Micro Exam 2 Acronyms: all lectures, by lecture (L15 to L22)

How to use: cover the lines, read only the big letters and the phrase, say each word, then uncover. Look-alikes sit together in one family. **Red line = a common trap.** (tb) = a slide blank left empty in the complete notes, filled from the textbook.

Lecture 15 Flagella and Motility (23 acronyms)

1. Size and shape of microbes

⚠ **Do not mix up: Viruses smallest (10 to 100 nm); eukaryotes widest (10 to 100 micrometers).**

EBV·M Sizes of microbes

Eukaryotic microbes are big, Bacteria in the middle, Viruses tiny / Micron ruler

- **E** **Eukaryotic** *(cells with a nucleus)* **microbes** **10** to **100** micrometers *(one millionth of a meter)*; widest
- **B** **Bacteria** **0.4** to **10** micrometers wide; middle
- **V** **Viruses** **0.01** to **0.1** micrometers (**10-100 nm**); smallest
- **M** **Micron** **1 um** = **10**^-6 m = **1000 nm**

L15 p05

CB·V·S·C Shapes of bacteria

Cocci are balls, Bacillus a rod / Vibrio a comma / Spiral corkscrew / Clusters or filaments

- **C** **Cocci** *(round cells)* Spherical balls; one is a coccus
- **B** **Bacillus** *(rod shaped cell)* Cells shaped like rods
- **V** **Vibrio** Curved rod, comma-shaped
- **S** **Spiral** Twisted corkscrew-shaped cells
- **C** **Clusters or filaments** Grow in clusters or filaments

L15 p06

2. External structures and flagella layout

⚠ **Do not mix up: Flagella are for motility; pili and fimbriae are for adherence, not motility.**

P·FP·NO External structures: flagella vs pili

Protein filaments / Flagella move, Pili stick / Not enclosed, Others

- **P** **Protein filaments** Protein filaments projecting out from cell
- **F** **Flagella** *(whip tails that spin)* One of two main types: motility *(ability to move)*
- **P** **Pili** *(thin hairs on the cell)* **and fimbriae** *(short sticky hairs)* Other main type: adherence (type IV: twitching)
- **N** **Not enclosed** Not enclosed by membrane *(thin lipid layer)* or wall
- **O** **Others** Others: stalks *(stem that anchors the cell)*, nanotubes *(tiny tube joining two cells)*

L15 p07

N·OBA·PL Flagella number and location

Number from none to many / One end, Both ends, All over / Periplasm, Lose and regain

- **N** **Number** **0** to many per cell; species trait
- **O** **One end** At one end of cell
- **B** **Both ends** At both ends of cell
- **A** **All over** Spread over whole cell
- **P** **Periplasm** *(space between the two membranes)* Spirochetes *(long corkscrew shaped bacteria)*: in periplasm, from each pole, wrap cell
- **L** **Lose and regain** Some can lose and regain them

L15 p08, L15 p09, L15 p10, L15 p11

3. Flagellum parts and how it is built

⚠ **Do not mix up: Hook is hook protein plus 2 HAPs; filament is flagellin; Mot proteins added last.**

The four sections, rings, filament

BHFM **Four sections of the flagellum**

Basal body anchors, Hook joins, Filament sticks out, Motor spins

- **B** **Basal body** *(anchor of the whip in the envelope)* Spans membrane *(thin lipid layer)*; about **15 proteins**; whole about **40**
- **H** **Hook** Hook protein plus **2** HAPs *(hook associated proteins)*; filament is flagellin *(protein that builds the whip)*
- **F** **Filament** Sticks out; usually single protein, flagellin
- **M** **Motor** Rotor plus Mot proteins *(motor proteins that turn the flagellum)*; drives movement

L15 p12, L15 p13, L15 p14, L15 p15, L15 p16

LP·SM·RC **Basal body rings and rod**

L ring, P ring / S ring, M ring / Rod, C ring

- **L** **L ring** Outer membrane *(extra membrane outside the wall)*; outermost; rings number **1** to **4**
- **P** **P ring** In peptidoglycan *(sugar and peptide mesh of the wall)* layer, just below L ring
- **S** **S ring** Inner membrane *(the skin around the cytoplasm)*; with M ring, the MS ring
- **M** **M ring** Inner membrane, at **base** of rod
- **R** **Rod** Central rod of basal body *(anchor of the whip in the envelope)*
- **C** **C ring** The switch, below MS ring

L15 p13, L15 p14, L15 p16

W·FC·GS·H **Flagellar filament features**

Width and length / Flagellin, Cap / Genes, Self polymerize / Hollow tube

- **W** **Width and length** **14-20 nm** wide; up to **5-10 um** long
- **F** **Flagellin** *(protein that builds the whip)* Usually one protein; hook = hook protein + HAPs *(hook associated proteins)*
- **C** **Cap** Different protein on **tip**: cap protein
- **G** **Genes** Several flagellin genes; cell can switch
- **S** **Self polymerize** Subunits *(building block piece)* self polymerize, helical or spiral
- **H** **Hollow tube** Hollow tube; Mot proteins *(motor proteins that turn the flagellum)* in motor, not filament

L15 p15

Building it: steps in order

MROHFM **steps in order: Flagellum assembly order**

Membrane rings, then Rod, Outer rings, Hook, Filament, Mot proteins last

- **M** **Membrane** *(thin lipid layer)* **rings** Steps **1** and **2**: membrane rings first
- **R** **Rod** Step **3**: rod after membrane rings
- **O** **Outer rings** Steps **4, 5**: **outer** rings P and L
- **H** **Hook** Steps **6** and **7**: hook, before filament
- **F** **Filament** Step **8**: filament after hook
- **M** **Mot proteins** *(motor proteins that turn the flagellum)* Step **9,** last: Mot proteins in membrane

L15 p17, L15 p18

HFCT **steps in order: Filament growth by extrusion**

Hook done, Flagellin goes through the Core to the Tip

- **H** **Hook finished** Hook finished before filament grows
- **F** **Flagellin** *(protein that builds the whip)* Flagellin subunits *(building block piece)* made and extruded
- **C** **Core** Subunits pass through hollow core
- **T** **Tip** Subunits add at **tip**; filament grows from **tip**

L15 p15, L15 p18

4. Flagella-driven motility: swimming, periplasmic, swarming

⚠ **Do not mix up: Swarming needs a slime layer on a surface; swimming is in liquid.**

All six types (overview)

SPS·TGS **Six types of bacterial motility**

Swimming, Periplasmic, Swarming need flagella / Twitching, Gliding, Sliding do not

- **S** **Swimming** Flagella *(whip tails that spin)*: runs and tumbles *(stop and turn to a new direction)* in liquid
- **P** **Periplasmic** *(in the space between the two membranes)* **flagella** Flagella in spirochetes *(long corkscrew shaped bacteria)*; corkscrew or wiggle
- **S** **Swarming** *(group moving on a surface using flagella)* Flagella; surface or semi-solid; group raft
- **T** **Twitching** *(jerky crawl using pili)* Non-flagellar; surface; type IV pili *(thin hairs on the cell)*
- **G** **Gliding** *(smooth crawl on a surface)* Non-flagellar; solid surface; over **12** genera
- **S** **Sliding** *(passive spreading by pushing)* Non-flagellar; passive *(needs no energy)*; pushed by dividing cells

L15 p22, L15 p25, L15 p34

Swimming: runs, tumbles, CCW vs CW

RTSL **Swimming: runs, tumbles, sensing**

Runs and Tumbles, Sense change, Length of runs

- **R** **Runs** Flagella *(whip tails that spin)* on: a run in liquid
- **T** **Tumbles** *(stop and turn to a new direction)* Brief stops break up runs; reorient
- **S** **Sense change** Sense concentration change; flagella on or off
- **L** **Length of runs** Taxis *(moving toward or away from something)* comes from controlling run length

L15 p21, L15 p26

SS·MCC **Flagella turning: single vs many**

Single flagellum, Stop by halting or reversing / Multiple flagella, Counterclockwise runs, Clockwise tumbles

- **S** **Single flagellum** *(whip tail that spins)* Polar: reversible **CCW** or **CW**; or **CW only**
- **S** **Stop** Stop (tumble): stops turning or reverses
- **M** **Multiple flagella** *(whip tails that spin)* Coordinated turning; slower than single flagellum
- **C** **Counterclockwise** *(spinning the opposite way of a clock)* Multiple **CCW**: forward movement (run)
- **C** **Clockwise** *(spinning the way a clock goes)* Multiple **CW**: stop (tumble), flagella pushed apart

L15 p27, L15 p28

Periplasmic flagella (spirochetes)

SPEDC **Spirochete periplasmic flagella**

Spirochetes have Periplasm flagella from Each end, Direction of rotation, Corkscrew

- **S** **Spirochetes** *(long corkscrew shaped bacteria)* Seen in spirochete bacteria
- **P** **Periplasm** *(space between the two membranes)* Flagella *(whip tails that spin)* in periplasm, wrap around cell
- **E** **Each end** Extend from each end (pole)
- **D** **Direction** Rotation direction at each end sets motility *(ability to move)* direction
- **C** **Corkscrew** Wiggling corkscrew; burrows into thick mucus

L15 p11, L15 p29, L15 p30, L15 p31

Swarming

SFR·SPT **Swarming motility**

Surface, Flagella, Raft / Slime layer, Proteus, Test

- **S** **Surface** Across surface or semi-solid media
- **F** **Flagella** *(whip tails that spin)* Flagella-mediated; position may shift lateral
- **R** **Raft** Group (raft) moves together
- **S** **Slime layer** *(loose sticky coat outside)* Requires a slime layer
- **P** **Proteus** Examples: Proteus and E. coli; some species **only**
- **T** **Test** Inoculate center; ring or dendritic spread = swarming *(group moving on a surface using flagella)*

L15 p32, L15 p33

5. Non-flagellar motility: twitching, gliding, sliding

⚠ **Do not mix up: Gliding is active on solid surface; sliding is passive, pushed by dividing cells.**

EASP steps in order: Twitching by type IV pili

pili Extend, Attach, Shorten, Pull

- **E Extend** Type IV pili *(thin hairs on the cell)* extend out from cell
- **A Attach** Pilus *(thin hair for sticking or DNA swap)* attaches to surface
- **S Shorten** Pilus shortens (retracts)
- **P Pull cell forward** Shortening pulls cell forward; **Gram-negative** *(thin wall plus outer membrane)* species

L15 p35, L15 p36

SOMFN Gliding motility

Solid surface, Over twelve genera, Mechanism unknown, Flavobacterium feet, No slime

- **S Solid surface** Motility *(ability to move)* across solid surface
- **O Over 12 genera** Over **12** genera, e.g. Myxococcus
- **M Mechanism unknown** Mechanism not understood in all genera
- **F Flavobacterium** Bacteroidetes: membrane *(thin lipid layer)* proteins act like feet
- **N No slime** No slime, pili *(thin hairs on the cell)* or flagella *(whip tails that spin)*

L15 p37, L15 p38

PDSEP Sliding motility

Passive spread, pushed by Dividing cells, Surfactants, Exopolysaccharide, Protein slime layer

- **P Passive** *(needs no energy)* Passive spread; no flagella *(whip tails that spin)*, pili *(thin hairs on the cell)* or feet
- **D Dividing cells** Powered by pushing of dividing cells
- **S Surfactants** *(soap like slippery chemicals)* Needs surface factors: surfactants
- **E Exopolysaccharide** *(sugar chains outside the cell)* Or exopolysaccharide layer as factor
- **P Protein slime layer** *(loose sticky coat outside)* Or protein slime layer as factor

L15 p39

6. Taxis: motility vs taxis, chemotaxis

⚠ **Do not mix up: Multiple flagella: CCW is a run, CW is a tumble.**

MTE·CV Motility and taxis defined

Motility, Taxis toward or away from an Effecter / Chemotaxis, not Vibration

- **M Motility** *(ability to move)* Purposeful movement in liquid or on surface
- **T Taxis** *(moving toward or away from something)* Movement toward or away from stimuli
- **E Effecter** *(outside signal that triggers a response)* **External** stimulus that triggers taxis
- **C Chemotaxis** *(moving toward or away from chemicals)* Taxis to chemicals; cells have receptors *(proteins a signal or virus binds to)*
- **V Vibration** Jiggling in place is **NOT** motility

L15 p22, L15 p23, L15 p24, L15 p40

CMLTPO What can drive taxis

Chemicals, Metals, Light, Temperature, PH, Oxygen

- **C Chemicals** Nutrients affect motility *(ability to move)* and taxis *(moving toward or away from something)*
- **M Metals** Metals affect it; many are toxic
- **L Light** Light affects taxis
- **T Temperature** Temperature affects taxis
- **P pH** pH affects taxis
- **O Oxygen level** Oxygen level affects taxis

L15 p23

RSCCL steps in order: Chemotaxis: receptors to runs

Receptors send a Signal, Counterclockwise runs, Clockwise tumbles, Longer runs up the gradient

- **R Receptors** *(proteins a signal or virus binds to)* Receptors for attractants *(chemical that pulls cells in)* and repellents *(chemical that pushes cells away)*
- **S Signal** Signal affects whether flagella *(whip tails that spin)* turn
- **C Counterclockwise** *(spinning the opposite way of a clock)* Many flagella: **CCW** gives forward run
- **C Clockwise** *(spinning the way a clock goes)* **CW** pushes flagella apart: tumble *(stop and turn to a new direction)*, reorient
- **L Longer runs** Runs toward attractant last longer; tumbles still occur

L15 p24, L15 p26, L15 p28

ARG Attractant, repellent, gradient

Attractant pulls, Repellent pushes, Gradient guides

A **Attractant** *(chemical that pulls cells in)* Move toward it; signal changes turning

R **Repellent** *(chemical that pushes cells away)* Move away from it

G **Gradient** *(gradual change in amount)* Sense concentration change, adjust run length

L15 p24, L15 p26, L15 p43

7. Detecting motility

⚠ **Do not mix up: Motility agar is 0.75%, not 1.5%; growth only at stab means non-motile.**

WBPAFE Wet mount and flagella detection

Wet mount, Bright-field or dark-field, Purposeful, Absence not proof, Flagellar stain, Electron microscopy

W **Wet mount** Observe movement in live wet mounts

B **Bright-field or dark-field** Light microscopy on live wet mount

P **Purposeful** Movement must be purposeful, not vibrational

A **Absence not proof** No movement seen is **NOT** definitive

F **Flagellar stain** Detects flagella *(whip tails that spin)*: number and location

E **Electron microscopy** Also detects flagella

L15 p40

MNT·SA Soft agar motility assays

Motility agar, Non-motile at the stab, Turbidity throughout / Swarm plate, Attractant plate

M **Motility** *(ability to move)* **agar** **0.75%** (not **1.5%**) semi-soft; stab; misses some motility

N **Non-motile** Growth **only** at stab = non-motile

T **Turbidity** *(cloudiness of liquid)* **throughout** Turbidity throughout tube = motile

S **Swarm plate** Cells in center; circular spread = motility

A **Attractant** *(chemical that pulls cells in)* **plate** Cells at one end, test substance at other

L15 p41, L15 p42, L15 p43

Lecture 16 Pili, External Structures and Envelope Styles (35 acronyms)

1. Pili and fimbriae: types and roles

⚠ **Do not mix up: Common pili: adhesion and 100s per cell; sex pili: conjugation and under 10.**

Pili vs flagella, and the three roles

TS·NG·R Pili and fimbriae vs flagella: size, number

Thinner and Shorter / Numerous, mostly Gram-negatives / three Roles

- **T Thinner** Pili *(thin hairs on the cell)* **3-10 nm**; **18 nm** is flagellum (**14-20**)
- **S Shorter** Shorter than flagella *(whip tails that spin)*; protein tube, no membrane *(thin lipid layer)*
- **N Numerous** Pili **100**s, sex under **10**; more than flagella
- **G Gram-negatives** *(thin wall plus outer membrane)* More common in **Gram-negative** bacteria
- **R Roles** **3** types: common, Type IV, sex pili

L16 p03, L16 p04, L16 p06, L16 p10

C·T·S·A Roles: common, Type IV and sex pili

Common pili stick to surfaces / Type four pili twitch / Sex pili swap genes / Adhesin at the tip

- **C Common pili (fimbriae)** Adhesion *(sticking to a surface)*, biofilm *(slimy community on a surface)*; **NOT** motility *(ability to move)*, **NOT** DNA *(cell genetic instruction molecule)* transfer
- **T Type IV pili** Twitching *(jerky crawl using pili)*: extend, attach, shorten to pull cell
- **S Sex (F) pili** DNA transfer by conjugation *(cells passing DNA by contact)*
- **A Adhesin** *(sticky protein for attaching)* Tip protein binds sugars; virulence *(ability to cause disease)* factor

L16 p08, L16 p09, L16 p10, L16 p05

LF·CS Sex (F) pili vs common pili

Longer and wider, Fewer than ten / Conjugation, then Shortens

- **L Longer and wider** Longer, wider: sex **7 nm** vs common **3-10**
- **F Few per cell** Under **10 per cell** vs **100**s common
- **C Conjugation** *(cells passing DNA by contact)* DNA *(cell genetic instruction molecule)* transfer; conjugative plasmids *(small extra DNA circle)*; E. coli F pilus *(thin hair for sticking or DNA swap)*
- **S Shortens** Attaches, shortens, pulls cells together, DNA transfers

L16 p10, L16 p11, L16 p05

TA·BD·R Type IV pili: functions

Twitching, Adhesion / Biofilm, DNA uptake / Retract

- **T Twitching** *(jerky crawl using pili)* **motility** *(ability to move)* Extend, attach, shorten: pulls cell toward site
- **A Adhesion** *(sticking to a surface)* Attachment to surfaces
- **B Biofilm** *(slimy community on a surface)* **formation** Helps build biofilms
- **D DNA** *(cell genetic instruction molecule)* **uptake** Takes up DNA; sex pili *(thin hairs on the cell)* do conjugation *(cells passing DNA by contact)*
- **R Retract** *(pull back in)* Extend and retract; Pseudomonas, Neisseria; pili not fimbriae *(short sticky hairs)*

L16 p05, L16 p09

Which pili are fimbriae, which are not

T·P·V·C·T Pili that form fimbriae

Type one binds mannose / P pili hit urinary cells / Vee fibers aggregate / Curli amyloid / Tad sticks

- **T Type I** Type **1**: adhesion *(sticking to a surface)*, biofilms *(slimy community on a surface)*; binds mannose
- **P P pili** *(thin hairs on the cell)* Urinary tract infection adhesion; chaperone-usher
- **V V pili** Type V: adhesion and aggregation *(clumping together)*; short fibers
- **C Curli** Amyloid *(stacked protein fibers)*; E. coli, Salmonella; attachment, aggregation, biofilm
- **T Tad** *(tight adherence pili)* **pili** Tight adherence; persistent colonization

L16 p05, L16 p07

T·C·S·C·G Pili not called fimbriae: DNA movers

Type four twitches / Conjugative sends genes / Secretion sends genes or proteins / Competence takes up genes / Gram-positive cousins

- **T** **Type IV** Twitching *(jerky crawl using pili)*, adhesion *(sticking to a surface)*, biofilm *(slimy community on a surface)*, DNA *(cell genetic instruction molecule)* uptake; pili *(thin hairs on the cell)* not fimbriae *(short sticky hairs)*
- **C** **Conjugative (sex)** DNA transfer between cells; **NOT** called fimbriae
- **S** **Secretion pili** Type IV secretion: DNA or protein transfer
- **C** **Competence** *(ability to take up DNA)* **pili** DNA uptake in transformation *(cell taking up free DNA)*; Type IV related
- **G** **Gram-positive** *(thick wall, stains purple)* **Type IV-like** Adhesion, motility *(ability to move)*, DNA uptake; Type IV related

L16 p05

What a pilus is made of

F·T·G·V Pilus composition: filament and tip

Filament and Tip / Genes change / Virulence

- **F** **Filament** Many copies of one protein: pilin *(protein that builds a hair)*
- **T** **Tip** Tip: **1** to **2** other proteins; binds sugars
- **G** **Genes** Multiple pilin genes; can switch pilin made
- **V** **Virulence** *(ability to cause disease)* Adhesins *(sticky protein for attaching)* are virulence factors; biofilm *(slimy community on a surface)* too

L16 p13, L16 p14, L16 p08

2. How pili and flagella are assembled

⚠ **Do not mix up: Type I pilus builds on outer membrane; Type IV builds in inner membrane.**

S·CU·TP·A steps in order: Type I pilus assembly (chaperone-usher)

Sec sends / Chaperone guides to Usher / Tip first, then Pilin / Anchor ends

- **S** **Sec system** *(protein export machine)* Sec secretes proteins into periplasm *(space between the two membranes)*
- **C** **Chaperone (PapD)** PapD chaperone carries them to usher *(channel that assembles pili)*
- **U** **Usher (PapC)** PapC usher: **outer** membrane *(extra membrane outside the wall)* channel, assembled there
- **T** **Tip adhesin (PapG)** Adhesin PapG at **tip**, first
- **P** **Pilin (PapA)** PapA pilin added at **base** of shaft
- **A** **Anchor (PapH)** PapH anchors PapA, can end assembly

L16 p16, L16 p13

P·L·I·S·E·B steps in order: Type IV pilus assembly

Pilin made, Leader cut / Inner membrane builds it / Secretin channel / Energy to retract / Base shortens

- **P** **Pilin (PilA)** PilA made as preprotein, **inner** membrane *(the skin around the cytoplasm)*
- **L** **Leader** *(temporary starting piece of protein)* **removed** PilD peptidase *(enzyme that trims proteins)* removes leader from PilA
- **I** **Inner membrane assembly** Assembled in **inner** membrane (Type I: **outer**)
- **S** **Secretin** *(large exit channel in outer membrane)* Pushed through **outer** membrane *(extra membrane outside the wall)* secretin channel
- **E** **Energy (NTP)** PilT and PilF NTP-binding give retraction energy
- **B** **Base disassembly** Shortens by disassembling pilin from **base**

L16 p17

TB·C·S·A Pilus vs flagellum assembly

flagella add at the Tip, pili at the Base / flagellin runs the Core / some pili Shorten / Assembly sites differ

T **Tip growth** Flagellum *(whip tail that spins)*: flagellin *(protein that builds the whip)* added at **tip**

B **Base growth** Pili *(thin hairs on the cell)*: subunits *(building block piece)* added at **base**

C **Core** Flagellin goes through filament core

S **Shorten** Type IV pili shorten from **base**; flagella *(whip tails that spin)* **NOT**

A **Assembly site** Type I: **outer** membrane *(extra membrane outside the wall)*; Type IV: **inner** membrane *(the skin around the cytoplasm)*

L16 p15, L16 p18, L16 p19, L16 p16, L16 p17

NCD·PN Nanotubes

Nanotube from Cytoplasm joins Different species / Proteins and Nucleic acids

N **Nanotube** *(tiny tube joining two cells)* Between **2** cells; **NOT** pilus *(thin hair for sticking or DNA swap)*, **NOT** stalk *(stem that anchors the cell)*

C **Cytoplasm** *(jelly inside the cell membrane)* **or periplasm** *(space between the two membranes)* Cytoplasm or periplasm; periplasm **Gram-negative** *(thin wall plus outer membrane)* **only**

D **Different species** Can connect different species

P **Proteins** Shares Cat and Erm proteins

N **Nucleic acids** Shares cat and erm mRNA *(message copy of a gene)*

L16 p21, L16 p22, L17 p31

3. Other external structures: stalks and nanotubes

⚠ Do not mix up: Stalk is for adhesion; nanotube connects two cells; neither is a pilus.

F·P·S·N External structures: who does what

Flagella swim / Pili stick / Stalks anchor / Nanotubes share

F **Flagella** *(whip tails that spin)* Motility *(ability to move)*; protein filaments, no membrane *(thin lipid layer)* or wall

P **Pili** *(thin hairs on the cell)* **and fimbriae** *(short sticky hairs)* Adherence (common), twitching (Type IV), DNA *(cell genetic instruction molecule)* transfer (sex)

S **Stalks** *(stem that anchors the cell)* Others **3**a: adhesion *(sticking to a surface)*

N **Nanotubes** *(tiny tube joining two cells)* Others **3**b: cytoplasm *(jelly inside the cell membrane)* extension between **2** cells

L16 p03, L16 p20, L16 p21

SCA Stalks

Stalk of Caulobacter for Adhesion

S **Stalk** *(stem that anchors the cell)* Seen in Caulobacter and other bacteria

C **Caulobacter** Example of a stalked bacterium

A **Adhesion** *(sticking to a surface)* Adhesion; **NOT** swimming, twitching *(jerky crawl using pili)*, DNA *(cell genetic instruction molecule)* transfer

L16 p20

4. Gram positive vs Gram negative envelopes

⚠ Do not mix up: Teichoic acids and 3 to 20 layers are Gram-positive; outer membrane, periplasm, LPS Gram-negative.

All five styles side by side

GM·GM·A Five envelope styles

Gram-positives and Mycobacteria / Gram-negatives and Mollicutes / Archaea

G **Gram positive** *(thick wall, stains purple)* Thick peptidoglycan *(sugar and peptide mesh of the wall)*, teichoic acids *(charged chains in Gram positive wall)*, no **outer** membrane *(extra membrane outside the wall)*

M **Mycobacterial** *(about waxy walled bacteria)* **Gram-positive**, acid-fast *(holds dye despite acid wash)*; mycolic acids *(waxy fatty acids of mycobacteria)*; no LPS *(outer membrane sugar and fat coat)*

G **Gram negative** *(thin wall plus outer membrane)* Outer membrane LPS, thin peptidoglycan, **inner** membrane *(the skin around the cytoplasm)*

M **Mollicutes** *(bacteria with no cell wall)* Mycoplasma: no wall, **only** plasma membrane *(thin lipid layer)*

A **Archaeal** *(of archaea)* S-layer *(crystal like protein coat outside)*, sometimes pseudopeptidoglycan *(archaea version of wall mesh)*; isoprenoid *(branched five carbon repeat fat)* lipids

L16 p27, L16 p30, L16 p31, L16 p32, L16 p33, L16 p34

PT·O·M·S·N Which envelope has which layer

Peptidoglycan with Teichoic in positives / Outer membrane in negatives / Mycolic in mycobacteria / S-layer in some / No wall in mollicutes

P **Peptidoglycan** *(sugar and peptide mesh of the wall)* Gram+, mycobacteria *(waxy walled bacteria)*, Gram-; not mollicutes *(bacteria with no cell wall)*, archaea *(single cell microbes, their own group)*

T **Teichoic acids** *(charged chains in Gram positive wall)* Most **Gram-positive** *(thick wall, stains purple)*; **NOT Gram-negative** *(thin wall plus outer membrane)*

O **Outer membrane (LPS)** LPS *(outer membrane sugar and fat coat)* type **Gram-negative only**; mycobacteria mycolic *(waxy fatty acid type)*

M **Mycolic acids** *(waxy fatty acids of mycobacteria)* Mycobacteria **only**; NEVER archaea

S **S-layer** *(crystal like protein coat outside)* Some **Gram positive**, negative, archaea; not Mycoplasma

N **No cell wall** *(stiff layer around the cell membrane)* Mollicutes: no wall, membrane *(thin lipid layer)* **only**

L16 p27, L16 p30, L16 p31, L16 p32, L16 p33, L16 p34, L16 p43

SLO·LP·I Gram-negative layers, outside in

S-layer, LPS on the Outer membrane / Lipoproteins hold Periplasm peptidoglycan / Inner membrane

S **S-layer** *(crystal like protein coat outside)* Some **Gram-negative**s *(thin wall plus outer membrane)*; outside **outer** membrane *(extra membrane outside the wall)*

L **LPS** *(outer membrane sugar and fat coat)* LPS in **outer** leaflet, sugar chain out

O **Outer membrane** Porins *(channels in the outer membrane)*; phospholipids *(membrane fat with a charged head)* mainly **inner** leaflet

L **Lipoproteins** *(proteins with fat tails)* Murein lipoprotein *(protein anchoring outer membrane to wall)* links **outer** membrane to peptidoglycan *(sugar and peptide mesh of the wall)*

P **Periplasm** *(space between the two membranes)* Periplasm holds thin peptidoglycan, **1** to **2 layers**

I **Inner membrane** *(the skin around the cytoplasm)* Cell membrane *(thin skin around the cell)*, innermost layer

L16 p32, L17 p05, L17 p06, L17 p11, L17 p15, L17 p31

Gram positive vs Gram negative, layer by layer

GS·PT·C Gram-positive layers, outside in

Glycosyl chains cover the S-layer / Peptidoglycan with Teichoic acids / Cell membrane

G **Glycosyl** *(sugar group)* **chains** Glycosyl chains outermost

S **S-layer** *(crystal like protein coat outside)* Protein layer, some **Gram-positive** *(thick wall, stains purple)*, outside wall

P **Peptidoglycan** *(sugar and peptide mesh of the wall)* Thick, **3** to **20 layers**; no **outer** membrane *(extra membrane outside the wall)*

T **Teichoic acids** *(charged chains in Gram positive wall)* Glycerol *(three carbon fat backbone)* or ribitol *(five carbon sugar alcohol)* phosphate *(PO4 group)* polymers in peptidoglycan

C **Cell membrane** *(thin skin around the cell)* Single membrane, innermost

L16 p30, L17 p15, L17 p26

ST·T·OPL Gram positive vs Gram negative envelopes

Same core, Thickness differs / Teichoic in positives / Outer membrane, Periplasm, LPS in negatives

S **Same core** Both: cell membrane *(thin skin around the cell)*, peptidoglycan *(sugar and peptide mesh of the wall)*, can have S-layer *(crystal like protein coat outside)*

T **Thickness** Positive **3**-**20** peptidoglycan layers; negative **1**-**2**

T **Teichoic acids** *(charged chains in Gram positive wall)* Most **Gram-positive** *(thick wall, stains purple)* **only**, not **Gram-negative** *(thin wall plus outer membrane)*

O **Outer membrane** *(extra membrane outside the wall)* Only **Gram-negative** has **outer** membrane

P **Periplasm** *(space between the two membranes)* Only **Gram-negative** has periplasm

L **LPS** *(outer membrane sugar and fat coat)* Only **Gram-negative** has LPS

L16 p30, L16 p32, L17 p15, L17 p26, L17 p31

Envelope layer list

GS·O·C·P·C Envelope layers, outside in

Glycocalyx, S-layer / Outer membrane / Cell wall / Periplasm / Cell membrane

G **Glycocalyx** *(sugary coat outside the cell)* Capsule (sugars or proteins)

S **S-layer** *(crystal like protein coat outside)* Protein layer outside wall or membrane *(thin lipid layer)*

O **Outer membrane** *(extra membrane outside the wall)* LPS *(outer membrane sugar and fat coat)*, phospholipids *(membrane fat with a charged head)*, proteins

C **Cell wall** *(stiff layer around the cell membrane)* Peptidoglycan *(sugar and peptide mesh of the wall)*, pseudopeptidoglycan *(archaea version of wall mesh)*, teichoic *(charged wall chain type)*, mycolic acids *(waxy fatty acids of mycobacteria)*, arabinogalactan *(chain of arabinose and galactose sugars in the wall)*

P **Periplasm** *(space between the two membranes)* **Gram-negative** *(thin wall plus outer membrane)* **only**; between **outer** and **inner** membrane *(the skin around the cytoplasm)*

C **Cell membrane** *(thin skin around the cell)* Phospholipids, isoprenoids *(branched five carbon repeat fats)*, hopanoids *(five ring cholesterol like fat)*; proteins

L16 p36, L17 p04, L17 p30

5. Mycobacteria, mollicutes and archaea

⚠ **Do not mix up: Mycolic acids: mycobacteria only. Pseudopeptidoglycan: some archaea only. Mollicutes: no wall.**

CM·AG·PC Mycobacterial layers, outside in

Capsule over Mycolic acids / Arabinan, Galactan / Peptidoglycan on the Cell membrane

C **Capsule** *(firm sugar coat outside the cell)* Outermost: glycolipids, sugar mycolates

M **Mycolic acids** *(waxy fatty acids of mycobacteria)* Mycolic acids: **60** to **90 carbons**, on arabinan *(five carbon sugar chain)*

A **Arabinan** **5**-carbon arabinose *(a five carbon sugar)* chains; ethambutol blocks synthesis

G **Galactan** *(chain of galactose sugars)* Galactose chains; with arabinan, arabinogalactan *(chain of arabinose and galactose sugars in the wall)*

P **Peptidoglycan** *(sugar and peptide mesh of the wall)* Next to cell membrane *(thin skin around the cell)*; **NOT** pseudopeptidoglycan *(archaea version of wall mesh)*

C **Cell membrane** Innermost; phospholipid *(membrane fat with a charged head)* bilayer *(two layers)*; no LPS *(outer membrane sugar and fat coat)*

L16 p31, L17 p28, L17 p29

AGP·M·N Mycobacteria vs other envelopes

Acid-fast Gram-positives share Peptidoglycan / Mycolic acids / Non-LPS outer membrane

A **Acid-fast** *(holds dye despite acid wash)* Acid-fast stain; mycolic acids *(waxy fatty acids of mycobacteria)* resist acids

G **Gram-positive** *(thick wall, stains purple)* **actinomycete** *(branching thread bacterium)* **Gram-positive** actinomycete, **NOT Gram-negative** *(thin wall plus outer membrane)*

P **Peptidoglycan** *(sugar and peptide mesh of the wall)* Shared with **Gram positive** and negative

M **Mycolic acids** Mycolic acids **only** here, linked to arabinogalactan *(chain of arabinose and galactose sugars in the wall)*

N **Non-LPS outer membrane** *(extra membrane outside the wall)* No LPS *(outer membrane sugar and fat coat)* **outer** membrane; no teichoic acids *(charged chains in Gram positive wall)*

L16 p27, L16 p31, L17 p28

MNP·LL·P Mollicutes (Mycoplasma) envelope

Mollicutes have No wall, only Plasma membrane / Lipoproteins, Lipid-glycans / Proteins

M **Mollicutes** *(bacteria with no cell wall)* Mollicutes are Mycoplasma

N **No cell wall** *(stiff layer around the cell membrane)* No peptidoglycan *(sugar and peptide mesh of the wall)*, S-layer *(crystal like protein coat outside)*, or **outer** membrane *(extra membrane outside the wall)*

P **Plasma membrane** *(thin lipid layer)* Only envelope *(layers wrapped around the cell)* layer

L **Lipoproteins** *(proteins with fat tails)* LPPs on membrane surface

L **Lipid-glycans** LG with oligosaccharide repeats

P **Proteins** IMP intermembrane protein; PMP peripheral membrane

L16 p27, L16 p33

SS·MP·I·N Archaeal envelope

S-layer on Sulfolobus / Methanothermus adds Pseudopeptidoglycan / Isoprenoids / No mycolic acid

S **S-layer** *(crystal like protein coat outside)* Crystalline *(neat repeating pattern)* protein layer; especially archaea *(single cell microbes, their own group)*

S **Sulfolobus** *(heat and acid loving archaea)* Sulfolobus: S-layer **only**, no wall

M **Methanothermus** *(heat loving archaea)* Methanothermus: S-layer over pseudopeptidoglycan *(archaea version of wall mesh)*

P **Pseudopeptidoglycan** Some archaea; NAG *(one wall sugar)*, NAT *(archaeal wall sugar)*, beta-**1,3,** L-amino acids

I **Isoprenoids** *(branched five carbon repeat fats)* Ether-linked *(joined by a C O C bond)* **20** or **40 carbon** isoprenoid *(branched five carbon repeat fat)* lipids

N **No mycolic acid** *(waxy fatty acid of mycobacteria)* NO mycolic acid, LPS *(outer membrane sugar and fat coat)*, teichoic acid *(charged chains in Gram positive wall)*

L16 p34, L17 p24, L17 p39

6. What the envelope is and how we detect it

⚠ **Do not mix up: Gram stain color may mislead; acid-fast stain finds mycobacteria.**

CC·O·G What the cell envelope includes

Cell membrane, Cell wall / Outer membrane / Glycocalyx

C **Cell membrane** *(thin skin around the cell)* Innermost layer: phospholipid *(membrane fat with a charged head)* bilayer *(two layers)*

C **Cell wall** *(stiff layer around the cell membrane)* Wall outside membrane; peptidoglycan *(sugar and peptide mesh of the wall)* in most

O **Outer membrane** *(extra membrane outside the wall)* Outer membrane: part if **Gram-negative** *(thin wall plus outer membrane)*

G **Glycocalyx** *(sugary coat outside the cell)* **or capsule** *(firm sugar coat outside the cell)* Glycocalyx or capsule: part; ribosomes *(protein building machine)*, flagella *(whip tails that spin)* **NOT**

L16 p25, L16 p24

G·A·E Detecting the envelope: stains and EM

Gram stain can mislead / Acid-fast finds mycobacteria / Electron microscopy shows layers

G **Gram stain** *(stain that sorts bacteria purple or pink)* Color may not match actual envelope *(layers wrapped around the cell)* style

A **Acid-fast** *(holds dye despite acid wash)* **stain** Recognizes mycobacterial *(about waxy walled bacteria)* envelope

E **Electron microscopy** Gram+: thick wall; Gram-: thin, two membranes *(thin lipid layer)*

L16 p25, L16 p27, L16 p28, L16 p35

ET·P·S·G Confirming a Gram-positive envelope

Electron microscope, Teichoic acid isolated / Penicillin works / Selective media silent / Genome genes

E **Electron microscopy** TEM: thick peptidoglycan *(sugar and peptide mesh of the wall)*, no **outer** membrane *(extra membrane outside the wall)*

T **Teichoic acid** *(charged chains in Gram positive wall)* Isolate teichoic acid from wall

P **Penicillin sensitivity** Penicillin more effective on **Gram-positive** *(thick wall, stains purple)*

S **Selective media** No growth on **Gram-negative** *(thin wall plus outer membrane)* selective media

G **Genome genes** Genes: teichoic *(charged wall chain type)* yes; no LPS *(outer membrane sugar and fat coat)*, **outer** membrane, periplasm *(space between the two membranes)*

L16 p35, L17 p26

CT·AD·O Why the envelope matters

Classify, Transport / Antibiotics, Disinfectants / Outer membrane blocks

C **Classify** Major feature to classify bacteria

T **Transport** Affects transport into cell

A **Antibiotics** Drug must cross envelope *(layers wrapped around the cell)* to enter

D **Disinfectants** Chemical must cross envelope to enter

O **Outer membrane** *(extra membrane outside the wall)* **Gram-negative** *(thin wall plus outer membrane)* barrier: blocks hydrophobic *(water hating)* bile salts, dyes, antibiotics

L16 p25, L16 p26, L17 p05, L17 p08

7. Glycocalyx and S-layer

⚠ **Do not mix up: Slime layer is loose, capsule is firm; S-layer is protein, glycocalyx mostly polysaccharide.**

Glycocalyx: slime layer vs capsule

GSC Glycocalyx: slime layer vs capsule

Glycocalyx: loose Slime, firm Capsule

G **Glycocalyx** *(sugary coat outside the cell)* Material beyond cell wall *(stiff layer around the cell membrane)*; varies by species

S **Slime layer** *(loose sticky coat outside)* Slime: loosely attached

C **Capsule** *(firm sugar coat outside the cell)* Capsule: firmly attached

L16 p37, L16 p38

PPD·K·V Glycocalyx composition

Polysaccharides, Peptides, DNA / K antigens / Varies

P **Polysaccharides** *(long chain of sugars)* Usually polysaccharides, called EPS

P **Peptides** *(short chain of amino acids)* May be short peptides

D **DNA** *(cell genetic instruction molecule)* May contain DNA

K **K antigen** About **80** capsular polysaccharides in E. coli

V **Varies** Varies by species, strain, life stage

L16 p40

BB·SSS Capsule table: Gram-positive examples

Bacillus anthracis, Bacillus megaterium make peptides / Streptococcus mutans dextran, Streptococcus pneumoniae sugars, Streptococcus pyogenes hyaluronic

B **Bacillus** *(rod shaped cell)* **anthracis** Bacillus anthracis: D-glutamic acid polypeptide

B **Bacillus megaterium** Bacillus megaterium: peptide *(short chain of amino acids)* plus polysaccharide *(long chain of sugars)*

S **Streptococcus mutans** Streptococcus mutans: dextran of glucose

S **Streptococcus pneumoniae** Streptococcus pneumoniae: sugars, amino sugars, uronic acids *(acid sugars)*

S **Streptococcus pyogenes** Streptococcus pyogenes: hyaluronic acid *(slippery sugar chain)*

L16 p39

A·E·P·A·A Capsule table: Gram-negative examples

Acetobacter cellulose / Escherichia colonic acid / Pseudomonas mannuronic / Azotobacter glucuronic / Agrobacterium glucan

A **Acetobacter xylinum** Acetobacter xylinum: cellulose of glucose

E **Escherichia coli** E. coli: colonic acid; fucose, glucuronic acid

P **Pseudomonas aeruginosa** Pseudomonas aeruginosa: mannuronic acid

A **Azotobacter vinelandii** Azotobacter vinelandii: glucuronic acid

A **Agrobacterium tumefaciens** Agrobacterium tumefaciens: glucan of glucose

L16 p39

APDB Glycocalyx roles

Attachment, Phagocytosis, Desiccation, Biofilm matrix

A **Attachment** Attachment to surfaces (biofilms)

P **Phagocytosis** *(immune cells eating germs)* **protection** Protects from phagocytosis (engulfing)

D **Desiccation** *(drying out)* **protection** Protects from drying out

B **Biofilm** *(slimy community on a surface)* **matrix** Attachment builds biofilms

L16 p41

S-layer

PCO·M·L S-layer: composition and structure

Protein Crystals sit Outside / Most (not all) / Lost in labs

P **Protein or glycoprotein** Protein or glycoprotein, **NOT** polysaccharide *(long chain of sugars)*

C **Crystalline** *(neat repeating pattern)* **matrix** Crystalline, porous matrix

O **Outside wall or membrane** *(thin lipid layer)* Outside cell wall *(stiff layer around the cell membrane)* or membrane

M **Most (?) bacteria** Most (?) bacteria, especially archaea *(single cell microbes, their own group)*; not all

L **Lost in lab** Lost in lab cultures; underestimated

L16 p42, L16 p43

A·G·G·N S-layer: where it sits

Archaea on the membrane / Gram-positives over the wall / Gram-negatives outside the outer membrane / Not on all

A **Archaea** *(single cell microbes, their own group)***, no wall** Archaea without wall: S-layer *(crystal like protein coat outside)* on membrane *(thin lipid layer)*

G **Gram-positive** *(thick wall, stains purple)* **Gram-positive**: outside peptidoglycan *(sugar and peptide mesh of the wall)*

G **Gram-negative** *(thin wall plus outer membrane)* **Gram-negative**: outside **outer** membrane *(extra membrane outside the wall)*

N **Not on all** Not on all bacteria

L16 p43, L16 p42

OS·VB·AP S-layer: hypothesized roles

Osmotic stress, Shape / Viruses, Barrier / Attachment, Protein site

O **Osmotic** *(about water moving across membranes)* **stress** Osmotic stress protection

S **Shape** Cell shape (archaea)

V **Viruses** Protection from viruses

B **Barrier** Barrier to large molecules

A **Attachment** Attachment to surfaces

P **Protein site** Site for protein attachment

L16 p44

Lecture 17 Envelope Layers (33 acronyms)

1. Gram-negative outer membrane: LPS, porins, lipoprotein

⚠ **Do not mix up: Murein lipoprotein links OM to peptidoglycan; it is NOT an LPS function.**

Where the outer membrane sits

O·P·I steps in order: Gram-negative envelope, outside to inside

Outer membrane / Periplasm with peptidoglycan / Inner membrane

- **O Outer membrane** *(extra membrane outside the wall)* LPS *(outer membrane sugar and fat coat)*, phospholipids *(membrane fat with a charged head)*, porins *(channels in the outer membrane)*, murein lipoprotein *(protein anchoring outer membrane to wall)*
- **P Periplasm** *(space between the two membranes)* **with peptidoglycan** *(sugar and peptide mesh of the wall)* Aqueous space holding thin peptidoglycan
- **I Inner membrane** *(the skin around the cytoplasm)* Cell membrane *(thin skin around the cell)*; energy reactions happen here

L17 p04, L17 p06, L17 p31

GL·P·P·M Outer membrane components

Gram-negative skin: LPS in the outer leaflet / Phospholipids inside / Porins / Murein lipoprotein

- **G Gram-negative** *(thin wall plus outer membrane)* **only** Second membrane *(thin lipid layer)*; no teichoic *(charged wall chain type)* or mycolic acids *(waxy fatty acids of mycobacteria)*
- **L LPS** *(outer membrane sugar and fat coat)* Outer leaflet, sugar chain points out
- **P Phospholipids** *(membrane fat with a charged head)* Mainly **inner** leaflet; **outer** is mostly LPS
- **P Porins** *(channels in the outer membrane)* Protein channels through **outer** membrane *(extra membrane outside the wall)*
- **M Murein lipoprotein** *(protein anchoring outer membrane to wall)* Links **outer** membrane to peptidoglycan *(sugar and peptide mesh of the wall)*

L17 p05, L17 p06, L17 p11

LPS and what it does

L·C·O steps in order: LPS layers from anchor outward

Lipid anchors / Core in the middle / O-chain sticks out

- **L Lipid A** *(toxic fatty part of LPS)* **4-6** fatty acids; endotoxin *(toxin built into the cell)*, septic shock *(dangerous body wide infection response)*
- **C Core polysaccharide** *(long chain of sugars)* Branched sugar chain, same per species
- **O O-specific polysaccharide** **4-5** sugar repeat; varies; sticks out of OM

L17 p07, L17 p08

B·I·G·M Outer membrane and LPS roles

Barrier blocks bile salts / Inflammation from the lipid / Glycocalyx gets the outer sugar repeat / Murein lipoprotein ties on

- **B Barrier** Blocks bile salts, some antibiotics, dyes
- **I Inflammation** Lipid A *(toxic fatty part of LPS)* causes inflammation, septic shock *(dangerous body wide infection response)*
- **G Glycocalyx** *(sugary coat outside the cell)* O-specific polysaccharide *(long chain of sugars)* adds to glycocalyx
- **M Murein lipoprotein** *(protein anchoring outer membrane to wall)* Links OM to peptidoglycan *(sugar and peptide mesh of the wall)*; **NOT** an LPS *(outer membrane sugar and fat coat)* function

L17 p05, L17 p07, L17 p08, L17 p11

Porins and murein lipoprotein

S·M·P Porins: size limit and route

Selective channels / Maximum of seven hundred daltons / Periplasm entry

- **S Selective** Selective by molecule type or size
- **M Maximum 700 daltons** *(unit of molecule weight)* Max **700 daltons**; larger cannot pass
- **P Periplasm** *(space between the two membranes)* Small nutrient enters periplasm

L17 p09, L17 p31

OO·O·L·P E. coli porins and phage receptors

OmpF and OmpC nonspecific / OmpA peptides / LamB maltose / PhoE anions

- **O** **OmpF** Nonspecific, small molecules; phage *(virus that infects bacteria)* T2 receptor
- **O** **OmpC** Nonspecific, small molecules; phage T4 receptor
- **O** **OmpA** Peptides *(short chain of amino acids)*; mating pili *(thin hairs on the cell)* receptor
- **L** **LamB** Maltose, maltodextrin *(short chains of glucose)*; lambda phage receptor
- **P** **PhoE** Anion channel; no phage receptor

L17 p10

PN·C·L Murein lipoprotein

Protein with N-terminus in the lipids / C-terminus in the wall / Links them

- **P** **Protein, 65 aa** **65** amino acid **outer** membrane *(extra membrane outside the wall)* protein
- **N** **N-terminus** N-terminus binds fatty acids, **inner** leaflet
- **C** **C-terminus** C-terminus binds peptidoglycan *(sugar and peptide mesh of the wall)*
- **L** **Links** Links OM to peptidoglycan; loss breaks link

L17 p11

2. Periplasm: space between the membranes

⚠ Do not mix up: Periplasm exists only in Gram-negative; porin leads to periplasm, transporter to cytoplasm.

GABUP Periplasm: what and where

Gram-negative cells keep an Aqueous space Between the membranes with Unique proteins and Peptidoglycan

- **G** **Gram-negative** *(thin wall plus outer membrane)* **only** Not in **Gram-positive** *(thick wall, stains purple)*; between two membranes *(thin lipid layer)*
- **A** **Aqueous compartment** Watery compartment, not hydrophobic *(water hating)*
- **B** **Between membranes** Between **outer** and **inner** membranes *(the skin around the cytoplasm)*
- **U** **Unique proteins** Has its own unique proteins
- **P** **Peptidoglycan** *(sugar and peptide mesh of the wall)* Holds thin peptidoglycan; murein lipoprotein *(protein anchoring outer membrane to wall)* ties it

L17 p31, L17 p11

O·T·R·H Periplasm functions

Osmotic protection / Transport proteins / Redox with stored protons / Hydrolysis

- **O** **Osmotic** *(about water moving across membranes)* **protection** Oligosaccharides *(short sugar chains)* give osmotic protection
- **T** **Transport of nutrients** Binding proteins *(protein that grabs one solute)* hand solutes to transporters *(protein that carries molecules across)*
- **R** **Redox** *(electron passing reactions)* **reactions** Electron transport chain redox; stores H+
- **H** **Hydrolysis** *(breaking with water)* Breaks nutrients into smaller subunits *(building block piece)*

L17 p32

P·B·T steps in order: Nutrient route into a Gram-negative cell

Porin lets it in / Binding protein grabs it / Transporter takes it across

- **P** **Porin** *(water filled channel in outer membrane)* Small nutrient passes **outer** membrane *(extra membrane outside the wall)* into periplasm *(space between the two membranes)*
- **B** **Binding protein** *(protein that grabs one solute)* Periplasmic *(in the space between the two membranes)* protein binds the solute
- **T** **Transporter** *(protein that carries molecules across)* Hands to **inner** membrane *(the skin around the cytoplasm)* transporter, then cytoplasm *(jelly inside the cell membrane)*

L17 p09, L17 p31, L17 p32

3. Peptidoglycan: sugars, peptide, crosslink

⚠ Do not mix up: Gram negative: DAP bonds D-Ala directly; staphylococci add a (Gly)5 bridge.

The basics and the sugars

MA·O·T·T Peptidoglycan basics

Murein has Alternating sugars / One molecule / Thickness varies / Target of antibiotics

- **M** **Murein** *(another name for peptidoglycan)* Another name for peptidoglycan *(sugar and peptide mesh of the wall)*
- **A** **Alternating sugars** Two alternating sugars, peptide *(short chain of amino acids)* cross-links
- **O** **One molecule** One large molecule around cell
- **T** **Thickness varies** **Gram positive** *(thick wall, stains purple)* **3-20 layers**; **Gram negative** *(thin wall plus outer membrane)* **1-2**
- **T** **Target of antibiotics** Many antibiotics inhibit its synthesis

L17 p15, L17 p16, L17 p14

NN·B·P Peptidoglycan sugars and linkage

NAG alternates with NAM / Beta-1,4 bond / Peptide cross-links

N **NAG** *(one wall sugar)* N-acetylglucosamine (GlcNAc); alternates with NAM *(the other wall sugar)*

N **NAM** N-acetylmuramic acid (MurNAc); carries the peptide *(short chain of amino acids)*

B **Beta-1,4 linkage** Beta-**1,4** joins sugars; pseudo uses beta-**1,3**

P **Peptide** Cross-links chains; some D-amino acids (proteins L)

L17 p17, L17 p18

The peptide and the crosslink

L·D·D·D steps in order: Gram-negative peptide, positions 1 to 4

L-Ala starts / D-Glu next / DAP third / D-Ala fourth

L **L-Ala** Position **1,** L-amino acid

D **D-Glu** *(D form of glutamic acid)* Position **2,** D-amino acid

D **DAP** *(special amino acid in wall peptide)* Position **3,** diaminopimelic acid (modified lysine)

D **D-Ala** *(D form of alanine amino acid)* Position **4,** D-amino acid; DAP bonds here

L17 p19, L17 p21

S·C·C steps in order: Crosslink formation and the 5th amino acid

Starts with five / Crosslink forms / Cut between the two alanines

S **Starts with five** Starts with five amino acids

C **Crosslink** DAP (**3**) bonds neighbor D-Ala (**4**)

C **Cut** **5**th amino acid cut off between two D-Ala

L17 p19, L17 p22

Look-alikes compared

TP·GD·S Gram-positive vs Gram-negative peptidoglycan

Thickness and Position differ / Glycine bridge versus Direct bond / Same sugars

T **Thickness** **Gram positive** *(thick wall, stains purple)* **3-20 layers**; **Gram negative** *(thin wall plus outer membrane)* **1-2**

P **Position 3** **Gram negative** DAP *(special amino acid in wall peptide)*; staphylococci L-Lys

G **Glycine bridge** *(short chain of five Gly linking peptides)* Staphylococci: (Gly)**5** joins L-Lys to D-Ala *(D form of alanine amino acid)*

D **Direct bond** **Gram negative**: DAP bonds D-Ala, no bridge

S **Same sugars** NAG *(one wall sugar)*, NAM *(the other wall sugar)*, beta-**1,4** same in both

L17 p15, L17 p17, L17 p19, L17 p20, L17 p23

AN·B·L·M·L Pseudopeptidoglycan vs Gram-negative PG

Archaea use NAT / Beta-1,3 bond / L-amino acids / Many layers / Lysozyme ignores it

A **Archaea** *(single cell microbes, their own group)* Some archaea (Methanothermus), not **Gram-negative** *(thin wall plus outer membrane)*

N **NAT** *(archaeal wall sugar)* NAT replaces NAM *(the other wall sugar)*; NAG *(one wall sugar)* shared

B **Beta-1,3 linkage** Beta-**1,3** joins NAG and NAT, not **1,4**

L **L-amino acids only** L-forms **only**; **Gram negative** D at **2, 4**

M **Many layers** Many layers; **Gram negative** has **1-2**

L **Lysozyme-insensitive** *(not cut by wall cutting enzyme)* Lysozyme *(enzyme that cuts wall sugars)* does not cut it

L17 p24, L17 p25

What the wall does

S·L·B·P·D Cell wall role: support and osmotic stress

Structural support / Lysis stopped / Burst without a wall / Plasmolysis / Distorted

S **Structural support** Semi-rigid, porous; support, rigidity, cell shape

L **Lysis** *(bursting open)* **prevented** Hypotonic *(low solute outside)* with wall: prevents lysis

B **Burst without a wall** Hypotonic, no wall: swells, may burst

P **Plasmolysis** *(cell shrinking away from wall)* Hypertonic *(high solute outside)* with wall: plasmolysis, shrinks from wall

D **Distorted** Hypertonic, no wall: shrinks, distorted

L17 p12, L17 p13

4. Other wall parts: teichoic, mycolic, arabinogalactan

⚠ **Do not mix up: Teichoic acid is Gram-positive; mycolic acid and arabinogalactan are mycobacterial.**

Wall polymers by group

P·C·C Wall polymers: bacteria, plants, fungi

Peptidoglycan for bacteria / Cellulose for plants / Chitin for fungi

- **P Peptidoglycan** *(sugar and peptide mesh of the wall)* Bacteria: two sugars, peptide *(short chain of amino acids)* cross-links
- **C Cellulose** Plants: chains of glucose
- **C Chitin** Fungi: chains of modified glucose

L17 p14

PP·T·M·A Bacterial cell wall components

Peptidoglycan and Pseudo for archaea / Teichoic / Mycolic / Arabinogalactan

- **P Peptidoglycan** *(sugar and peptide mesh of the wall)* Murein *(another name for peptidoglycan)*; principal component in most eubacteria
- **P Pseudopeptidoglycan** *(archaea version of wall mesh)* Some archaea (Methanothermus) instead
- **T Teichoic acid** *(charged chains in Gram positive wall)* Most **Gram-positive** *(thick wall, stains purple)* bacteria
- **M Mycolic acid** *(waxy fatty acid of mycobacteria)* Mycobacteria *(waxy walled bacteria)*; linked to arabinogalactan *(chain of arabinose and galactose sugars in the wall)*
- **A Arabinogalactan** Mycobacteria; linked to peptidoglycan and mycolic acid

L17 p12, L17 p14, L17 p24, L17 p26, L17 p28, L17 p29

Gram-positive: teichoic acid

PG·RL·I Teichoic acids: what and where

Polyanionic polymers in Gram-positive cells / Run through the wall, Lipoteichoic to the membrane / Identification

- **P Polyanionic** *(many negative charges)* **polymers** Glycerol *(three carbon fat backbone)* or ribitol *(five carbon sugar alcohol)* phosphate *(PO4 group)* chains; charged
- **G Gram-positive** *(thick wall, stains purple)* Most **Gram-positive**, not **Gram-negative** *(thin wall plus outer membrane)*
- **R Run through the wall** Runs through peptidoglycan *(sugar and peptide mesh of the wall)*; linked to it
- **L Lipoteichoic** *(teichoic acid anchored in membrane)* Linked to cell membrane *(thin skin around the cell)* lipids
- **I Identification** Composition varies; used for identification

L17 p26, L17 p27

SD·A·I Teichoic acid roles

Shape and Division control / Antibiotic resistance / Integrity of the wall

- **S Shape** Regulates cell shape
- **D Division** Regulates cell division
- **A Antibiotic resistance** Affects antibiotic resistance
- **I Integrity of the wall** Maintains cell wall *(stiff layer around the cell membrane)* integrity

L17 p27

Mycobacteria: mycolic acid and arabinogalactan

FM·A·B·R Mycolic acids

Fatty acids in Mycobacteria / Arabinogalactan tether / Blocks nutrients / Resists acid

- **F Fatty acids** **60-90 carbons**, hydroxylated *(with OH groups added)*, branched, hydrophobic *(water hating)*
- **M Mycobacteria** *(waxy walled bacteria)* Mycobacterial *(about waxy walled bacteria)* wall; acid-fast *(holds dye despite acid wash)* **Gram-positive** *(thick wall, stains purple)*
- **A Arabinogalactan** *(chain of arabinose and galactose sugars in the wall)* **link** Linked to arabinogalactan sugars
- **B Blocks diffusion** *(drifting from high to low amount)* Blocks diffusion of most molecules, nutrients
- **R Resistance** Resists acids, bases, antibiotics, dehydration

L17 p03, L17 p28

PAG·L·I Arabinogalactan

Polysaccharide of Arabinose and Galactose / Linked to wall and mycolic acid / Inhibited by drugs

P **Polysaccharide** *(long chain of sugars)* Mycobacterial *(about waxy walled bacteria)* cell wall *(stiff layer around the cell membrane)* polysaccharide

A **Arabinose** *(a five carbon sugar)* Chains of arabinose, **5**-carbon sugar

G **Galactose** Chains of galactose

L **Linked** Linked to peptidoglycan *(sugar and peptide mesh of the wall)* and mycolic acid *(waxy fatty acid of mycobacteria)*

I **Inhibited** Synthesis inhibited by ethambutol

L17 p29

Look-alikes compared

TM·IH·LA Which lipid or polymer is which

Teichoic and Mycolic in walls / Isoprenoid and Hopanoid in membranes / Lipid and Arabinogalactan

T **Teichoic acid** *(charged chains in Gram positive wall)* Glycerol *(three carbon fat backbone)* or ribitol *(five carbon sugar alcohol)* phosphate *(PO4 group)*; **Gram-positive** *(thick wall, stains purple)* wall

M **Mycolic acid** *(waxy fatty acid of mycobacteria)* Hydroxylated *(with OH groups added)* fatty acids, **60-90 carbons**; mycobacteria *(waxy walled bacteria)*

I **Isoprenoid** *(branched five carbon repeat fat)* **20** or **40 carbon**, ether-linked *(joined by a C O C bond)*; archaeal *(of archaea)* membrane *(thin lipid layer)*

H **Hopanoid** *(five ring cholesterol like fat)* **5**-ring hydrocarbon like cholesterol; bacterial membrane

L **Lipid A** *(toxic fatty part of LPS)* **4-6** fatty acids; LPS *(outer membrane sugar and fat coat)* of **outer** membrane *(extra membrane outside the wall)*

A **Arabinogalactan** *(chain of arabinose and galactose sugars in the wall)* Arabinose *(a five carbon sugar)* and galactose chains; mycobacterial *(about waxy walled bacteria)* wall

L17 p07, L17 p26, L17 p28, L17 p29, L17 p39, L17 p40

5. Membrane lipids: ester vs ether

⚠ **Do not mix up: Bacteria use ester links; archaea use ether-linked isoprenoids.**

Components and bacterial phospholipids

PI·H·C·P Cell membrane components

Phospholipids and Isoprenoids / Hopanoids / Cardiolipin / Proteins

P **Phospholipids** *(membrane fat with a charged head)* Most bacteria: glycerol *(three carbon fat backbone)*, fatty acids, phosphoryl head

I **Isoprenoids** *(branched five carbon repeat fats)* Found in Archaea *(single cell microbes, their own group)*

H **Hopanoids** *(five ring cholesterol like fat)* **5**-ring, sterol-like; some **Gram-negative** *(thin wall plus outer membrane)*, few **Gram-positive** *(thick wall, stains purple)*

C **Cardiolipin** *(double phospholipid joined by glycerol)* Two phospholipids linked by glycerol

P **Proteins** Largest by weight; E. coli about **75** percent

L17 p33, L17 p35, L17 p42

GE·P·LD Bacterial phospholipid structure

Glycerol with Ester links / Phosphoryl head / Length and Double bonds

G **Glycerol** *(three carbon fat backbone)* Backbone of the phospholipid *(membrane fat with a charged head)*

E **Ester** *(bond of acid and alcohol)* **linkages** Two fatty acids, ester linkages

P **Phosphoryl head group** Head group varies

L **Length** Chain length varies

D **Double bonds** Number of double bonds varies

L17 p36

Bacteria vs archaea

BE·AE Ester (bacteria) vs ether (archaea)

Bacteria use Ester links / Archaea use Ether links

B **Bacteria** Phospholipids *(membrane fat with a charged head)*: glycerol *(three carbon fat backbone)* with fatty acids

E **Ester** *(bond of acid and alcohol)* Ester links join fatty acids to glycerol

A **Archaea** *(single cell microbes, their own group)* Isoprenoids *(branched five carbon repeat fats)*: **20** or **40 carbon** chains

E **Ether** *(C O C bond)* Ether links join isoprenoids to glycerol

L17 p36, L17 p39

ATE·BM Archaeal isoprenoids

Archaea make Terpenoids with Ether links / Bilayer or Monolayer

A **Archaea** *(single cell microbes, their own group)* Archaeal *(of archaea)* cell membrane *(thin skin around the cell)*, not wall or OM

T **Terpenoids** **20** or **40 carbon** branched **5**-carbon repeats

E **Ether** *(C O C bond)* **linkage** Ether links to glycerol *(three carbon fat backbone)*, not ester *(bond of acid and alcohol)*

B **Bilayer** *(two layers)* **20**-carbon glycerol diethers: bilayer

M **Monolayer** *(one layer)* **40**-carbon diglycerol tetraethers: monolayer

L17 p39

Hopanoids and cardiolipin

HSG Hopanoids

Hydrocarbon rings, Sterol-like, mostly Gram-negative

H **Hydrocarbon rings** A **5** ring hydrocarbon

S **Sterol-like** Like sterols *(stiff ring shaped fat)* such as cholesterol

G **Gram-negative** *(thin wall plus outer membrane)* **mostly** Some **Gram-negative**, few **Gram-positive** *(thick wall, stains purple)*; not archaea *(single cell microbes, their own group)*

L17 p40

T·SP·H Cardiolipin

Two phospholipids linked / Stationary cells gather at Poles / Heart cells too

T **Two phospholipids** *(membrane fat with a charged head)* Two phospholipids linked by glycerol *(three carbon fat backbone)*

S **Stationary phase** Made entering stationary phase, cells shrink

P **Poles** Gathers at poles, highly bent membrane *(thin lipid layer)*

H **Heart cells** Also in heart cell membranes *(thin skin around the cell)*

L17 p41

Temperature changes

ACWN Fatty acids and temperature

Alter chains: Cold adds double bonds, Warm saturates, Notation counts carbons and double bonds

A **Alter** Alter chain length and double bonds with temperature

C **Cold** Cold: more **18:1** unsaturated; ratio **2.9** at **10** C

W **Warm** Warm: **16:0 48%** at **40** C; ratio **0.38**

N **Notation** **16:0** saturated; **18:1** one double bond, **18 carbons**

L17 p37, L17 p38

6. What the membrane lets through and does

⚠ Do not mix up: Charged ions and large polar sugars cannot diffuse; hydrophobic and small polar can.

HS·CL What diffuses through the membrane

Hydrophobic and Small polar slip through / Charged and Large polar need help

H **Hydrophobic** *(water hating)* Hydrophobic diffuse: O2, CO2, N2

S **Small polar** Small polar diffuse: H2O, glycerol *(three carbon fat backbone)*

C **Charged** Charged ions *(charged particle)* cannot diffuse without help

L **Large polar** Large polar (sugars) need transporters *(protein that carries molecules across)*

L17 p34, L17 p43

P·R·E·S·S Cell membrane functions

Permeability barrier / Regulates contents / Energy reactions / Sensing / Synthesis of lipids

P **Permeability barrier** Hydrophobic *(water hating)*, small polar diffuse; charged, large cannot

R **Regulates contents** Nutrients in, osmotic *(about water moving across membranes)* balance, ion *(charged particle)* gradients *(gradual change in amount)*

E **Energy reactions** Proton gradient drives ATP *(cell energy molecule)*; **inner** membrane *(the skin around the cytoplasm)* Gram-neg

S **Sensing environment** Receptor proteins sense environment

S **Synthesis of lipids** Synthesizes membrane *(thin lipid layer)* lipids

L17 p33, L17 p43, L17 p44, L17 p45, L17 p46

Lecture 18 Transport, Peptidoglycan Synthesis and Antibiotics (33 acronyms)

1. Crossing the membrane: passive routes

⚠ **Do not mix up: Simple diffusion needs no protein; facilitated uses a protein, both passive.**

Ion levels inside vs outside

KP·NC·N **Ions kept inside vs outside**

K+ Phosphate high / Na+ Cl- low / Negative inside

- **K** **K+ high inside** K+ high inside: **150 mM** vs **5 mM**
- **P** **Phosphate** *(PO4 group)* **high inside** Phosphate high inside: **50-150** vs **1-10 mM**
- **N** **Na+ low inside** Na+ low inside: **5 mM** vs **150 mM**
- **C** **Cl- low inside** Cl- low inside: **5** vs **150 mM**
- **N** **Negative inside** Inside negative, about **-60 mV**

L18 p06

Five ways across

SF·IAG **Five ways across the membrane**

Simple and Facilitated flow free / Ion, ABC and Group pay

- **S** **Simple diffusion** *(passing straight through membrane)* Passive *(needs no energy)*: small uncharged (O2, H2O, CO2), hydrophobic *(water hating)*
- **F** **Facilitated diffusion** *(passing through helper protein)* Passive via protein: porins *(channels in the outer membrane)*, glycerol *(three carbon fat backbone)*; high to low
- **I** **Ion-coupled** Active: ion *(charged particle)* with gradient *(gradual change in amount)* powers lactose with H+
- **A** **ABC transporter** *(ATP powered pump with binding protein)* Active: ATP *(cell energy molecule)* high energy phosphate *(PO4 group)*; galactose, binding protein *(protein that grabs one solute)*
- **G** **Group translocation** *(carry in while adding a phosphate)* Active: PEP *(high energy phosphate donor)* phosphate added (PTS); glucose-**6**-P

L18 p05, L18 p07, L18 p14

Simple diffusion

SH·G·P **Simple diffusion through the bilayer**

Small Hydrophobic / things follow the Gradient / Passive

- **S** **Small uncharged** O2, H2O, CO2 cross with no protein
- **H** **Hydrophobic** *(water hating)* **molecules** Hydrophobic molecules (benzene) cross straight through
- **G** **Gradient** *(gradual change in amount)* **high to low** Net direction high to low
- **P** **Passive** *(needs no energy)* No energy, no protein; unlike facilitated

L18 p08, L18 p05

TU·HD·AB **Weak acids and bases: only HA crosses**

Two forms, Uncharged crosses / High outside, Deprotonates inside / Acids and Bases

- **T** **Two forms** Acid: HA or A-; **base**: B or BH+
- **U** **Uncharged form** Only uncharged HA or B crosses
- **H** **High H+ outside** High H+ outside protonates acids to HA (tb)
- **D** **Deprotonates inside** Inside, HA loses proton, water soluble
- **A** **Acids** Weak acids: aspirin, penicillin
- **B** **Bases** Weak bases: Prozac, tetracycline

L18 p09

Facilitated diffusion

MN·CC·G **Facilitated diffusion: channel and carrier**

Membrane protein, No payment / Channel or Carrier / Glycerol

- **M** **Membrane** *(thin lipid layer)* **protein** Through membrane protein; passive *(needs no energy)*, high to low
- **N** **No energy** No energy; molecules not modified
- **C** **Channel proteins** Outer membrane *(extra membrane outside the wall)* porins *(channels in the outer membrane)* in **Gram-negative** *(thin wall plus outer membrane)*; max **700 daltons** *(unit of molecule weight)*
- **C** **Carrier proteins** Bind specific molecules, change shape; uncommon in bacteria
- **G** **Glycerol** *(three carbon fat backbone)* **transporter** *(protein that carries molecules across)* Bacterial example; glycerol used up inside

L18 p10, L18 p11, L18 p13

OOO·L·P E. coli porin proteins

OmpF, OmpC, OmpA / then LamB / and PhoE

O **OmpF** Nonspecific small molecules; phage *(virus that infects bacteria)* T2 receptor

O **OmpC** Nonspecific small molecules; phage T4 receptor

O **OmpA** Specific for peptides *(short chain of amino acids)*; mating pili *(thin hairs on the cell)* receptor

L **LamB** Maltose, maltodextrin *(short chains of glucose)*; phage lambda receptor

P **PhoE** Anion-selective channel; selects by charge

L18 p12

2. Active transport: ion-coupled vs ABC vs PTS

⚠ **Do not mix up: Ion-coupled uses an ion gradient, ABC uses ATP, PTS uses PEP phosphate.**

What powers it

AI·A·PW What powers active transport

Against the grain: Ion / ATP / PEP, never Water

A **Against gradient** *(gradual change in amount)* Against gradient; needs energy

I **Ion** *(charged particle)* **gradient** Ion (H+ or Na+) with its gradient powers it

A **ATP** *(cell energy molecule)* **cleavage** ATP high energy phosphate *(PO4 group)* bond cleavage

P **PEP** *(high energy phosphate donor)* **phosphate** PEP phosphate cleavage powers group translocation *(carry in while adding a phosphate)*

W **Water channel** Water channel is **NOT** a power source

L18 p14, L18 p26

Ion-coupled

IU·S·A Ion-coupled: uniport, symport, antiport

Ion Uniport / Symport goes same way / Antiport goes opposite

I **Ion** *(charged particle)* **down, solute up** Ion with gradient *(gradual change in amount)* powers solute up

U **Uniport** *(one molecule, one direction)* One solute, one direction; potassium uniporter *(carries one molecule)*

S **Symport** *(two molecules, same direction)* Two, same direction: lactose with H+

A **Antiport** *(two molecules, opposite directions)* Two like-charged ions, opposite directions: Na+/H+

L18 p15, L18 p16

HP·NF·A H+ and Na+ gradients power transport

H+ and Proton force / Na+ spins Flagella / Antiporter holds pH

H **H+ going in** Most use H+ going in; some Na+

P **Proton motive force** *(stored energy from H+ imbalance)* Inner membrane *(the skin around the cytoplasm)*: transport, ATP *(cell energy molecule)* synthesis, flagellar rotation

N **Na+ gradient** *(gradual change in amount)* Haloalkaliphiles *(salt and high pH loving microbes)*, alkaline lakes: both Na+ and H+

F **Flagellar motility** *(ability to move)* Na+ force powers flagella *(whip tails that spin)*, symports (tb)

A **Antiporter** *(carries two opposite directions)* **Na+/H+** Inside pH below outside; lakes above **10** (tb)

L18 p16, L18 p17, L18 p18, L18 p19

ABC transporters

CT·D·E·G ABC transporter features

Common in bacteria, Two or four proteins / Domains split or joined / Exporters push drugs out / GAG

C **Common in bacteria** Common; ATP-binding cassette *(protein part)*; E. coli has **78**

T **Two or four proteins** Formed by **2** or **4 proteins**

D **Domains** Two domains: transmembrane, ATP-binding; same or separate protein

E **Exporters** Exporters: MacAB-TolC pumps erythromycin out, ATP *(cell energy molecule)*

G **GAG disaccharide** GAG: Streptobacillus ABC; Streptococcus PTS

L18 p21, L18 p22, L18 p23

PD·HR steps in order: ABC transport steps (Gram negative)

Porin then Docks / Hydrolysis then Release

P Porin *(water filled channel in outer membrane)* **entry** Solute enters porin, binds periplasmic *(in the space between the two membranes)* binding protein *(protein that grabs one solute)*

D Docks Binding protein docks; solute binds, shape change

H Hydrolysis *(breaking with water)* **of ATP** *(cell energy molecule)* Hydrolysis: **2** ATP to **2** ADP *(used up energy molecule)* + P

R Release Solute released into cytoplasm *(jelly inside the cell membrane)*

L18 p24

SO·E·A·R steps in order: Siderophore iron uptake

Secrete siderophores, Outer door / Escort in / ABC / Release iron

S Secrete siderophore *(iron grabbing molecule)* Secrete siderophores (enterochelin); bind Fe3+

O Outer membrane *(extra membrane outside the wall)* Complex crosses **outer** membrane via FepA

E Escort Periplasmic *(in the space between the two membranes)* FepB escorts it to transporter *(protein that carries molecules across)*

A ABC transporter *(ATP powered pump with binding protein)* Crosses cell membrane *(thin skin around the cell)* by ABC transporter, ATP *(cell energy molecule)*

R Release iron Fe3+ released from siderophore inside

L18 p25

Group translocation (PTS)

PE·H·EG steps in order: PTS phosphate relay

PEP to Enzyme-I / HPr / Enzyme-II into Glucose-6-P

P PEP *(high energy phosphate donor)* PEP donates phosphate *(PO4 group)*, becomes pyruvate

E Enzyme I Passes phosphate to HPr (tb)

H HPr Carries phosphate to Enzyme II (tb)

E Enzyme II IIC takes in glucose, mannitol *(sugar alcohol)*; IIB phosphorylates

G Glucose-6-P Enters as glucose-**6**-phosphate, a different molecule

L18 p05, L18 p22, L18 p26

MS·P·B·F Group translocation (PTS) facts

Modified Sugars / PEP / Bacteria-only / Free glucose

M Modified Transported molecule modified (phosphorylated)

S Sugars Used for some sugars

P PEP *(high energy phosphate donor)* **phosphate** *(PO4 group)* PEP phosphate added to sugar

B Bacteria and some archaea *(single cell microbes, their own group)* Only bacteria and some archaea

F Free glucose stays low Glucose-**6**-P new; free glucose near zero (tb)

L18 p26

3. Building peptidoglycan

⚠ **Do not mix up: Step 7 transglycosylation, step 8 transpeptidation (cross-link); penicillin and vancomycin block step 8.**

DMO·N Where new wall is made

Dispersed or Middle or One-end / Needed for growth and repair

D Dispersed Along side wall: E. coli, Bacillus

M Middle Mid-cell septum *(cross wall)*: Streptococcus, Staphylococcus

O One end One end polar: Actinomycetes *(branching thread bacteria)*, Rhizobiales *(group of soil bacteria)*

N Needed for growth Growth/division and repair/replacement; links cut

L18 p28, L18 p29

ST·DT·N steps in order: Peptidoglycan steps 1 to 5: inside the cell

Sugar precursors, Three amino acids / D-Ala dipeptide, Transfer to the carrier / NAG joins

S Sugar precursors Step **1**: NAG *(one wall sugar)*, NAM *(the other wall sugar)* from fructose-**6**-P, on UDP

T Three amino acids Step **2**: add **3** amino acids to UDP-NAM

D D-Ala *(D form of alanine amino acid)* **dipeptide** Step **3**: add **2** D-Ala; D-cycloserine *(drug blocking D alanine steps)* blocks

T Transfer to bactoprenol *(fat carrier moving wall pieces)* Step **4**: to bactoprenol C55; also LPS *(outer membrane sugar and fat coat)*, teichoic *(charged wall chain type)*

N NAG linked Step **5**: link NAG to NAM, **2**-sugar unit

L18 p32, L18 p33, L18 p34, L18 p35

FTT·R·P steps in order: Peptidoglycan steps 6 to 9: out, cross-link

Flip out, Transglycosylation then Transpeptidation / Regenerate the carrier / PBPs do both

F **Flip** Step **6**: MurJ *(flipper protein for wall units)* flips sugars to other side

T **Transglycosylation** *(joining sugar chains longer)* Step **7**: join new unit to existing chain

T **Transpeptidation** *(making peptide bridges between chains)* Step **8**: **4**th D-Ala *(D form of alanine amino acid)* attacked, **5**th leaves; penicillin, vancomycin *(drug blocking wall building)*

R **Regenerate bactoprenol-P** Step **9**: remove phosphate *(PO4 group)*, reuse carrier; bacitracin *(drug blocking carrier recycling)* blocks

P **PBPs** PBPs do both transglycosylation, transpeptidation

L18 p34, L18 p35, L18 p36, L18 p37, L18 p38

FM·DZ·N FtsZ ring at the division site

FtsZ Mid-cell / Divisome ZipA / Not flagella

F **FtsZ** *(protein ring for cell splitting)* **protein** Ring at division site in cytokinesis *(splitting the cell in two)*

M **Mid-cell** Mid-cell, where division wall is made

D **Divisome** *(cell splitting machine)* Anchors FtsN, PBP1, PBP3 at septum *(cross wall)*

Z **ZipA** ZipA (also FtsA) ties ring to membrane *(thin lipid layer)*

N **Not flagella** *(whip tails that spin)* **or pili** *(thin hairs on the cell)* **NOT** flagella, pili, replication, endospores *(tough dormant survival form)*

L18 p28, L18 p38

4. Wall drugs: look-alikes

⚠ **Do not mix up: Vancomycin binds the substrate D-Ala-D-Ala; penicillin binds the PBP enzyme.**

All wall drugs in step order

D·VPC·BL steps in order: Wall drugs in step order

D-cycloserine starts / Vancomycin, Penicillin, Cephalosporins cross-link / Bacitracin ends, Lysozyme cuts

D **D-cycloserine** *(drug blocking D alanine steps)* Step **3**: D-Ala *(D form of alanine amino acid)* analog; no D-Ala-D-Ala

V **Vancomycin** *(drug blocking wall building)* Step **8**: binds pentapeptide; prevents cleavage, linkage

P **Penicillin** Step **8**: binds PBP (transpeptidase)

C **Cephalosporins** *(penicillin like wall blocking drugs)* Step **8**: beta-lactam *(drug family with four member ring)*, same as penicillin

B **Bacitracin** *(drug blocking carrier recycling)* Step **9**: blocks bactoprenol *(fat carrier moving wall pieces)* dephosphorylation; no recycling

L **Lysozyme** *(enzyme that cuts wall sugars)* **NOT** a blocker: cuts beta-**1,4** NAM-NAG

L18 p33, L18 p34, L18 p36, L18 p39

Beta-lactams

BP·CGN Penicillin and cephalosporins

Beta-lactam rings grab PBP / Cross-linking stops in Growing cells, Not the carrier

B **Beta-lactam** *(drug family with four member ring)* **ring** Both beta-lactams; ring mimics D-Ala-D-Ala (tb)

P **PBP** *(penicillin binding wall builder enzyme)* **binding** Bind PBP, the transpeptidase *(enzyme making wall cross bridges)*

C **Cross-linking blocked** Step **8** blocked: no cross-links, weak wall

G **Growing cells** Kills growing cells; weak wall bursts (tb)

N **Not the carrier** **NOT** bactoprenol *(fat carrier moving wall pieces)* recycling or D-Ala *(D form of alanine amino acid)* synthesis

L18 p30, L18 p36, L18 p39

RPP·AM·CT Penicillin family and R groups

R-groups: Penicillin-G, Penicillin-V / Ampicillin, Methicillin / Carbenicillin, Ticarcillin

R **R groups** Vary on ring: spectrum, properties, beta-lactamase *(enzyme that destroys beta lactam drugs)* sensitivity

P **Penicillin G** **Gram-positive** *(thick wall, stains purple)*; destroyed by acid, penicillinase *(enzyme that breaks the drug)*

P **Penicillin V** More acid resistant than G

A **Ampicillin** **Gram-positive** and negative; acid stable

M **Methicillin** Penicillinase resistant, acid-labile; MRSA *(methicillin resistant staph germ)* **1961** (introduced **1959**)

C **Carbenicillin** **Gram-negative** (Pseudomonas, Proteus); acid stable; poorly absorbed

T **Ticarcillin** Like carbenicillin, more active vs Pseudomonas

L18 p51, L18 p45

Vancomycin vs D-cycloserine and bacitracin

BTT·I·VN Vancomycin: binds the substrate

Binds the end, Terminal cleavage and Transpeptidation stop / Introduced in nineteen fifty-eight / VRE, Not cycloserine

B **Binds D-Ala-D-Ala** Binds D-Ala-D-Ala end: substrate, not enzyme

T **Terminal D-Ala** *(D form of alanine amino acid)* **cleavage** No cleavage of end D-Ala; step **8**

T **Transpeptidation** *(making peptide bridges between chains)* Step **8** (transpeptidase): no cross-link

I **Introduced 1958** Introduced **1958**; rarely used until mid-**1980**s

V **VRE** *(drug resistant gut germ)* **1987** VRE **1987**; VISA **1996**; VRSA **2002**

N **Not D-Ala synthesis** **NOT** D-Ala synthesis (that is D-cycloserine)

L18 p30, L18 p33, L18 p39, L18 p45, L18 p46

DE·BN D-cycloserine and bacitracin

D-cycloserine starves Enzymes / Bacitracin blocks, No recycling

D **D-cycloserine** *(drug blocking D alanine steps)* D-Ala *(D form of alanine amino acid)* analog; step **3,** cytoplasm *(jelly inside the cell membrane)*, earliest

E **Enzymes blocked** Blocks alanine racemase, D-Ala-D-Ala ligase (tb)

B **Bacitracin** *(drug blocking carrier recycling)* Binds bactoprenol *(fat carrier moving wall pieces)*, blocks dephosphorylation, step **9**; not beta-lactam *(drug family with four member ring)*

N **No recycling** Carrier not recycled; no units carried across

L18 p33, L18 p39

5. Lysozyme, and why penicillin kills or fails

⚠ **Do not mix up: Lysozyme cuts made wall; penicillin only works on growing cells.**

LB·E·A·P Lysozyme and autolysin

Lysozyme cuts Beta-1,4 / Existing wall / Autolysin / Pseudopeptidoglycan spared

L **Lysozyme** *(enzyme that cuts wall sugars)* Our defensive enzyme; tears, saliva, mucus (tb)

B **Beta-1,4 bond** Cuts NAM-NAG bond, not peptide (tb)

E **Existing wall** Acts on made wall; non-growing cells too (tb)

A **Autolysin** *(wall-cutting enzyme made by the bacterium itself)* Produced by bacteria; opens wall for growth, separation

P **Pseudopeptidoglycan** *(archaea version of wall mesh)* Archaeal *(of archaea)* wall, beta-**1,3**; lysozyme-insensitive *(not cut by wall cutting enzyme)*

L18 p27, L18 p39, L17 p24

NA·GB·I Why penicillin kills only growing cells

New wall needed, Autolysin keeps cutting / Gaps, Burst in water / Isotonic is safe

N **New wall** Only growing cells make new peptidoglycan *(sugar and peptide mesh of the wall)*

A **Autolysin** *(wall-cutting enzyme made by the bacterium itself)* Autolysin keeps cutting; penicillin does not (tb)

G **Gaps** No new cross-links: weak wall, gaps (tb)

B **Burst** Growing cell: weak wall bursts as water enters (tb)

I **Isotonic** *(equal solute inside and out)* Isotonic: no net water flow, no bursting

L18 p28, L18 p39, L17 p13

BA·NO·MN Why penicillin fails

Beta-lactamase, Altered target / Narrow porins, Outer membrane / Mycoplasma lacks a wall, Not every drug

B **Beta-lactamase** *(enzyme that destroys beta lactam drugs)* Cleaves beta-lactam *(drug family with four member ring)* ring; S. aureus resistant **1945**

A **Altered target** PBP *(penicillin binding wall builder enzyme)* target changes, drug no longer binds

N **Narrow porins** *(channels in the outer membrane)* Narrowed porin *(water filled channel in outer membrane)*: less drug enters

O **Outer membrane** *(extra membrane outside the wall)* **Gram-negative** *(thin wall plus outer membrane)* **outer** membrane blocks drug from wall

M **Mycoplasma** No cell wall *(stiff layer around the cell membrane)*, no target

N **Not every beta-lactam** **NOT** every beta-lactam destroyed; R groups vary

L18 p45, L18 p49, L18 p50, L18 p51, L16 p26, L16 p27

WSL·NM·F Drug targets by class

Wall, Small Large / Nucleic Membrane / Folic

W **Wall synthesis** Penicillins, cephalosporins *(penicillin like wall blocking drugs)*, vancomycin *(drug blocking wall building)*, bacitracin (cycloserine)

S **Small subunit** *(building block piece)* **30S** **30S**: aminoglycosides (gentamicin), tetracyclines (doxycycline)

L **Large subunit 50S** **50S**: chloramphenicol, macrolides (erythromycin), clindamycin, linezolid

N **Nucleic acids** Quinolones *(drugs blocking DNA coiling enzyme)*: DNA gyrase *(enzyme that coils DNA)*; rifampin *(drug blocking RNA making)*: RNA polymerase *(enzyme copying DNA into RNA)*, **NOT 30S**

M **Membrane** *(thin lipid layer)* Polymyxins (also daptomycin, gramicidin)

F **Folic acid** Sulfonamides, trimethoprim block folic acid synthesis

L18 p41, L18 p42, L18 p43

6. Resistance and antibacterial drug basics

⚠ **Do not mix up: Cidal kills, static only inhibits growth; resistance either blocks entry or binding.**

UE·CS·R Antibacterial drug basics

Unique targets, Enzyme blocked / Cidal or Static / Resistant strains

U **Unique features** Target unique bacterial features, not shared human ones

E **Enzyme** Inhibit biosynthesis enzyme: wall, protein, nucleic acid, metabolite

C **Cidal** *(kills the germs)* Cidal drugs kill bacteria

S **Static** *(only stops germ growth)* Static drugs **only** inhibit growth

R **Resistant** One or more drugs; growing, worldwide, complex problem

L18 p40, L18 p41, L18 p44

DEU·TD·R Six ways bacteria resist drugs

Degrade, Efflux, Uptake keep it out / Target, Drug modified stop binding / Reverse

D **Degrade the drug** Prevent entry: beta-lactamase *(enzyme that destroys beta lactam drugs)* cleaves beta-lactam *(drug family with four member ring)* ring

E **Efflux** *(pumping the drug out)* Prevent entry: elimination increased, multidrug exporter pumps out

U **Uptake reduced** Prevent entry: eliminate porin *(water filled channel in outer membrane)*, less uptake

T **Target altered** Prevent binding: target changes; drug no longer binds

D **Drug modified** Prevent binding: enzyme modifies or cleaves drug

R **Reverse binding** Strategy **3**: ribosome *(protein building machine)* protection protein removes macrolide *(protein building blocker drug family)*

L18 p49, L18 p50

PM·VV·FR Resistance timeline and trend

Penicillinase, MRSA / VRE, VRSA / Few years, Rising

P **Penicillinase** *(enzyme that breaks the drug)* **1940** Identified **1940**; penicillin used from **1942**

M **MRSA** *(methicillin resistant staph germ)* **1961** Methicillin **1959**; MRSA observed **1961**

V **VRE** *(drug resistant gut germ)* **1987** VRE **1987** (vancomycin introduced **1958**)

V **VRSA 2002** VRSA **2002**; VISA **1996** (intermediate)

F **Few years** Within few years; vancomycin *(drug blocking wall building)*, macrolides *(protein building blocker drugs)* slower

R **Rising** **1980-2008**: MRSA **2-57%**, VRE **25%**, FQRP **31%**

L18 p44, L18 p45, L18 p46, L18 p47, L18 p48

7. Susceptibility tests: MIC vs Kirby-Bauer

⚠ Do not mix up: MIC uses dilution tubes; Kirby-Bauer uses disks and zones; a Gram stain tests neither.

M·K·G Three susceptibility tests

MIC tubes / Kirby-Bauer plate / Genetic genes

M **MIC** MIC: minimal inhibitory concentration; tubes or microtiter plate

K **Kirby-Bauer** Disk diffusion *(drifting from high to low amount)*: zone of no growth on plate

G **Genetic methods** Finds resistance genes; Gram stain *(stain that sorts bacteria purple or pink)* does **NOT** test

L18 p52, L18 p53, L18 p54

SCI·L steps in order: MIC steps

Serial dilution, Cells in tubes, Incubate / Lowest clear tube

S **Serial dilution** Serially dilute the drug

C **Cells 10^5** Add **10^5** cells to each tube

I **Incubate** Incubate tubes; no zone to measure

L **Lowest clear tube** Lowest concentration blocking growth; tetracycline **1.0** ug/ml

L18 p53

SD·ZC·R steps in order: Kirby-Bauer steps

Spread cells, Disks / Zone, Compare / Resistant if no zone

S **Spread cells** Spread cells on plate; no dilution tubes

D **Disks** Place drug-impregnated disks on plate

Z **Zone of no growth** Measure zone of no growth

C **Compare to chart** Compare zone size to chart

R **Resistant: no zone** No zone around oxacillin disk means resistant (MRSA)

L18 p54

Lecture 19 Internal Structures, Cytoplasm and Ribosomes (20 acronyms)

1. What is inside a bacterial cell

⚠ **Do not mix up: Capsule and slime layer are External; endospore is Internal.**

CR·IN·CEC Internal structures of the cell

Cytoplasm and Ribosomes / Inclusions near the Nucleoid / Cytoskeleton and Endospore, then Compartments

- **C Cytoplasm** *(jelly inside the cell membrane)* **Internal** group; everything inside cell membrane *(thin skin around the cell)*
- **R Ribosomes** *(protein building machine)* **Internal**; the cell's protein makers
- **I Inclusions** *(clumps of protein and other material)* **Internal**; aggregates of proteins, other material
- **N Nucleoid** *(DNA region without a membrane)***/chromosome** *(one long DNA molecule)* **Internal**; tightly coiled DNA *(cell genetic instruction molecule)*
- **C Cytoskeleton** *(inner scaffold of the cell)* **Internal**; tree now says cytoskeleton
- **E Endospore** *(tough dormant survival form)* **Internal**; capsule *(firm sugar coat outside the cell)* and slime layer *(loose sticky coat outside)* are **External**
- **C Compartments** Added to the internal structures list; few have

L19 p39, L19 p40, L19 p41

CR·CN·CI·E steps in order: Internal structures outline order

Cytoplasm hosts Ribosomes / Cytoskeleton frames the Nucleoid / Compartments hold Inclusions / Endospores close

- **C Cytoplasm** *(jelly inside the cell membrane)* **First** in outline
- **R Ribosomes** *(protein building machine)* Second, right after cytoplasm
- **C Cytoskeleton** *(inner scaffold of the cell)* Third, **BEFORE** nucleoid *(DNA region without a membrane)*
- **N Nucleoid** Fourth, after cytoskeleton
- **C Compartments** Fifth: membrane-bound, a few have
- **I Inclusions** *(clumps of protein and other material)* **and granules** Sixth, before endospores *(tough dormant survival form)*
- **E Endospores** **Last** in outline

L19 p40

MD·CW·AC Observed in some bacterial cytoplasm

Membrane around DNA / Cytoskeleton Wrapped / Aggregates and Clumps

- **M Membrane** *(thin lipid layer)* **compartments** Membrane compartments: **Yes**, a few have
- **D DNA** *(cell genetic instruction molecule)* **in a membrane** DNA in membrane: **Yes** (tb)
- **C Cytoskeleton** *(inner scaffold of the cell)* Three cytoskeleton types observed (tb)
- **W Wrapped DNA** Wrapped around HU *(DNA binding protein)*, H-NS *(DNA bridging protein)*, **NOT** histone *(eukaryote protein that DNA winds around)* octamers (tb)
- **A Aggregates** Aggregates (inclusions): **Yes**, most bacteria
- **C Clumps iron sulfur** Iron and sulfur clumps: **Yes** (tb)

L19 p37, L19 p42

HH·RR E. coli cutaway: HU and H-NS

HU and HNS / Ribosome and RNA

- **H HU** *(DNA binding protein)* DNA-binding protein on nucleoid *(DNA region without a membrane)* DNA *(cell genetic instruction molecule)*
- **H H-NS** *(DNA bridging protein)* DNA-bridging protein linking DNA strands
- **R Ribosome** *(protein building machine)* Cytoplasm *(jelly inside the cell membrane)* bracket, with peptide *(short chain of amino acids)* and RNA
- **R RNA polymerase** *(enzyme copying DNA into RNA)* Also in cytoplasm bracket

L19 p42

2. Cytoplasm: what fills it (two sources of numbers)

⚠ **Do not mix up: List: protein 20%, DNA 1 to 2%; E. coli table: 16% and 1%.**

What the cytoplasm is

CC·NI Cytoplasm vs cytosol vs nucleoid

Cytoplasm contains Cytosol / Nucleoid and Inclusions

- **C Cytoplasm** *(jelly inside the cell membrane)* Everything inside cell membrane *(thin skin around the cell)*, not periplasm *(space between the two membranes)*
- **C Cytosol** *(liquid part of the cytoplasm)* Liquid portion of cytoplasm
- **N Nucleoid** *(DNA region without a membrane)* Tightly coiled DNA *(cell genetic instruction molecule)*, no membrane
- **I Inclusions** *(clumps of protein and other material)* Aggregates of proteins, other material; most have

L19 p41

GP·SG·C Inclusions: granules and vesicles

Glycogen with PHB / Sulfur and Gas / Carboxysomes

G **Glycogen** *(stored chain of glucose)* Storage granule in some bacteria (tb)

P **PHB/PHA** PHB/PHA storage granules (tb)

S **Sulfur** Sulfur granules stored (tb)

G **Gas vesicles** *(gas filled floating bubbles)* Named in study guide inclusions *(clumps of protein and other material)* line

C **Carboxysomes** *(protein-shell bodies that fix carbon dioxide)* Named with gas vesicles in guide

L19 p41, L19 p37

CR·VS Crowded viscous cytoplasm

Crowded Ribosomes / Viscous and Slow

C **Crowded** Packed with macromolecules, especially ribosomes *(protein building machine)*

R **Ribosomes** About **15,000 per cell**; rRNA *(RNA building ribosomes)* **65%**

V **Viscous** *(thick and syrupy)* Thick from macromolecule crowding

S **Slow diffusion** *(drifting from high to low amount)* Diffusion reduced **10** fold

L19 p44

The numbers: the list first, then the E. coli table (two different sources)

WP·RLD Cytoplasm makeup list

Water and Protein / RNA, Lipid, DNA

W **Water** List: **60** to **70%**; E. coli table: **70%**

P **Protein** List: **20%**; E. coli table: **16%**

R **RNA** **7** to **20%** weight; rRNAs **65%** of ribosomes *(protein building machine)*

L **Lipid** **3%** of weight

D **DNA** *(cell genetic instruction molecule)* **1** to **2%** weight, **NOT 20%**

L19 p44, L19 p43

WP·DP·I E. coli table: weight vs count extremes

Water and Proteins / DNA and Peptidoglycan / Ions

W **Water** **70%** weight, **20,000,000,000 molecules**, **1 kind**

P **Proteins** **16%** weight, **2,400,000 molecules**, **4,000 kinds** (most)

D **DNA** *(cell genetic instruction molecule)* **1%** weight, **2 molecules**, division lags

P **Peptidoglycan** *(sugar and peptide mesh of the wall)* **0.8%** weight, ONE molecule (sacculus)

I **Inorganic ions** *(charged particle)* **0.1%** weight, **250,000,000 molecules**

L19 p43

RM·PL·MP·W E. coli table: RNA, lipids, small molecules

RNAs and Messenger / Phospholipids and LPS / Metabolites, Polyamines / Whole cell

R **rRNA** *(RNA building ribosomes)* **tRNA** *(adapter that carries amino acids)* **sRNA** **6%** weight, **250,000 molecules**, **200 kinds**

M **mRNA** *(message copy of a gene)* **0.7%** weight, **4,000 molecules**, **2,000 kinds**

P **Phospholipids** *(membrane fat with a charged head)* **3%**, **25,000,000 molecules**, outnumber **2,400,000 proteins**, **50 kinds**

L **Lipopolysaccharide** *(outer membrane sugar and fat coat)* **1%** weight, **1,400,000 molecules**, **1 kind**

M **Metabolites** *(small working molecules of the cell)* **precursors** **1.3%** weight, **50,000,000 molecules**, **1,000 kinds**

P **Polyamines** *(small charged helper molecules)* **0.1%** weight, **6,700,000 molecules**, **2 kinds**

W **Whole cell** About **1** picogram (**10**^-12 g)

L19 p43

3. Ribosomes: 70S vs 80S

⚠ **Do not mix up: Prokaryotic 50S has no 5.8S rRNA; eukaryotic 60S does.**

BLS·I 70S ribosome and selective inhibition

Bacterial Large Small / Inhibited selectively

B **Bacterial 70S** Differs from **eukaryotic** *(cells with a nucleus)* in size: **70S** vs **80S**

L **Large 50S** **23S** and **5S** rRNAs, **34 proteins**

S **Small 30S** **16S** rRNA *(RNA building ribosomes)*, **21 proteins**

I **Inhibited selectively** Some antibiotics: streptomycin, tetracycline, chloramphenicol, erythromycin

L19 p45

EL·S 80S eukaryotic ribosome

Eukaryotic ribosome has Large / Small

E **Eukaryotic** *(cells with a nucleus)* **80S** Larger than **prokaryotic 70S**

L **Large 60S** **28S**, **5.8S**, **5S** rRNAs, about **45 proteins**

S **Small 40S** **18S** rRNA *(RNA building ribosomes)*, about **30 proteins**

L19 p45

SLE Which rRNA in which subunit

Small is one, Large prokaryote has two, Eukaryotic has three

S **Small subunit** *(building block piece)* One rRNA *(RNA building ribosomes)*: **16S** in **30S**, **18S** in **40S**

L **Large prokaryotic** **50S**: **23S** and **5S only**, no **5.8S**

E **Eukaryotic** *(cells with a nucleus)* **large** **60S**: **28S**, **5.8S**, **5S**; **28S** sarcin-ricin loop *(key spot in large rRNA)*

L19 p45, L19 p46

4. Drugs that block translation

⚠ **Do not mix up: Chloramphenicol is prokaryotic; cycloheximide is eukaryotic, same peptidyl transferase step.**

Where each drug acts

CE·F Inhibitors on the prokaryotic 50S

Chloramphenicol, Erythromycin / Fusidic

C **Chloramphenicol** Blocks peptidyl transferase *(enzyme joining amino acids together)*, **prokaryotic large subunit** *(building block piece)*

E **Erythromycin** Blocks translocation *(ribosome stepping along the mRNA)*, **prokaryotic large subunit**

F **Fusidic acid** *(drug trapping EF-G on ribosome)* Traps EF-G *(bacterial elongation helper protein)* GDP; blocks **prokaryotic** elongation

L19 p46

TS·P Tetracycline, streptomycin, paromomycin

Tetracycline, Streptomycin / Paromomycin

T **Tetracycline** Blocks aminoacyl-tRNA *(tRNA carrying its amino acid)* binding, **prokaryotic small subunit** *(building block piece)*

S **Streptomycin** mRNA *(message copy of a gene)* misreading, blocks **prokaryotic** initiation

P **Paromomycin** Raises ribosomal *(about protein building machines)* error rate; no subunit given

L19 p46

CP·D·RA Eukaryotic and both-way inhibitors

Cycloheximide Puromycin / Diphtheria / Ricin and Alpha

C **Cycloheximide** *(drug blocking eukaryotic peptide bonds)* Blocks peptidyl transferase *(enzyme joining amino acids together)*, **eukaryotic** *(cells with a nucleus)* **large subunit** *(building block piece)*

P **Puromycin** *(drug mimicking tRNA, ends protein early)* Aminoacyl-tRNA *(tRNA carrying its amino acid)* analog, premature termination, prokaryotes **AND** eukaryotes

D **Diphtheria toxin** *(toxin shutting down eEF2)* ADP-ribosylates eEF2 *(eukaryotic elongation helper protein)*, inactivating it

R **Ricin** *(castor bean poison)***/abrin** *(rosary pea poison)* Plant glycosidases; depurinate *(remove an A or G base)* A in **28S** rRNA *(RNA building ribosomes)*

A **Alpha-sarcin** *(fungal toxin that cuts rRNA)* Fungal; cleaves bond in sarcin-ricin loop *(key spot in large rRNA)*

L19 p46

Look-alike pairs (same drugs, compared)

PCC Chloramphenicol vs cycloheximide

Peptidyl transferase hit by Chloramphenicol and Cycloheximide

P **Peptidyl transferase** *(enzyme joining amino acids together)* Both block it, **large subunit** *(building block piece)*, not translocation *(ribosome stepping along the mRNA)*

C **Chloramphenicol** **Prokaryotic large subunit** (bacteria)

C **Cycloheximide** *(drug blocking eukaryotic peptide bonds)* **Eukaryotic** *(cells with a nucleus)* **large subunit**

L19 p46

EFD Diphtheria toxin vs fusidic acid

Elongation factors: Fusidic and Diphtheria

E **Elongation factors** EF-G *(bacterial elongation helper protein)* **prokaryotic**; eEF2 *(eukaryotic elongation helper protein)* **eukaryotic** *(cells with a nucleus)*

F **Fusidic acid** *(drug trapping EF-G on ribosome)* Keeps EF-G GDP on **large subunit** (prokaryotes)

D **Diphtheria toxin** *(toxin shutting down eEF2)* ADP-ribosylation *(tagging a protein to disable it)* inactivates eEF2 (eukaryotes)

L19 p46

RAL Ricin, abrin vs alpha-sarcin

Ricin and Alpha attack the Loop

R **Ricin** *(castor bean poison)* **and abrin** *(rosary pea poison)* Plant glycosidases; depurinate *(remove an A or G base)* A in **28S** rRNA *(RNA building ribosomes)*

A **Alpha-sarcin** *(fungal toxin that cuts rRNA)* Fungal; cleaves bond in same loop

L **Loop (sarcin-ricin)** **28S** rRNA, **eukaryotic** *(cells with a nucleus)* **large subunit** *(building block piece)*, **NOT 16S**

L19 p46

ATR Three uses of translation inhibitors

Antibiotic Toxin Research

A **Antibiotic drugs** Some treat bacterial infections

T **Toxins** Some toxins: ricin *(castor bean poison)*, abrin *(rosary pea poison)*, alpha-sarcin *(fungal toxin that cuts rRNA)*, diphtheria toxin *(toxin shutting down eEF2)*

R **Research** Some used for research

L19 p46

Lecture 20 Internal Structures and Cell Division (36 acronyms)

1. Cytoskeleton and nucleoid

⚠ **Do not mix up: FtsZ is like tubulin, MreB like actin; bacteria have NO histones.**

Cytoskeleton: three homologs of eukaryotic proteins

F·M·C Cytoskeleton: three homologs

FtsZ tubes / MreB acts / Crescentin curves

F **FtsZ** *(protein ring for cell splitting)* Like tubulin *(protein of eukaryote tube filaments)*; division; Z ring at midcell

M **MreB** Like actin *(protein of eukaryote thin filaments)*; polarity *(which end is which)*; helix, then midcell band

C **Crescentin (CreS)** Like intermediate filaments *(rope-like eukaryote filaments)*; shape; **inner** curve

L20 p11, L20 p12

D·P·S·P Cytoskeleton roles

Division and Polarity / Shape and Plasmid partition

D **Division** FtsZ *(protein ring for cell splitting)* column; eukaryote tubulin *(protein of eukaryote tube filaments)*

P **Polarity** *(which end is which)* MreB column; eukaryote actin *(protein of eukaryote thin filaments)*

S **Shape regulation** CreS column; eukaryote intermediate filaments *(rope-like eukaryote filaments)*

P **Plasmid** *(small extra DNA circle)* **partition** Also listed; DNA *(cell genetic instruction molecule)* packing is **NOT**

L20 p11

SEC Shape proteins in three cells

Staph has one, E. coli two, Caulobacter all three

S **Staphylococcus** Coccus: FtsZ *(protein ring for cell splitting)* Z ring **only**

E **E. coli** Straight rod: FtsZ ring plus MreB arcs

C **Caulobacter crescentus** Curved rod: FtsZ, MreB **AND** crescentin *(protein that keeps the cell curved)*

L20 p12

Nucleoid: where the DNA is and how it is packed

D·L·N·B Nucleoid: the DNA region

DNA zone Lacks ribosomes / No nuclear membrane, seen in Bdellovibrio

D **DNA** *(cell genetic instruction molecule)* **region** Cytosol *(liquid part of the cytoplasm)* region with chromosomal DNA

L **Lacks ribosomes** *(protein building machine)* Ribosomes are dark grains; nucleoid *(DNA region without a membrane)* lighter

N **No membrane** *(thin lipid layer)* Not a nucleus; Gemmata the exception

B **Bdellovibrio** Tomograph *(3D microscope image)*: ribosomes yellow, nucleoid pink

L20 p13, L20 p14, L20 p18

N·D·H·N·L·L Packing the nucleoid DNA

No histones, DNA binders like HU / Negatively supercoiled Loops / Lysis makes it viscous

N **No histones** *(eukaryote protein that DNA winds around)* NO histone proteins; not well understood

D **DNA-binding proteins** IHF, H-NS *(DNA bridging protein)*, Fis help pack, in part

H **HU** *(DNA binding protein)* Also binds DNA *(cell genetic instruction molecule)*; like a histone protein, **NOT** one

N **Negatively supercoiled** *(underwound, then twisted into coils)* By topoisomerases *(enzymes that twist or untwist DNA)*, **NOT** positively

L **Loops** Packed DNA arranged in loops

L **Lysis** *(bursting open)* Lysed *(broken open)*: less condensed, viscous *(thick and syrupy)*

L20 p15, L20 p16

L·S·P·R Loop domains of the chromosome

Loops Supercoiled, Proteins hold the Rosette

L **Loop domains** Loops of about **50** kB

S **Supercoiled** *(twisted into coils)* Looped DNA *(cell genetic instruction molecule)* also supercoiled

P **Proteins hold loops** DNA-binding proteins hold each loop

R **Rosette** Rosette about **1,000 nm**, **NOT** loop size

L20 p17

GNI Gemmata: DNA inside membranes

Gemmata has Nuclear and Inner membranes

G Gemmata One type (Planctomycetes): DNA *(cell genetic instruction molecule)* in membrane *(thin lipid layer)* compartment

N Nuclear membrane A DOUBLE membrane around chromosome *(one long DNA molecule)*

I Inner cell membrane *(membrane that lies inside another membrane)* Also around it: two membranes total

L20 p18

2. Internal membranes (compartments)

⚠ Do not mix up: Thylakoids: cyanobacteria. Chlorosomes: green. Invaginations: purple. Methanotroph membranes: methane.

MS·MP Membrane compartments

Membrane rooms in Some bacteria / Metabolic jobs like Photosynthesis

M Membrane *(thin lipid layer)* Surrounded by lipid membrane: a compartment

S Some bacteria Methanotrophs *(bacteria that use methane)*, N fixers, nitrifiers *(bacteria that turn ammonia into nitrate)*, phototrophs *(organisms that use light for energy)*; **NOT** all

M Metabolic reactions Specialized physiological role; metabolic reactions

P Photosynthesis One of those reactions; phototrophs have many

L20 p19, L20 p20, L20 p21

TCI Phototroph membranes by color group

Thylakoids are blue-green, Chlorosomes green, Invaginations purple

T Thylakoids *(membrane sacs for photosynthesis)* Cyanobacteria; stacked, chloroplast-like

C Chlorosomes *(light catching sacs)* Green sulfur **AND** nonsulfur; monolayer *(one layer)* linked to membrane *(thin lipid layer)*

I Invaginations *(inward folds)* Purple sulfur **AND** nonsulfur; membrane folds

L20 p21, L20 p24, L20 p26

The three photosynthetic membranes, then the methane one

LFPCP Thylakoids of cyanobacteria

Light harvesting, Full bilayers, PS one and two, Chloroplast-like Prochlorococcus

L Light harvesting Site of light harvesting reactions

F Full lipid bilayers *(two layers)* Full lipid bilayers, **NOT** a monolayer *(one layer)*

P PS I and PS II Cyanobacteria; oxygenic *(gives off oxygen)*, chlorophyll *(green light-catching pigment)* a/b

C Chloroplast-like Some like chloroplast *(plant part that does photosynthesis)* thylakoids *(membrane sacs for photosynthesis)*

P Prochlorococcus Marine: concentric thylakoids, central carboxysomes *(protein-shell bodies that fix carbon dioxide)*

L20 p21, L20 p22, L20 p23

G·MBB Chlorosomes of green bacteria

Green bacteria / Monolayer linked, Bacteriochlorophyll, Baseplate

G Green bacteria Green sulfur PS I, nonsulfur PS II; **NOT** purple

M Monolayer *(one layer)* SINGLE monolayer, not bilayer *(two layers)*, linked to membrane *(thin lipid layer)*

B Bacteriochlorophyll *(bacterial light-catching pigment)* Light harvesting pigments: Bchl rods inside

B Baseplate Sac sits on membrane baseplate

L20 p24, L20 p25

PCLE Purple bacteria: membrane invaginations

Purple folds stay Contiguous, catch Light, as in Ectothiorhodospira

P Purple bacteria Sulfur and nonsulfur: membrane *(thin lipid layer)* folds inward

C Contiguous *(still joined)* Contiguous with cell membrane *(thin skin around the cell)*

L Light capture Photosynthetic light capture reactions; BChl a/b, PS II

E Ectothiorhodospira Curved cell, stacked lamellar *(in flat sheets)* membranes

L20 p26, L20 p27

MMSN Methanotroph membranes

Methylococcus eats Methane and Single carbons, Not light

M Methylococcus Methanotroph *(bacterium that uses methane)*; stacked parallel internal membranes *(thin lipid layer)*

M Methane Breaks down methane

S Single carbon molecules Other one carbon (C1) molecules

N Not light capture For methane, **NOT** light

L20 p28

3. Inclusions and granules

⚠ **Do not mix up: Gas vesicles and carboxysomes have protein shells, not membranes.**

GVPS Inclusions and granules

Granules are Visible, some in Protein shells, for Storage

G Granules or clumps Clumps of material in cytoplasm *(jelly inside the cell membrane)*

V Visible Visible in microscope, **NOT** too small

P Protein shell Some: protein shell or lipid monolayer *(one layer)*

S Storage Store energy, building blocks, metabolites *(small working molecules of the cell)*

L20 p29

GC·MES Five inclusions

Gas and Carboxysomes / Magnetosomes, Energy and Sulfur

G Gas vesicles *(gas filled floating bubbles)* A. Gas in protein shell; buoyancy *(ability to float)*

C Carboxysomes *(protein-shell bodies that fix carbon dioxide)* B. Polyhedral protein shell; carbon fixing (CO_2)

M Magnetosomes C. Iron magnetite *(magnetic iron mineral)* Fe_3O_4; magnetotaxis *(moving along magnetic field lines)*

E Energy storage granules D. PHA (PHB) and glycogen *(stored chain of glucose)*

S Sulfur granules E. Elemental sulfur; sulfur oxidizers

L20 p30, L20 p31, L20 p32, L20 p33, L20 p34

Look-alike pairs

PGC Gas vesicles vs carboxysomes

Protein shells: Gas or Carboxysome

P Protein shell **BOTH** protein shell, **NOT** membrane *(thin lipid layer)*

G Gas vesicles *(gas filled floating bubbles)* Store gas; aquatic; control float depth

C Carboxysomes *(protein-shell bodies that fix carbon dioxide)* Polyhedral; carbon fixing in SOME autotrophs

L20 p30, L20 p31

MM·SS Magnetosomes and sulfur granules

Magnetosomes give Magnetotaxis / Sulfur granules in Sulfur oxidizers

M Magnetosomes Iron magnetite *(magnetic iron mineral)* Fe_3O_4 crystal chain

M Magnetotaxis *(moving along magnetic field lines)* What magnetosomes allow; **NOT** carbon fixing

S Sulfur granules Elemental sulfur inside

S Sulfur oxidizing bacteria Where sulfur granules are seen

L20 p32, L20 p34

PGE Storage granules: PHA vs glycogen

PHA or Glycogen, both Energy stores

P PHA For example poly-beta-hydroxybutyrate (PHB)

G Glycogen *(stored chain of glucose)* Chain of glucose; **NOT** a PHA

E Energy and carbon storage Both store; PHB can fill cell

L20 p33

4. Types of cell division

⚠ Do not mix up: Budding: SMALLER offspring. Multiple fission: MANY. Asymmetric: a different cell type.

BB·MA Four types of cell division

Binary splits, Budding shrinks / Multiple pops, Asymmetric differs

B Binary fission Most bacteria: two equal cells, **2** fold

B Budding Smaller offspring cells

M Multiple fission Multiple offspring, usually in a sac

A Asymmetric division Different type of cell; differentiation *(becoming a different cell type)*

L20 p39, L20 p40, L20 p41, L20 p42

PP·SPD·C Division types: example bacteria

Pedomicrobium and Planctomyces bud / Stanieria, Pleurocapsa, Dermocarpella burst / Caulobacter splits unequal

P Pedomicrobium Budding, on prosthecae *(thin cell extensions)*; yeast buds too

P Planctomyces Budding bacterium

S Stanieria Multiple fission; fills with baeocytes *(small offspring cells)*

P Pleurocapsa Multiple fission

D Dermocarpella Multiple fission into many baeocytes

C Caulobacter crescentus Asymmetric: stalked plus swarmer *(swimming daughter cell)* cell

L20 p40, L20 p41, L20 p42

FSSD steps in order: Caulobacter: stalked and swarmer

Flagellum lost, Stalk grows, Swarmer born: Differentiation

F Flagellum *(whip tail that spins)* **lost** Swimming cell loses its flagellum

S Stalk *(stem that anchors the cell)* **with holdfast** *(sticky foot at the stalk tip)* Grows stalk with holdfast

S Swarmer *(swimming daughter cell)* **plus stalked** STALKED cell divides: swarmer plus stalked

D Differentiation *(becoming a different cell type)* Cell differentiation: different cell type

L20 p42

5. Endospores and the other spores

⚠ Do not mix up: Endospores: inside, hardy. Exospores: filament tips, NOT hardy. Heterocysts fix nitrogen.

Endospores of Bacillus

IS·DBL·SF Endospores: inside, dormant, hardy

Inside for Survival / Dormant through Boiling in Layers / Starving Firmicutes

I Inside the cell A few bacteria: spores inside cell

S Survival Reproductive cells for survival or dispersal

D Dormant *(inactive, not growing)* Dormant and very hardy

B Boiling Survive boiling, dehydration, radiation

L Layers of coats Wrapped in several coats

S Starvation Starvation, high density; **NOT** plentiful food

F Firmicutes *(Gram positive group that includes Bacillus)* Made by Firmicutes; viable for centuries

L20 p35, L20 p36

SFE·DCD·RG steps in order: Endospore formation stages

Septum, Forespore, Engulf / Disintegrate, Cortex, Dipicolinic / Release, Germinate

S Septum *(cross wall)* **near one pole** Stage I: septum near pole; axial filament *(stretched-out DNA strand)*

F Forespore *(the part that becomes the spore)* Stage II: forespore split off; DNA *(cell genetic instruction molecule)* pumped

E Engulfment Stage III: engulfed; second membrane *(thin lipid layer)*

D Disintegrate Stage IV: mother chromosomes *(one long DNA molecule)* disintegrate

C Cortex *(thick spore wall layer)* Stage V: peptidoglycan *(sugar and peptide mesh of the wall)* cortex; coat proteins

D Dipicolinic acid *(heat-protecting spore chemical)* Stage VI: dipicolinic acid; calcium into coat

R Release Stage VII: mother cell releases spore

G Germination Germinates *(wakes up and grows)* back to vegetative cell *(normal growing cell)*

L20 p36

Other spores (asymmetric divisions)

AE·EE·MF Spore types and who makes them

Akinete and Exospore / Elementary and Endospore / Myxospore and Fungal

- **A** **Akinete** *(hardy resting cell)* Filamentous cyanobacteria; oval, near heterocyst *(nitrogen-fixing cell)*
- **E** **Exospore** Actinomycetes *(branching thread bacteria)*; tips of aerial mycelia *(mats of filaments)*
- **E** **Elementary body** Chlamydia; inactive spore leaves host
- **E** **Endospore** *(tough dormant survival form)* Some Firmicutes *(Gram positive group that includes Bacillus)*; inside cell; **NOT** Streptomyces
- **M** **Myxospore** Myxococcus; fruiting body *(raised clump of cells that holds spores)* sacs
- **F** **Fungal spores** Fungi; aerial hyphae *(fungal filaments)* tips; gametes or clones

L20 p43, L20 p44, L20 p45, L20 p46, L20 p47, L20 p49, L20 p50

SSEEA Spores: hardy or not

Survival, but only Some are dormant: Endospores yes, Exospores no, Akinetes yes

- **S** **Survival** Reproductive cells for survival or dispersal
- **S** **Some dormant** *(inactive, not growing)* SOME are dormant, not all
- **E** **Endospores** *(tough dormant survival form)* Dormant and very hardy
- **E** **Exospores** **NOT** dormant or hardy; wind dispersal
- **A** **Akinetes** *(hardy resting cell)* Hardy; form under stress

L20 p43, L20 p36, L20 p45, L20 p44

AHV Akinete vs heterocyst

Akinete endures, Heterocyst fixes nitrogen, Vegetative cells grow

- **A** **Akinete** *(hardy resting cell)* Larger, oval, hardy; forms under stress
- **H** **Heterocyst** *(nitrogen-fixing cell)* Fixes nitrogen; **NOT** the stress cell
- **V** **Vegetative cells** *(normal growing cell)* Other cells of the Anabaena chain

L20 p44

ORE Chlamydia: reticulate vs elementary

Obligate parasite: Reticulate inside, Elementary outside

- **O** **Obligate intracellular parasite** Chlamydia; life cycle like viruses
- **R** **Reticulate bodies** *(dividing form inside the host)* Divide **only** inside a host cell
- **E** **Elementary bodies** *(infectious resting form outside the host cell)* Inactive spores released; NO outside division

L20 p46

NE·ML Endospore formers: division patterns

No wall, one Engulfed / Multiple spores or Live birth

- **N** **No septation** *(building the cross wall)* Divides, but NO cell wall *(stiff layer around the cell membrane)* septation
- **E** **Engulfed** One cell engulfed, becomes hardy spore
- **M** **Multiple endospores** *(tough dormant survival form)* Many endospores in one cell
- **L** **Live birth** Two offspring emerge from mother cell

L20 p47, L20 p48

AF·HGLI Myxospores and fungal spores

Aggregate into a Fruiting body / Hyphae make Gametes, Larger, for Identification

- **A** **Aggregate** Myxococcus cells gather after starvation
- **F** **Fruiting body** *(raised clump of cells that holds spores)* Sacs full of many myxospores
- **H** **Hyphae** *(fungal filaments)* Fungal filaments (hyphae); spores at aerial tips
- **G** **Gametes or clones** Gametes or asexual clones
- **L** **Larger** Fungal cells larger than bacteria
- **I** **Identification** Spore structures vary; identify fungi

L20 p49, L20 p50, L20 p51

6. Steps and mechanism of division

⚠ **Do not mix up: Cytokinesis: membranes. Septation: envelope partition. Separation: detachment. E. coli: all at once.**

RCSS steps in order: Cell division

Replication first, Cytokinesis splits membranes, Septation builds partitions, Separation detaches them

- **R Replication and segregation** Of chromosomes *(one long DNA molecule)*; the first step
- **C Cytokinesis** *(splitting the cell in two)* Splitting into two cells, each own membrane *(thin lipid layer)*
- **S Septation** *(building the cross wall)* Envelope *(layers wrapped around the cell)* partition (septum) forms
- **S Separation** Detachment of the two cells

L20 p52, L20 p53

ADC steps in order: Basic steps of the division wall

Autolysin opens, Double layer, Cut apart

- **A Autolysin** *(wall-cutting enzyme made by the bacterium itself)* Cuts old peptidoglycan *(sugar and peptide mesh of the wall)*, beta **1-4**; never builds
- **D Double layer** Synthesize double layer between cells
- **C Cut apart** Cut the two layers apart

L20 p54

NDSP Where new wall is made

New wall: Dispersed, Septal or Polar

- **N New peptidoglycan** *(sugar and peptide mesh of the wall)* Must cover each cell; location varies
- **D Dispersed zonal** *(in a band)* **growth** Many bands along rod: E. coli, Bacillus
- **S Septal** *(at the splitting wall)* **zonal growth** At septum *(cross wall)*: Streptococcus, Staphylococcus
- **P Polar growth** At one pole: Actinomycetales, Rhizobiales *(group of soil bacteria)*

L20 p55

E. coli vs Bacillus vs Staphylococcus

EBS Three division styles compared

E. coli pinches, Bacillus chains, Staphylococcus furrows

- **E E. coli** **Gram negative** *(thin wall plus outer membrane)* rod; constricts *(pinches in)*; all at once
- **B Bacillus** *(rod shaped cell)* **Gram positive** *(thick wall, stains purple)* rod; little constriction; chains
- **S Staphylococcus** **Gram positive** coccus; equator furrow *(groove)*

L20 p54, L20 p56, L20 p57, L20 p58

CALO E. coli division: all at once

Constrict All at once, Little wall, Outer membrane too

- **C Constriction** Entire envelope *(layers wrapped around the cell)* folds inward, middle
- **A All at once** Cytokinesis *(splitting the cell in two)*, septation *(building the cross wall)*, separation same time
- **L Little new wall** Little new wall at division site
- **O Outer and cell membrane** *(thin skin around the cell)* Both membranes pinch together; no chains

L20 p56

MFSLC steps in order: Bacillus division: chains

Membrane folds, Furrow grows, Septum forms, Later split, Chains stay

- **M Membrane** *(thin lipid layer)* **invaginates** *(folds inward)* Membrane folds in at middle
- **F Furrow** *(groove)* **of new wall** New wall furrow, little constriction
- **S Septum** *(cross wall)* **with cytokinesis** *(splitting the cell in two)* Septum forms with cytokinesis
- **L Later separation** Separation may occur later
- **C Chains** Often stay as chain or filament

L20 p57

FDCS·PT steps in order: Staphylococcus division and tetrads

Furrow, Double wall, Cytokinesis, Separation / Pairs or Tetrads

F **Furrow** *(groove)* **at the equator** New wall furrow at equator, grows inward

D **Double layer** Double layer of cell wall *(stiff layer around the cell membrane)*

C **Cytokinesis** *(splitting the cell in two)* When the septa furrows meet

S **Separation** When peptidoglycan *(sugar and peptide mesh of the wall)* between cells is cut

P **Pairs or tetrads** *(two or four cells left stuck together)* Some stay attached; plane sets arrangement

T **Tetrads** *(groups of four cells)* Septation *(building the cross wall)* in perpendicular *(at right angles)* planes

L20 p58, L20 p59

Lecture 21 Cell Polarity, Division Proteins and Envelope Review (15 acronyms)

1. Cell polarity and pole age

⚠ **Do not mix up: New flagellum goes on the OLD pole; TipN marks the NEW pole.**

PFC·AP Cell polarity and asymmetry

Polarity: Flagellum at one end, Caulobacter stalk / Asymmetric poles, Population differs

- **P Polarity** *(which end is which)* Two ends of a rod may differ
- **F Flagellum** *(whip tail that spins)* **at one end** Flagellum at one end **only**
- **C Caulobacter** Stalk *(stem that anchors the cell)* or flagellum on one end
- **A Asymmetry** Poles differ even after symmetric fission
- **P Population differs** Cells in a population differ

L21 p05

Caulobacter: swarmer, stalked and the pole markers

SLS·PDT steps in order: Caulobacter cycle and pole markers

Swarmer Loses its flagellum, Stalked divides / PodJ flags, DivJ stalks, TipN marks new

- **S Swarmer** *(swimming daughter cell)* **cell** One flagellum *(whip tail that spins)* on one pole
- **L Loses flagellum** Loses it, grows stalk *(stem that anchors the cell)*, SAME end
- **S Stalked cell divides** New cell: flagellum on OLD pole
- **P PodJ** Flagellum pole marker
- **D DivJ** Stalk pole marker
- **T TipN** New pole marker

L21 p06

MNDSL TipN: mutant and GFP results

Mutants grow many flagella; normally New pole, Delocalizes, Septum: a Landmark

- **M Mutants lacking TipN** Multiple flagella *(whip tails that spin)* from the stalk *(stem that anchors the cell)* end
- **N New pole** **First** at the new pole
- **D Delocalizes** Then spreads around the cell
- **S Septum** *(cross wall)* Then at the septum; new poles
- **L Landmark** Marker for the new pole end

L21 p07, L21 p08

Old and new poles after binary fission

NO·WD·A Polar aging: new pole vs old pole

New and Old poles / Weaker walls bring Death / Antimicrobials hit differently

- **N New pole (0)** New pole of new wall: **0**
- **O Old pole (1)** Other end; ages each division
- **W Weaker old wall** The old cell wall *(stiff layer around the cell membrane)* will be weaker
- **D Death** Could lead to cell death
- **A Antimicrobial sensitivity** May change antimicrobial sensitivity

L21 p09

NA·FS·O steps in order: Counting pole ages

New is zero, Add one / First split, Second split / Oldest on the far right

- **N New pole is 0** Every new pole starts at **0**
- **A Add 1** Each division adds **1** per pole
- **F First division** **0,1** gives **1,0** and **0,2**
- **S Second division** Then **2,0** | **0,1** | **1,0** | **0,3**
- **O Oldest pole** Far right, age **3**; far left, **2**

L21 p09, L21 p10

2. Division proteins: fts, FtsZ and the divisome

⚠ **Do not mix up: FtsZ is like tubulin, FtsA like actin; fts mutants make filaments, not minicells.**

ETPNF·F fts mutants: finding division genes

Essential, so Temperature sensitive mutants: Permissive grows, Non-permissive makes Filaments / Fts

- **E Essential process** Essential: genes cannot be eliminated completely
- **T Temperature sensitive** Found as temperature sensitive mutations
- **P Permissive temperature** Grow and divide at permissive temperature
- **N Non-permissive temperature** Usually higher temperature: no division
- **F Filaments** Long filaments, many nucleoids *(DNA region without a membrane)*
- **F fts** Filamentous temperature sensitive

L21 p11

FtsZ: where and how

TZMCD FtsZ: the tubulin homolog ring

Tubulin twin makes the Z ring in the Middle, Constricts, stays Dynamic

T Tubulin *(protein of eukaryote tube filaments)* **homolog** Homolog of tubulin (forms microtubules)

Z Z ring Filaments inside membrane *(thin lipid layer)*; ring at cleavage site

M Middle of the cell Band at midcell between nucleoids *(DNA region without a membrane)*

C Constricts *(pinches in)* Ring gets smaller: constriction

D Dynamic Dynamic: much subunit *(building block piece)* turnover

L21 p12, L21 p13, L21 p14, L21 p17

DST FtsZ in Bacillus: three cell states

Dividing in the middle, Sporulating at both poles, Transitioning throughout the cell

D Dividing cells Ring in the middle

S Sporulating cells At **BOTH** poles

T Transitioning cells Throughout the cell

L21 p15

FFZ·PT·O Divisome: proteins on the FtsZ ring

FtsZ ring builds with FtsA, ZipA / PBP3 does Two reactions / Others join

F FtsZ *(protein ring for cell splitting)* **ring** Proteins join it: the divisome *(cell splitting machine)*

F FtsA Actin *(protein of eukaryote thin filaments)* homolog; interacts with FtsZ and membrane *(thin lipid layer)*

Z ZipA Membrane protein; like FtsA

P PBP3 New murein *(another name for peptidoglycan)* at cleavage site

T Transglycosylation *(joining sugar chains longer)*, **transpeptidation** *(making peptide bridges between chains)* **BOTH** reactions; penicillin blocks

O Others Many more; MinCD is **NOT** one

L21 p16, L21 p17, L21 p18, L21 p19

3. Min proteins and methods

⚠ **Do not mix up: MinC blocks FtsZ at the poles; MinE drives MinD ATP hydrolysis.**

MMM·FM Min proteins: who does what

MinC blocks, MinD coats, MinE kicks / FtsZ rings in the middle, else Minicells

M MinC Blocks FtsZ *(protein ring for cell splitting)*; at the poles

M MinD MinD-ATP helical filaments on membrane *(thin lipid layer)*

M MinE Near center; MinD ATP *(cell energy molecule)* hydrolysis *(breaking with water)*

F FtsZ ring in the middle So rings form **only** in center

M Minicells Min mutants: division near one end

L21 p20, L21 p21, L21 p22, L21 p25

CM·HFE·RL steps in order: Min oscillation, pole to pole

Coats, MinE ring / Hydrolysis, Falls, Exchange / Rebinds, Least in the middle

C Coats one pole MinD-ATP plus MinC coat one pole

M MinE ring MinE ring at the edge

H Hydrolysis *(breaking with water)* MinE triggers ATP *(cell energy molecule)* hydrolysis

F Falls off MinD-ADP and MinC fall off

E Exchange ADP *(used up energy molecule)* swapped for ATP

R Rebinds Rebinds at the opposite pole

L Least time in middle MinC least in the middle

L21 p21, L21 p22, L21 p23, L21 p24

MGFT Methods to study division proteins

Mutants, GFP, Fluorescent antibody, Time lapse

M Mutants fts filaments, Min minicells, TipN flagella *(whip tails that spin)*

G GFP fusions TipN-GFP, GFP-MinD in living cells

F Fluorescent antibody Antibody to FtsZ *(protein ring for cell splitting)*, DAPI for DNA *(cell genetic instruction molecule)*

T Time lapse Images over time show movement

L21 p26, L21 p07, L21 p13, L21 p23

4. Review: envelopes and wall drugs

⚠ **Do not mix up: Vancomycin binds the peptide; penicillin, cephalosporins and D-cycloserine mimic D-Ala-D-Ala.**

G·MG·MA Envelope layers: all vs some

Gram-positive / Mycobacteria, Gram-negative / Mollicutes, Archaea: all or some

- **G Gram positive** *(thick wall, stains purple)* All: thick wall, membrane *(thin lipid layer)*; some: capsule *(firm sugar coat outside the cell)*, teichoic *(charged wall chain type)*
- **M Mycobacterial** *(about waxy walled bacteria)* Mycolic acid *(waxy fatty acid of mycobacteria)*, arabinan-galactan, peptidoglycan *(sugar and peptide mesh of the wall)* wall
- **G Gram negative** *(thin wall plus outer membrane)* All: **outer** membrane *(extra membrane outside the wall)*, thin wall, periplasm *(space between the two membranes)*
- **M Mollicutes** *(bacteria with no cell wall)* NO wall; sterols *(stiff ring shaped fat)*; pleomorphic shape
- **A Archaeal** *(of archaea)* Some: pseudopeptidoglycan *(archaea version of wall mesh)*; isoprenoid *(branched five carbon repeat fat)* membrane

L21 p29, L21 p30, L21 p31, L21 p32, L21 p34, L21 p35

The six wall drugs

PCD·VBL Wall drugs: D-Ala-D-Ala look-alikes

Penicillin, Cephalosporins, D-cycloserine mimic / Vancomycin grabs, Bacitracin jams, Lysozyme cuts

- **P Penicillin family** Like D-Ala-D-Ala; binds PBPs: transpeptidase *(enzyme making wall cross bridges)*, transglycosylation *(joining sugar chains longer)*
- **C Cephalosporins** *(penicillin like wall blocking drugs)* Also like D-Ala-D-Ala; same two reactions
- **D D-cycloserine** *(drug blocking D alanine steps)* Like ligated D-Ala-D-Ala; Ala racemase, ligase
- **V Vancomycin** *(drug blocking wall building)* **NOT** a look-alike; binds pentapeptide, prevents transpeptide linkage
- **B Bacitracin** *(drug blocking carrier recycling)* Blocks regeneration of bactoprenol-P
- **L Lysozyme** *(enzyme that cuts wall sugars)* Cuts M-G sugar bond; protoplast or spheroplast

L21 p37, L21 p41, L21 p42, L21 p43, L21 p44, L21 p45, L21 p46, L21 p48

HGLB·A·ROM Penicillin: holes, lysis, resistance

Holes in Growing cells, Lysis: Bactericidal / Ampicillin bulges / Resistance, Outer membrane, Mycoplasma

- **H Holes** Blocks NEW wall; growing cells get holes
- **G Growing cells** Only growing cells; dormant *(inactive, not growing)* cells unharmed
- **L Lysis** *(bursting open)* Hypotonic *(low solute outside)*: water in, membrane *(thin lipid layer)* lyses
- **B Bactericidal** Wall drugs kill; most are bacteriostatic
- **A Ampicillin** **2.5** bulges, **5** long, **10** spheres and lysis
- **R Resistance** Beta-lactamase *(enzyme that destroys beta lactam drugs)* or altered PBP *(penicillin binding wall builder enzyme)*
- **O Outer membrane** *(extra membrane outside the wall)* Some penicillins cannot cross it
- **M Mycoplasma** No wall: do **NOT** use penicillin

L21 p49, L21 p50, L21 p51, L21 p52, L21 p53, L21 p54, L21 p55

Lecture 22 Viruses and Atypical Bacteria (22 acronyms)

1. Virus particles: size, parts, covering

⚠ **Do not mix up: Nucleic acid and capsid are in ALL viruses; enzymes and envelope only in SOME.**

SEG·ISC Virus size and shape

Smaller, Electron microscope, Giants / Icosahedron, Spherical, Complex

- **S Smaller than bacteria** Most **0.02** to **0.2** microns *(one millionth of a meter)*; **10-100**x smaller
- **E Electron microscope** Needed to see viruses
- **G Giant viruses** Pandoravirus **1 um**, Mimivirus **450 nm**: like bacteria
- **I Icosahedron** **20**-sided polyhedron; large diversity of shapes
- **S Spherical** Round, such as enveloped viruses
- **C Complex** More complicated: tailed bacteriophage

L22 p05, L22 p06

Core vs covering

A·NE·CE Virus parts: core vs covering, all vs some

Acellular / Nucleic acid, Enzymes in the core / Capsid, Envelope cover it

- **A Acellular** Simpler than cells; nucleic acid in protein shell
- **N Nucleic acid** Core; in ALL; DNA or RNA, **NOT** both
- **E Enzymes** Core, inside capsid; in SOME; polymerase
- **C Capsid** Covering; in ALL: protein coat or shell
- **E Envelope** Covering; in SOME: phospholipid *(membrane fat with a charged head)* bilayer *(two layers)*, spikes

L22 p07, L22 p08, L22 p09, L22 p11, L22 p12, L22 p13

E·SS·CO Viral nucleic acid

Either kind, never both / Single or double, Segments / Copies, Overlapping genes

- **E Either DNA or RNA** DNA or RNA, **NOT** both; in all viruses
- **S Single or double** Single or double stranded
- **S Segments** May be in multiple segments
- **C Copies** More than **1** copy (HIV: two RNA strands)
- **O Overlapping genes** Overlapping genes; many proteins from one RNA (SARS-CoV-**2**)

L22 p09, L22 p10, L22 p11

CI·N·SI Capsid and envelope parts

Capsomeres, Icosahedral or helical / Nucleocapsid / Spikes outside, Inside enzymes

- **C Capsomeres** Identical units that form the capsid
- **I Icosahedral or helical** Capsid: icosahedral (**20** sided) or helical
- **N Nucleocapsid** Capsid plus nucleic acid
- **S Spikes** Envelope glycoproteins; HIV GP-**120** on GP-**41**
- **I Inside the HIV capsid** Two RNA, reverse transcriptase, integrase, protease

L22 p11, L22 p12, L22 p13

Naked vs enveloped

VNE·ELB Naked vs enveloped viruses

Viable? Naked tough, Enveloped wet / Escape: Lyse or Bud

- **V Viable** Still able to infect outside a host
- **N Naked: tougher** Tougher; resist drying, detergents, acids
- **E Enveloped: sensitive** More sensitive; must remain wet
- **E Escape** Covering sets how it escapes
- **L Lyse the cell** Naked must lyse the cell
- **B Budding** Enveloped bud out; naked cannot

L22 p14

2. Reproduction and classification

⚠ **Do not mix up: Groups: genetic material and replication. Subgroups: covering, shape, host, segments. Influenza is V, not IV.**

OS·AT Reproduction: parasites built from parts

Obligate parasites, Some microbes too / Assembled from parts, as T4

- **O Obligate intracellular parasites** Only replicate inside a host cell
- **S Some bacteria and protozoans** Also some bacteria and protozoans
- **A Assembled from parts** From parts inside host, **NOT** splitting
- **T T4 bacteriophage** Head, DNA packed, tail, fibers last

L22 p15, L22 p16, L22 p37

Groups vs subgroups

NM·OS·OS Classifying viruses: groups vs subgroups

for groups, Nature and Means / for subgroups, Outer covering, Shape / Organisms, Segments

- **N Nature of genetic material** Groups: DNA or RNA, ss vs ds
- **M Means of replication** Groups: how genome is copied; I to VII
- **O Outer covering** Subgroups: envelope or not
- **S Shape** Subgroups: particle or capsid shape
- **O Organisms infected** Subgroups: organisms or cells infected
- **S Segmented or not** Subgroups: genome segmented or not

L22 p17, L22 p18, L22 p19

DSD·PN·RD Baltimore Groups I to VII

Double, Single, Double again / Positive, Negative / Retro, DNA back

- **D dsDNA viruses** I: host or viral DNA pol; herpes, pox, T4
- **S ssDNA viruses** II: through dsDNA, host DNA pol; parvo, M13, phiX174
- **D dsRNA viruses** III: (+) ssRNA step, viral RdRP; rotavirus
- **P Positive sense ssRNA** IV: (+) to (-) to (+); polio, SARS
- **N Negative sense ssRNA** V: (-) to (+) to (-); influenza; RdRP inside
- **R RNA retroviruses** VI: ssRNA, ssDNA, dsDNA, ssRNA; HIV
- **D DNA reverse-transcribing** VII: dsDNA, RNA, dsDNA; hepatitis B

L22 p18, L22 p19, L22 p26, L22 p27, L22 p31, L22 p32, L22 p33, L22 p34, L22 p35

3. Synthesis: who makes the copies

⚠ **Do not mix up: Ribosomes always come from the host; retroviruses bring reverse transcriptase; poxvirus makes its own RNA polymerase.**

HH·VP·RR Who supplies the synthesis enzymes

Host ribosomes, Host copies parvo / Virus copies herpes, Pox transcribes / RdRP and Reverse from the virus

- **H Host ribosomes** *(protein building machine)* Every group: ribosomes from the host
- **H Host DNA polymerase** Parvovirus, papillomavirus: host DNA pol
- **V Virus DNA polymerase** Adeno, herpes, pox: own DNA pol
- **P Poxvirus RNA polymerase** *(enzyme copying DNA into RNA)* Only poxvirus makes its own RNA pol
- **R RdRP from the virus** RNA viruses: own RdRP
- **R Reverse transcriptase** Retroviruses: own, packaged; host RNA pol last

L22 p24, L22 p26, L22 p27, L22 p34, L22 p35, L22 p36

THE·RR·P RNA genomes: the copying problem

Template problem: Host lacks it, so viruses Encode / RdRP or Reverse transcriptase / Plus strand reads

- **T Template RNA** RNA template needs RdRP
- **H Host lacks RdRP** Most host cells: no RdRP
- **E Encode enzymes** Viruses encode RNA-copying enzymes
- **R RdRP mechanism** **1**: ssRNA, complementary ssRNA, ssRNA
- **R Reverse transcriptase** **2**: ssRNA, ssDNA, dsDNA, ssRNA (retroviruses)
- **P Plus strand** (+): template for translation; (-) complementary

L22 p28, L22 p29, L22 p30

4. Steps of multiplication and special cycles

⚠ **Do not mix up: Penetration is ENTRY; uncoating is RELEASE of the genome. Phages inject DNA, leaving the particle outside.**

APU·SAR steps in order: Animal virus multiplication

Adsorb, Penetrate, Uncoat / Synthesize, Assemble, Release

- **A Adsorption** Attach to receptors *(proteins a signal or virus binds to)*; sets host range
- **P Penetration** Entry: endocytosis or membrane *(thin lipid layer)* fusion
- **U Uncoating** Release of the viral genome
- **S Synthesis** Copy genome, make proteins; ways differ
- **A Assembly** From parts, **NOT** splitting
- **R Release or escape** Lysis *(bursting open)*, budding, or cell-to-cell spread

L22 p20, L22 p21, L22 p22, L22 p24, L22 p37, L22 p38, L22 p40

Getting in and uncoating

EF·SM·HA Entry and uncoating mechanisms

Endocytosis or Fusion / SARS, Measles / Hepatitis, Adeno

- **E Endocytosis** Engulfed into endosome vesicle, then uncoats
- **F Fusion** Envelope fuses with cell membrane *(thin skin around the cell)*
- **S SARS-CoV-2** ACE2; uncoated within endosome
- **M Measles** Fusion; coated RNA enters cytoplasm *(jelly inside the cell membrane)*
- **H Hepatitis C** Uncoated in acidified endosome
- **A Adenovirus** Uncoated at the nuclear pore

L22 p21, L22 p22, L22 p23

Special cycles

C·SET·PV·MB SARS-CoV-2: the coronavirus cycle

Coronavirus / Spike, Endocytosis, Translation / Protease, Viral factories / Minus copies, Budding

- **C Coronavirus** Enveloped, single-stranded, + sense RNA; COVID-19
- **S Spike binds ACE2** Spike binds ACE2 receptor
- **E Endocytosis** Endocytosis, uncoat in cytoplasm *(jelly inside the cell membrane)*
- **T Translation** Host ribosomes *(protein building machine)* make a polyprotein
- **P Protease** Cuts polyprotein: replicase; Paxlovid blocks
- **V Viral factories** ER becomes double-membrane vesicles
- **M Minus strand** Replicase makes (-) RNA; molnupiravir
- **B Budding** Golgi, then bud out

L22 p03, L22 p19, L22 p41

C·IDS·P·ILL Plant viruses vs bacteriophages

Cell wall / Insects, Damage, Seeds / Plasmodesma spread / phages Inject, Lysogen, Lysis

- **C Cell wall** *(stiff layer around the cell membrane)* Plant cell wall blocks entry
- **I Insect vector** Insect vector damages cells
- **D Damaged tissue** Contact with damaged, broken cells
- **S Seeds** Plant viruses infect seeds
- **P Plasmodesma** Then cell to cell via plasmodesma
- **I Inject DNA** Phages *(virus that infects bacteria)* inject DNA, particle stays outside
- **L Lysogen** Latent phage: prophage in chromosome *(one long DNA molecule)*
- **L Lysis** *(bursting open)* Most phages released by lysis

L22 p42, L22 p43

5. Outcomes for the host cell

⚠ **Do not mix up: Persistent: enveloped, budding, cell lives. Acute: lysis, cell dies. Influenza rounds up; herpes and measles fuse.**

APL·CT·SP Outcomes of viral infection

Acute, Persistent, Latent / Cytopathic, Transformed / Syncytia, Populations

- **A Acute** Host cells die by lysis *(bursting open)*
- **P Persistent** Long, slow budding; enveloped **only**; cell lives
- **L Latent** Dormant *(inactive, not growing)*, then reactivates; herpes in nerves
- **C Cytopathic changes** Cell looks altered; aids diagnosis
- **T Transformation** Cell becomes cancerous: oncogene
- **S Syncytia** Fused multinucleate cells; measles, RSV, herpes
- **P Populations** Gut phages *(virus that infects bacteria)*; ocean lysis recycles; Vibrio

L22 p38, L22 p44, L22 p45, L22 p46, L22 p47, L22 p48, L22 p49, L22 p50, L22 p51

RP·HM·IS·AR Cytopathic changes by virus

Rabies, Polio / Herpes, Measles fuse / Influenza, Smallpox round / Adeno clumps, Reo swells

- **R Rabies** No shape change; Negri bodies
- **P Poliovirus** Cell lysis *(bursting open)*; no inclusions *(clumps of protein and other material)*
- **H Herpes simplex** Syncytia; nuclear inclusions
- **M Measles** Syncytia (multinucleate)
- **I Influenza** Round up; no inclusions; **NOT** syncytia
- **S Smallpox** Round up; cytoplasmic inclusions
- **A Adenovirus** Clumping; nuclear inclusions
- **R Reovirus** Enlarge; vacuoles, cytoplasmic inclusions

L22 p47

6. Atypical bacteria and viruses

⚠ **Do not mix up: EB is the dormant infectious form outside; RB grows inside. Only Chlamydia has near complete metabolism.**

BF·VON Typical bacteria vs typical viruses

Bacteria: small, Free-living / Viruses: tiny, Obligate parasites, Nucleic acids only

- **B Bacteria size** **1-3 um**; **500-10,000** kB; **1000-10,000** genes
- **F Free-living** Reproduce by themselves
- **V Virus size** **0.02-0.2 um**; **1.8-100** kB; **1-100 proteins**
- **O Obligate parasites** Only reproduce inside cells
- **N Nucleic acids only** No ribosomes *(protein building machine)*, binary fission, cell wall *(stiff layer around the cell membrane)*

L22 p52, L22 p53

GF·IV·DRM Atypical small bacteria: thought viruses

Gram stain, Filters / Inside cells, so Virus? / then DNA, Ribosomes, Metabolic enzymes

- **G Gram stain** *(stain that sorts bacteria purple or pink)* Gram stain: no bacteria seen
- **F Filters** Passed **1** micron *(one millionth of a meter)* filters: under **1 um**
- **I Inside host cells** Something seen inside host cells
- **V Virus** So some said: a virus
- **D DNA, RNA and protein** Later: DNA, RNA and protein
- **R Ribosomes** *(protein building machine)* Later: ribosomes
- **M Metabolic enzymes** Later: metabolic enzymes, so bacteria

L22 p54

Rickettsia and Chlamydia

RLT·CN·ER·B Rickettsia vs Chlamydia

Rickettsia Lacks glycolysis, uses Translocase / Chlamydia Near complete / EB out, RB in / Both

- **R Rickettsia** **0.3** x **1 um**; **1000** kB, **830** genes
- **L Lacks glycolysis** No glycolysis or biosynthetic pathways
- **T Translocase** Steals ATP *(cell energy molecule)* with a translocase
- **C Chlamydia** EB **only 0.3 um**; **1000** kB, **900** genes
- **N Near complete metabolism** Steals ATP, but near complete metabolism
- **E EB** Dormant *(inactive, not growing)*, infectious; outside cells
- **R RB** Grows inside; divides by binary fission
- **B Both** Only inside hosts; steal ATP; stain poorly

L22 p55, L22 p56

Endosymbionts and organelles

LS·OD Endosymbiotic bacteria

Live inside, Smallest genomes / Own ribosomes, Divide alone

- **L Live inside** Inside cells or body parts; some obligate
- **S Smallest genomes** **150** kB, **182** genes: smallest
- **O Own DNA and ribosomes** *(protein building machine)* Own DNA, ribosomes, some enzymes
- **D Dividing** Grow independently by dividing

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OMC·DOA·R Mitochondria and chloroplasts

Obligate: Mito, Chloro / Divide, Own ribosomes, ATP / Rickettsia roots

- **O Obligate symbionts** Obligate intracellular symbionts
- **M Mitochondria genome** **6-300** kB, **30-60** genes
- **C Chloroplast** *(plant part that does photosynthesis)* **genome** **70-200** kB, about **120** genes
- **D Dividing, fusion** Divide and fuse on their own
- **O Own DNA, RNA, ribosomes** *(protein building machine)* Own DNA, RNA, ribosomes, tRNA *(adapter that carries amino acids)*
- **A ATP** *(cell energy molecule)* **for own use** Own ATP; many metabolites *(small working molecules of the cell)* from host
- **R Rickettsia ancestor** Mito from Rickettsia ancestor; chloroplast cyanobacterium

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Giant viruses

FLG·BTI Giant viruses

Fourth domain? Large, Genome big / Both nucleic acids, Translation, Infected too

- **F Fourth domain** Proposed fourth domain of life
- **L Large size** Over **0.15 um**
- **G Genome** **100-1000** kB, **100-1100** genes; Mimivirus beats Rickettsia
- **B Both DNA and RNA** Some have both DNA and RNA
- **T Translation enzymes** Some make translation enzymes
- **I Infected by viruses** Some infected by viruses

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