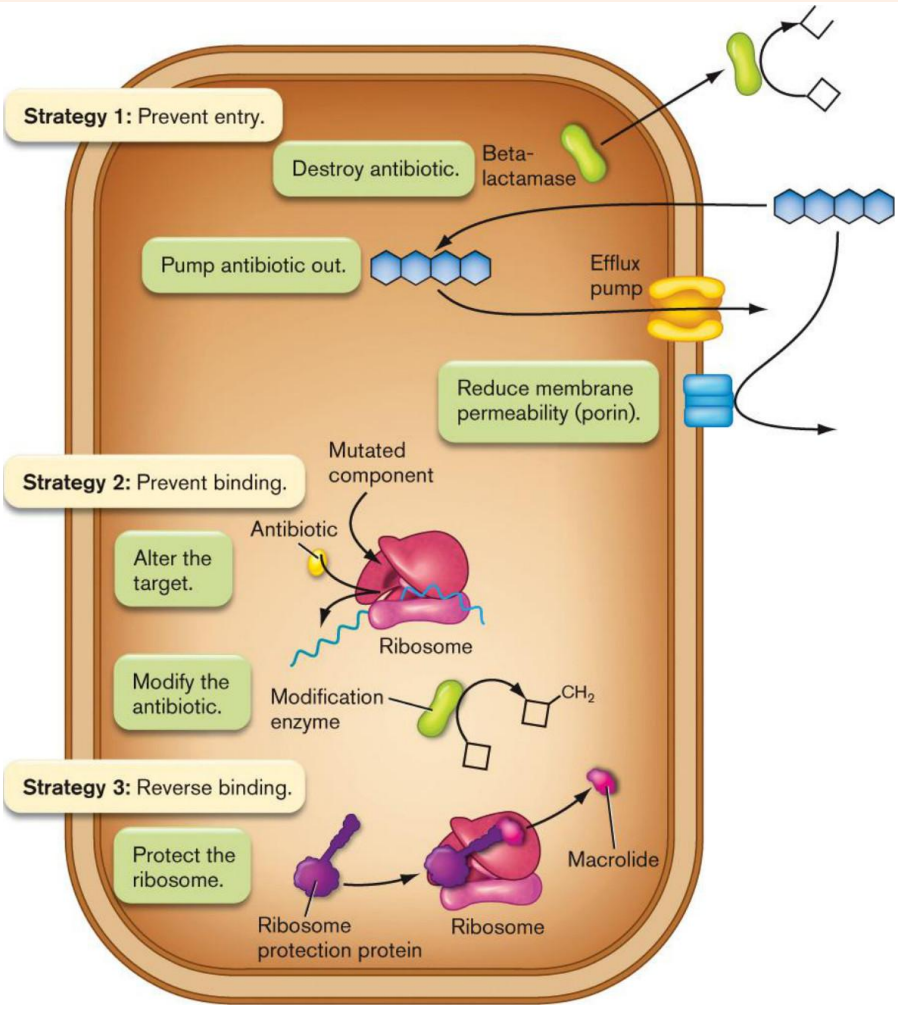
Antibiotic timeline: the earliest drug is **arsphenamine** (Salvarsan), approved about **1910.** [L19 p24]

Golden age of antibiotics is marked on the timeline of antibiotic use and appearance of resistance. [L19 p24]

Incidence of resistant strains: they spread rapidly, and **MRSA** (methicillin-resistant S. aureus) has the highest incidence. [L19 p25]

Resistant strain names: **VRE** *(drug resistant gut germ)* is vancomycin-resistant Enterococcus; **FQRP** is fluoroquinolone-resistant Pseudomonas aeruginosa. [L19 p23, L19 p25]

Resistance mechanisms



Three resistance strategies: prevent entry, prevent binding, reverse binding [L19 p26]

On the figure: Prevent entry · Prevent binding · target

Prevent entry (lower drug levels): **degrade** the drug. [L19 p27]

Increase elimination of the drug: a factor pumps the drug out (the multidrug exporter). [L19 p27]

Pumps bail the drug out faster than it can enter, usually powered by proton motive force (textbook).

Multidrug exporter spans the outer membrane *(extra membrane outside the wall)*, the periplasm and the cytoplasmic membrane. [L19 p27]

Reduce uptake of the drug: eliminate a transport protein. [L19 p27]

Beta-lactams *(drug family with four member ring)*, tetracyclines and fluoroquinolones *(DNA coiling blocker drug)* enter through outer-membrane porins *(channels in the outer membrane)*; **Gram-negative**s can express alternative porins too narrow to admit them (textbook).

Prevent binding: the **target** of the drug changes. [L19 p27]

The drug no longer **binds** to or inhibits the target enzyme. [L19 p27]

Prevent binding, drug modified: a factor cleaves or modifies the drug. [L19 p27]

Watch out: Degrading the drug is also listed under Prevent entry. [L19 p27]

Beta lactam family

Beta-lactam family: the functional groups off the ring **vary**. [L19 p28]

Functional groups off the ring affect spectrum of activity, properties and sensitivity to particular **beta-lactamases** *(enzyme that destroys beta lactam drugs)*. [L19 p28]

Susceptibility tests and MIC

Tests for antibiotic susceptibility: **1**) MIC, **2**) Kirby-Bauer disk diffusion *(drifting from high to low amount)* assay, **3**) genetic methods. [L19 p29]

MIC stands for **minimal inhibitory concentration**: the lowest concentration of drug that prevents growth. [L19 p29, L19 p30]

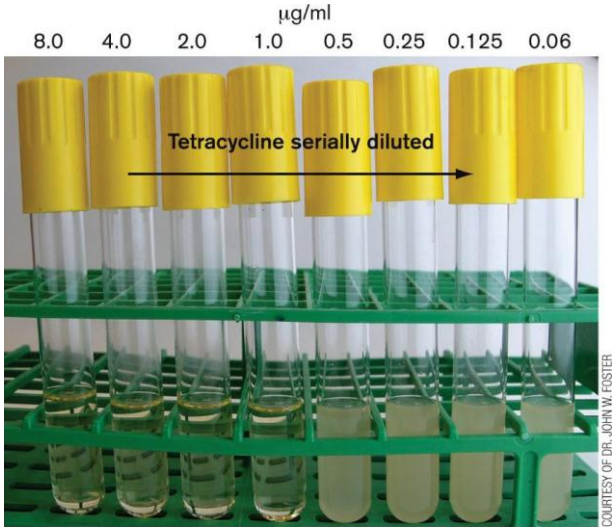
MIC step 1: **serially** dilute the drug. [L19 p30]

MIC step 2: add a small number of cells (**10^5**) to a tube with media and drug. [L19 p30]

MIC step 3: **incubate** the tubes. [L19 p30]

MIC step 4: find the lowest concentration that prevents growth; in the serially diluted **tetracycline** tubes (**8.0** to **0.06** ug/ml) the MIC is **1.0 ug/ml**. [L19 p30]

MIC examples: the MIC is **0.06** ug/ml for penicillin and **8** ug/ml for erythromycin. [L19 p30]



Tetracycline serially diluted in tubes; the MIC is the lowest clear tube [L19 p30]

On the figure: tetracycline · serially · 8.0 · 0.06 · 1.0

Kirby Bauer disk test

Kirby-Bauer is a **disk diffusion assay**: spread cells over the plate, place drug disks, measure the zone of no growth. [L19 p31]

Kirby-Bauer step 1: spread cells over the **surface** of the plate. [L19 p31]

Kirby-Bauer step 2: place one or more disks **impregnated** with a drug on the plate. [L19 p31]

Kirby-Bauer step 3: measure the zone of no growth around the disk and compare it to a **chart**. [L19 p31]

Antibiotic stewardship

Stewardship topic: what a doctor and medical center could do. [L19 p32]

Stewardship goal: reduce the increase of antibiotic resistance in pathogenic bacteria. [L19 p32]

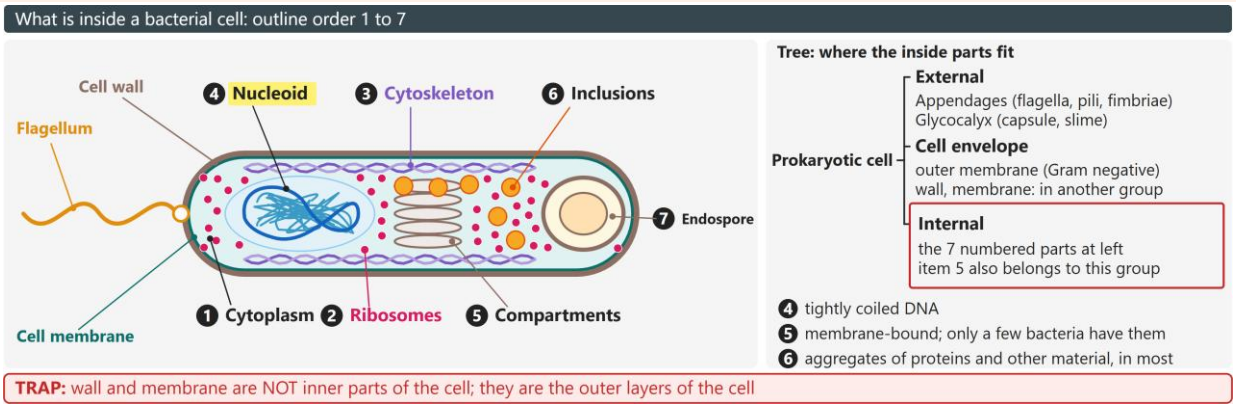
Stewardship:

- No antibiotics for likely viral infections (textbook fill).
- Treat **only** if the patient worsens or does not improve (textbook fill).
- Know which resistant strains are common in the community or hospital (textbook fill).
- Limit how long the drug is given (textbook fill).
- Switch from a broad-spectrum drug to a narrow-spectrum drug (textbook fill).
- Make that switch once the agent and its resistance pattern are known (textbook fill).
- Stop unnecessary antibiotics (textbook fill).
- Confirm a bacterial cause first (textbook fill). [L19 p32]

Sources for internal structures

Internal structures get little space in the textbook; other sources are used. [L19 p34]

Internal structures list



Internal structures of a bacterial cell in outline order [L19 p39]

On the figure: flagellum · cytoplasm · ribosomes · nucleoid · cytoskeleton · compartments · inclusions · endospores

Prokaryotic cell *(bacteria or archaea)*: its structures group into external, cell envelope and internal. [L19 p36, L19 p39]

Structures in the images of a typical bacteria cell: **flagellum** *(whip tail that spins)*, **ribosomes** *(protein building machine)*, **nucleoid** *(DNA region without a membrane)*, **cytoplasm** *(jelly inside the cell membrane)*, chromosome *(one long DNA molecule)*, cell membrane, cell wall. [L19 p36]

Of the structures in that image, ribosomes, nucleoid, cytoplasm and chromosome are internal; the flagellum is external; the cell membrane and cell wall are cell envelope. [L19 p36]

Structures observed inside a bacterial cell: ribosomes; nucleoid (chromosome / DNA); **inclusions** (storage granules, gas vesicles) (textbook fill). [L19 p35]

Internal structures outline: **1.** cytoplasm, **2.** ribosomes, **3.** **cytoskeleton** *(inner scaffold of the cell)*, **4.** nucleoid, **5.** **compartments**, **6.** inclusions and granules, **7.** **endospores** (a few bacteria form spores inside the cell). [L19 p40]

Internal structures (revised list, compartments added next to inclusions): cytoplasm, ribosomes, inclusions, compartments, nucleoid/chromosome, cytoskeleton, endospore. [L19 p39]

Compartments and protein-shell inclusions

Thylakoids *(membrane sacs for photosynthesis)* **and chlorosomes** *(light catching sacs)*: membrane compartments for photosynthesis; chlorosomes of green bacteria are enclosed by a phospholipid *(membrane fat with a charged head)* **monolayer** *(one layer)* linked to the cell membrane.

Carboxysomes *(protein-shelled bodies that fix carbon dioxide)*: site of carbon fixation; a protein shell, not a lipid membrane, so they are inclusions, not membrane compartments.

Gas vesicles *(gas filled floating bubbles)*: store gases inside a protein shell; an inclusion, not a membrane compartment.

A membrane surrounding DNA in one type of bacteria (Gemmata).

Growth pattern	Bacteria
Dispersed zonal growth	E. coli, Bacillus
Septal zonal growth	Streptococcus, Staphylococcus
Polar growth	Actinomycetes, Rhizobiales

Table source: [L19 p06]

Target of the drug	Drug examples
Cell wall synthesis (peptidoglycan)	penicillins, cephalosporins, vancomycin, bacitracin, monobactams, fosfomycin, cycloserine
Cell membrane integrity	polymyxins, daptomycin, gramicidin; amphotericin and imidazoles (vs. fungi)
Metabolic inhibitors	sulfonamides, trimethoprim, metronidazole (watch out: the other target table lists nitroimidazoles under nucleic acid function)
DNA replication inhibitors	quinolones (ciprofloxacin), which inhibit gyrase *(an unwinding enzyme)*
RNA polymerase inhibitors	rifampin, pyronins
Nucleic acid function	nitroimidazoles, nitrofurans, quinolones, rifampin
50S ribosome subunit	chloramphenicol, macrolides (erythromycin), clindamycin, oxazolidinones (linezolid), streptogramins (Synercid)
30S ribosome subunit	aminoglycosides (gentamicin, streptomycin, amikacin), tetracyclines (doxycycline)

Table source: [L19 p18, L19 p19, L19 p20]

Year	Event
1940	penicillinase, an enzyme that destroys penicillin, identified in bacteria
1942	first therapeutic use of penicillin
1943	penicillin mass-produced
1945	more than **20%** of S. aureus hospital isolates penicillin-resistant
1947	streptomycin approved by FDA; streptomycin resistance observed
1952 and **1956**	tetracycline approved by FDA (**1952**); tetracycline resistance observed (**1956**)
1958	vancomycin introduced, although rarely used until the mid-**1980**s
1959 and **1961**	methicillin introduced (**1959**); methicillin-resistant S. aureus (MRSA) observed (**1961**)
1964 and **1966**	cephalothin, the first antibiotic in the cephalosporin class, introduced (**1964**); cephalothin resistance observed (**1966**)
1967 and **1970**	gentamicin approved by FDA (**1967**); gentamicin resistance observed (**1970**)
1976	transferable penicillinase first observed in a gonococcus
1981 and **1983**	cefotaxime approved by FDA (**1981**); cefotaxime resistance observed (**1983**)
1983	first penicillin-resistant Enterococcus reported
1987	vancomycin-resistant Enterococcus (VRE) observed; first outbreak of Klebsiella pneumoniae resistant to third-generation cephalosporins
1996	S. aureus with intermediate resistance to vancomycin (VISA) reported
1999	community-acquired MRSA reported
2000 and **2001**	linezolid, the first antibiotic in the oxazolidinone class, approved by FDA (**2000**); linezolid-resistant S. aureus and VRE observed (**2001**)
2002	S. aureus with complete resistance to vancomycin (VRSA) observed

Table source: [L19 p22, L19 p23]

Resistance strategy	How the cell does it
Strategy 1: prevent entry	destroy the antibiotic (beta-lactamase); pump the antibiotic out (efflux pump); reduce membrane permeability (porin)
Strategy 2: prevent binding	alter the target (a mutated component, such as the ribosome); modify the antibiotic (modification enzyme)
Strategy 3: reverse binding	protect the ribosome (ribosome protection protein)

Table source: [L19 p26]

Beta-lactam	Properties
Penicillin G	high activity against most **Gram-positive** bacteria, low against **Gram-negative**; destroyed by acid and penicillinase (penicillinases attack the beta-lactam ring)
Penicillin V	more acid resistant than penicillin G
Ampicillin	active against **Gram-positive** and **Gram-negative** bacteria; acid stable
Carbenicillin	active against **Gram-negative** bacteria like Pseudomonas and Proteus; acid stable; not well absorbed by the small intestine
Methicillin	penicillinase-resistant, but less active than penicillin G; acid-labile
Ticarcillin	similar to carbenicillin, but more active against Pseudomonas

Table source: [L19 p28]

External group	Parts	Plain meaning
Appendages	flagella, pili, fimbriae	parts that stick out from the surface
Glycocalyx	capsule, slime layer	sticky coat outside the wall

Table source: [L19 p39]

Structure seen in some bacteria	Observed?	Basis
Membrane bound compartments	Yes (textbook)	Thylakoids, chlorosomes and a membrane around DNA; carboxysomes and gas vesicles have a protein shell and are inclusions, not membrane compartments
DNA within an intracellular membrane	Yes (textbook)	DNA inside a cytoplasmic membrane compartment in one type of bacteria is true
Three types of cytoskeleton	Yes (three types of cytoskeletal filaments: FtsZ, MreB and crescentin)	FtsZ is similar to tubulin, MreB is similar to actin and crescentin is similar to intermediate (filaments)
DNA wrapped around proteins	Yes, for proteins that fold and compact DNA; **NOT** histone octamers (textbook)	Proteins fold and compact bacterial DNA; bacterial DNA is **NOT** wrapped around an octamer of histones. The common DNA binding proteins are HU, IHF, H-NS and Fis
Aggregates of metabolites or glycogen	Yes (textbook)	Storage granules of glycogen come from the textbook; polyhydroxybutyrate (PHB) and poly-**3**-hydroxyalkanoate (PHA) granules are listed as observed in bacterial interiors
Clumps of iron and sulfur	Yes (textbook)	Granules of elemental sulfur and crystals of iron magnetite ARE observed (textbook)
UFOs (unidentified floating objects)	Yes (textbook)	Structures of unknown function are still being found

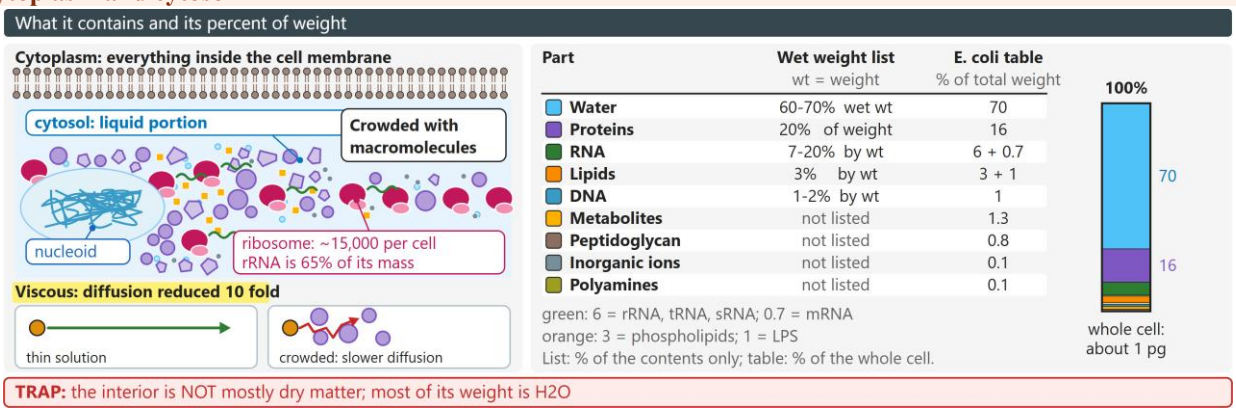
Table source: [L19 p37, L19 p42]

1. Cytoplasm and cytosol

Book: 3.1 The Bacterial Cell: An Overview, Model of a Bacterial Cell (chapter 3 PDF, p. 7); 3.1 The Bacterial Cell: An Overview, Biochemical Composition of Bacteria (chapter 3 PDF, p. 11).

⚠ **Do not mix up: Cytosol *(liquid part of the cytoplasm)* is the liquid part; cytoplasm *(jelly inside the cell membrane)* is everything inside the cell membrane *(thin skin around the cell)*.** [L19 p41]

Cytoplasm and cytosol



Cytosol, contents of the cytoplasm and share of weight [L19 p43]

On the figure: Cytosol · nucleoid · Viscous · Ribosomes · water · proteins · Lipid · DNA

Cytoplasm: everything inside the cell membrane. [L19 p41]

Cytosol: the liquid portion of the cytoplasm. [L19 p41]

Cytoplasm contains: cytosol, dissolved substances, **nucleoid** *(DNA region without a membrane)*, inclusions *(clumps of protein and other material)*, membrane-bound compartments. [L19 p41]

Cytosol:

- The liquid part of the cytoplasm.
- Is a variety of minerals, salts, **proteins**, sugars and other things dissolved in **water**. [L19 p41]

Ribosomes *(protein building machine)* are found in the cytoplasm. [L19 p42]

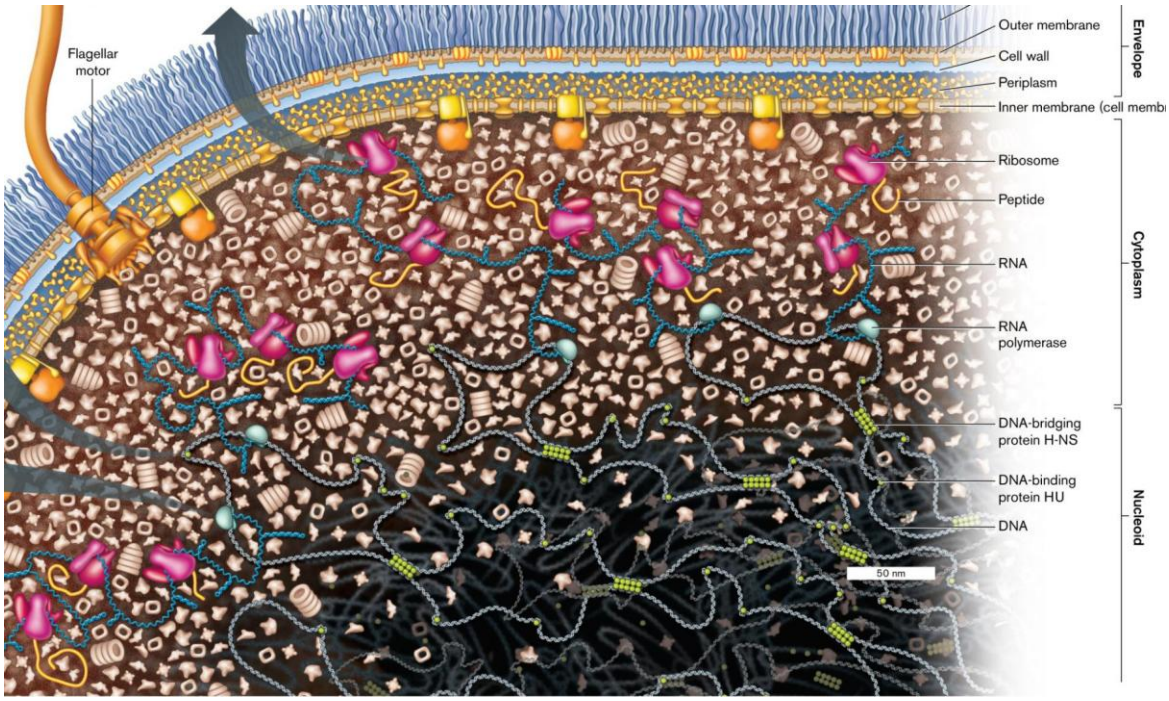
Nucleoid *(the cell's DNA region)*: tightly coiled **DNA** *(cell genetic instruction molecule)*. [L19 p41, L19 p42]

Inclusions:

- Aggregates of proteins and other material.
- Are found in most bacteria. [L19 p41, L19 p42]

Membrane-bound compartments: a few bacteria have them. [L19 p41]

Watch out: most bacteria have inclusions; **only** a few have membrane-bound compartments. [L19 p41, L19 p42]



Cytoplasm contents, nucleoid proteins and envelope layers of a bacterial cell [L19 p42]

On the figure: Ribosomes · RNA polymerase · H-NS · HU · lipopolysaccharide · outer membrane · periplasm · inner membrane

Cytoplasm, nucleoid and envelope contents

Cytoplasm contains ribosome, peptide *(short chain of amino acids)*, RNA and **RNA polymerase** *(enzyme copying DNA into RNA)*. [L19 p42]

Nucleoid contains **H-NS** *(DNA bridging protein)*, **HU** *(DNA binding protein)* and DNA. [L19 p42]

Cell envelope *(layers wrapped around the cell)* holds **lipopolysaccharide** *(outer membrane sugar and fat coat)*, **outer membrane** *(extra membrane outside the wall)*, cell wall *(stiff layer around the cell membrane)*, **periplasm** *(space between the two membranes)* and **inner membrane** (cell membrane); the flagellar motor is also part of the envelope. [L19 p42]

Flagellar motor *(the spinning anchor of the whip tail)*: part of the envelope. [L19 p42]

E. coli composition table

E. coli composition table: here they tried to estimate the number of each component per cell. [L19 p43]

Cell state: balanced exponential growth, a hypothetical average cell. [L19 p43]

Growth medium: glucose minimal salts medium at **37** C. [L19 p43]

Whole cell weight is about **10**^-12 g (**1** pg). [L19 p43]

Two DNA copies: fission lags about one generation behind DNA replication in fast growth. [L19 p43]

Kinds of proteins and mRNA *(message copy of a gene)* are hard to estimate. [L19 p43]

Cytoplasm makeup

Cytoplasm is crowded: packed with macromolecules, particularly **ribosomes** (about **15,000** per cell). [L19 p44]

Viscous *(thick and gel like)*: the rate of diffusion *(drifting from high to low amount)* is reduced **10** fold. [L19 p44]

The weight shares below are for the contents of the cytoplasm. [L19 p44]

Water is **60**-**70%** of the wet weight of the cytoplasm. [L19 p44]

Protein is **20%** of weight. [L19 p44]

RNA is **7**-**20%**. [L19 p44]

rRNAs make up **65%** of ribosomes. [L19 p44]

Lipid is **3%**. [L19 p44]

DNA is **1**-**2%**. [L19 p44]

Check the two lists

Check before you memorize: the cytoplasm percentages do not match the E. coli composition table. [L19 p43, L19 p44]

Protein: **20%** in the cytoplasm list vs **16%** in the composition table. [L19 p43, L19 p44]

DNA: **1**-**2%** in the cytoplasm list vs **1%** in the composition table. [L19 p43, L19 p44]

RNA: **7**-**20%** in the cytoplasm list vs **6.7%** in the composition table. [L19 p43, L19 p44]

The composition table RNA counts rRNA *(RNA building ribosomes)*, tRNA *(adapter that carries amino acids)*, sRNA and mRNA together. [L19 p43, L19 p44]

Lipid: **3%** in the cytoplasm list vs **4%** in the composition table for phospholipids *(membrane fat with a charged head)* plus LPS. [L19 p43, L19 p44]

Learn the cytoplasm list as written; use the composition table for molecule counts. [L19 p43, L19 p44]

Component	% of total weight	Molecules per cell	Different kinds
Water	70	20,000,000,000	1
Proteins	16	2,400,000	4,000
rRNA, tRNA and other small RNA	6	250,000	200
mRNA	0.7	4,000	2,000
Phospholipids (membrane)	3	25,000,000	50
Lipopolysaccharides (outer membrane)	1	1,400,000	1
DNA	1	2	1
Metabolites and biosynthetic precursors	1.3	50,000,000	1,000
Peptidoglycan (murein sacculus)	0.8	1	1
Inorganic ions	0.1	250,000,000	20
Polyamines (mainly putrescine and spermidine)	0.1	6,700,000	2

Table source: [L19 p43]

2. Ribosomes

Book: 27.2 Antibiotic Mechanisms of Action, Protein Synthesis Inhibitors (chapter 27 PDF, p. 50); 27.2 Antibiotic Mechanisms of Action, Targeting the 50S Subunit (chapter 27 PDF, p. 52).

⚠ **Do not mix up: Penicillin and cephalosporin do NOT inhibit ribosomes *(protein building machine)*; they block peptidoglycan *(sugar and peptide mesh of the wall)* synthesis.** [L19 p16]

⚠ **Do not mix up: 70S is NOT 50S + 30S added up: 50 + 30 would be 80, yet the whole bacterial ribosome is 70S (and 60S + 40S make 80S, not 100S).** [L19 p45]

What ribosomes are

Ribosome *(the protein making machine)*: bacterial and **eukaryotic** *(cells with a nucleus)* ribosomes differ in size and components. [L19 p45, L19 p46]

Size: **70S** in bacteria vs **80S** in eukaryotes. [L19 p45]

Subunits *(building block piece)*: the **70S** ribosome is made of a **50S** and a **30S** subunit; the **80S** ribosome is made of a **60S** and a **40S** subunit. [L19 p45]

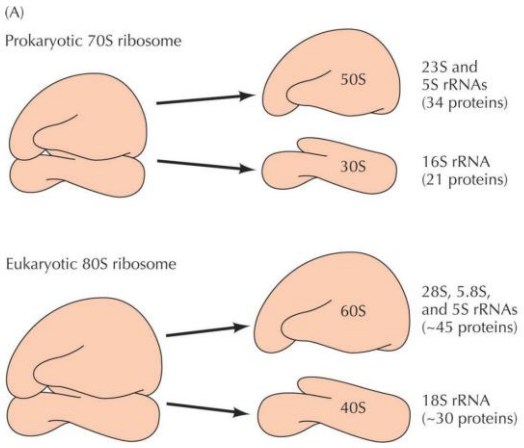
Selective inhibition

Selective inhibition: bacterial ribosomes are selectively inhibited by some antibiotics. [L19 p45, L19 p46]

Selective means the drug hits the bacterial **70S** ribosome and leaves the **eukaryotic 80S** ribosome (ours) working. [L19 p45]

Examples: streptomycin, tetracycline, chloramphenicol, erythromycin. [L19 p45, L19 p46]

Watch out: some antibiotics inhibit ribosomes, not all of them; penicillin and cephalosporin block peptidoglycan synthesis instead. [L19 p45, L19 p46]



Bacterial 70S and eukaryotic 80S ribosomes and their subunits [L19 p45]

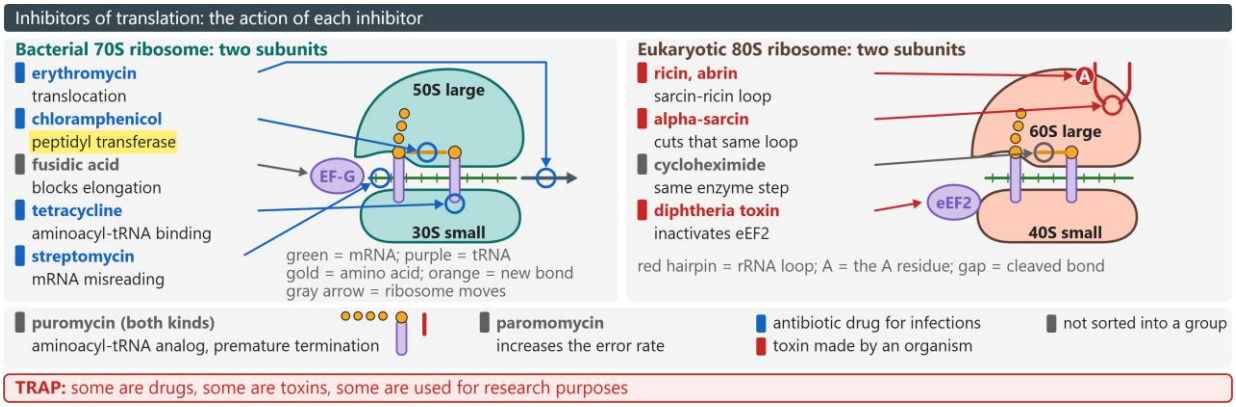
On the figure: 70S · 50S · 30S · 80S · 60S · 40S

Translation inhibitors by target

Translation inhibitors include antibiotic drugs used for bacterial infections. [L19 p46]

Some translation inhibitors:

- Are toxins produced by organisms.
- Are used for research purposes. [L19 p46]



Where each translation inhibitor acts on the ribosome [L19 p46]

On the figure: chloramphenicol · erythromycin · tetracycline · streptomycin · fusidic acid · puromycin · Paromomycin · Diphtheria toxin

Prokaryotic ribosome inhibitors: **chloramphenicol**, **erythromycin**, **tetracycline**, **streptomycin**, **fusidic acid** *(drug trapping EF-G on ribosome)*. [L19 p46]

Eukaryotic ribosome or its elongation factor inhibitors: cycloheximide *(drug blocking eukaryotic peptide bonds)*, ricin *(castor bean poison)*, abrin *(rosary pea poison)*, alpha-sarcin *(fungal toxin that cuts rRNA)*. [L19 p46]

Diphtheria toxin *(toxin shutting down eEF2)* inactivates eEF2 *(eukaryotic elongation helper protein)*. [L19 p46]

Inhibits both kinds of ribosome: **puromycin** *(drug mimicking tRNA, ends protein early)*. [L19 p46]

Paromomycin increases the ribosomal *(about protein building machines)* error rate; no subunit is named for it. [L19 p46]

Penicillin and cephalosporin

Both are **antibiotics that interfere with peptidoglycan synthesis**. [L19 p16]

Penicillin and cephalosporin both form a structure similar to D-Ala-D-Ala.

PBPs *(penicillin binding proteins)* are part of a complex involved in synthesis of peptidoglycan and do the transglycosylation *(joining sugar chains longer)* and transpeptidation *(making peptide bridges between chains)* reactions. [L19 p11, L19 p12]

Penicillin *(a beta-lactam)* blocks the PBPs (transpeptidases and transglycosylases), so peptides *(short chain of amino acids)* are not cross-linked. [L19 p10, L19 p16]

The weakened wall cannot counter intracellular turgor pressure, so the growing cell bursts (textbook).

Cephalosporins *(penicillin like wall blocking drugs)* also inhibit transpeptidase (peptide cross-linking) and transglycosylation, the reactions the PBPs carry out. [L19 p13]

	Prokaryotic 70S ribosome	Eukaryotic 80S ribosome
Large subunit	**50S**: **23S** and **5S** rRNAs, **34 proteins**	**60S**: **28S**, **5.8S** and **5S** rRNAs, about **45 proteins**
Small subunit	**30S**: **16S** rRNA, **21 proteins**	**40S**: **18S** rRNA, about **30 proteins**

Table source: [L19 p45]

Inhibitor	Action	Acts on
Chloramphenicol	Inhibits peptidyl transferase	**Prokaryotic** large subunit
Erythromycin	Inhibits translocation	**Prokaryotic** large subunit
Tetracycline	Inhibits binding of aminoacyl-tRNAs	**Prokaryotic** small subunit
Streptomycin	Causes mRNA misreading and inhibits chain initiation	Prokaryotes
Fusidic acid	Inhibits elongation by binding EF-G-GDP so it cannot dissociate from the large subunit	Prokaryotes
Paromomycin	Increases the ribosomal error rate	Not stated
Puromycin	Aminoacyl-tRNA analog that causes premature chain termination	Prokaryotes and eukaryotes
Cycloheximide	Inhibits peptidyl transferase	**Eukaryotic** large subunit
Diphtheria toxin	Inactivates eEF2 by ADP-ribosylation	eEF2 (no ribosome type named)
Ricin and abrin (plant glycosidases)	Catalytically inactivate the **eukaryotic** large subunit by removing a purine (depurination) from a highly conserved A in the **28S** RNA sarcin-ricin loop, a critical part of the factor binding center	**Eukaryotic** large subunit
Alpha-sarcin (fungal protein)	Cleaves a phosphodiester bond in the sarcin-ricin loop	The sarcin-ricin loop (in the **28S** RNA of the **eukaryotic** large subunit, as for ricin)

Table source: [L19 p46]