BIOL 4640 Study Guide for Exam 2 (Wed 10/28/26): Lecture 15 Flagella and Motility

Source: Dr. Rowen's lecture slides, in the order of the 2025 Exam 2 study guide outline.
Slide blanks still empty in the notes are filled from the textbook and marked "textbook".
Tags like [L16 p08] give the source page of each line.
Textbook to read (Slonczewski 6e, Textbook page on the site): 3.6 Specialized Structures (flagella and pili); 25.2 Microbial Attachment: First Contact (pili). **Also useful:** 3.5 Cell Asymmetry, Membrane Vesicles, and Extensions (stalks, nanotubes).
(teal italics) = plain meaning of the word before it. ⚠ **Do not mix up = a look-alike pair to keep apart.**

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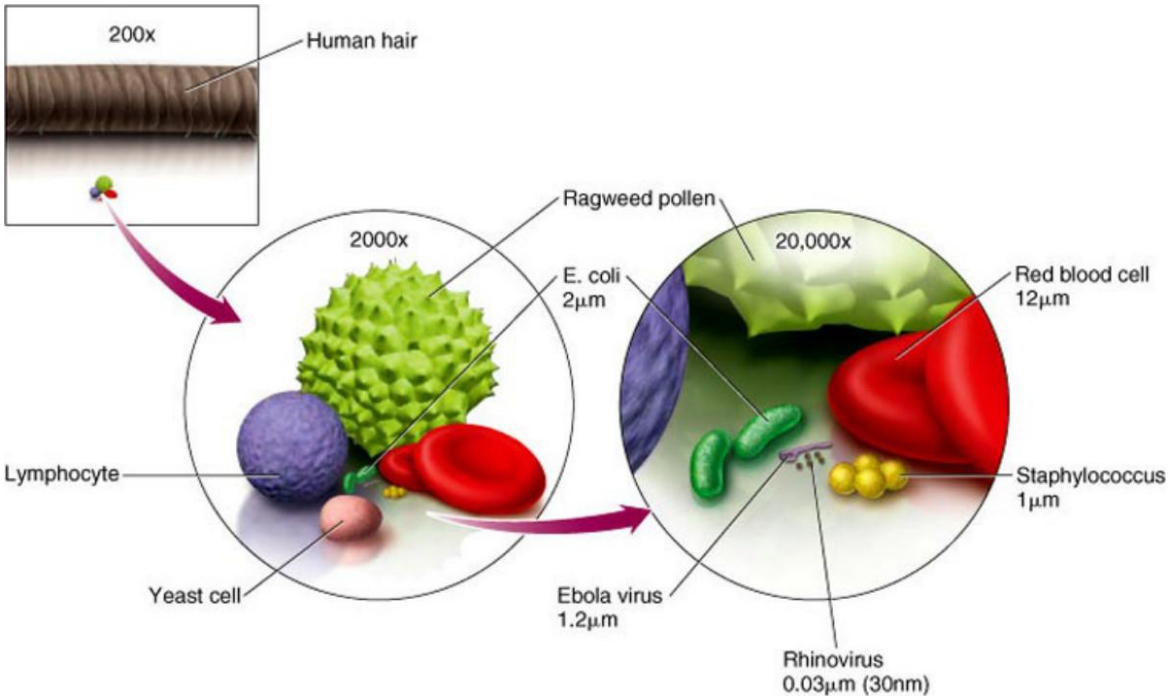
A. Size and shapes of bacteria

⚠ **Do not mix up: Viruses are 10-100 nm, not µm; bacteria are 0.4-10 µm.** [L15 p05]

Size units and ranges

Sizes of microbes: the unit is the micrometer (µm), also called micron, which is **10**^-6 m. [L15 p05]
Eukaryotic *(cells with a nucleus)* **microbes** are **10**-**100** µm wide. [L15 p05]
Bacteria are **0.4**-**10** µm. [L15 p05]
Viruses are **0.01**-**0.1** µm, which is **10**-**100 nm**. [L15 p05]
Nanometer (nm): **1** µm is **1,000 nm**; the virus range **0.01**-**0.1** µm is **10**-**100 nm**, and rhinovirus at **0.03** µm is **30 nm**. [L15 p05]

Size examples



Sizes of microbes beside blood cells and pollen at three scales [L15 p05]

On the figure: Ebola virus · E. coli · Staphylococcus · red blood cell · rhinovirus

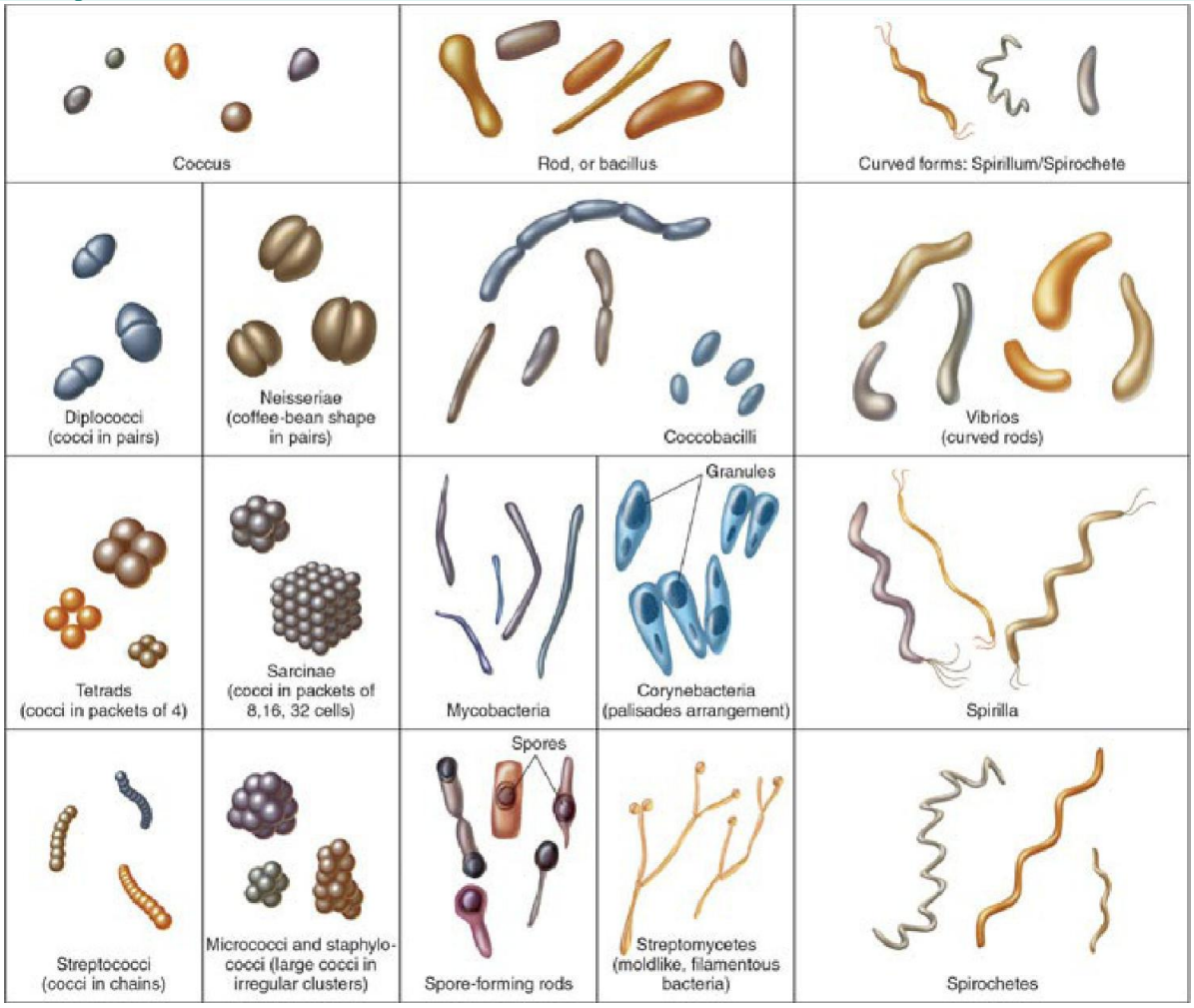
Sizes: E. coli is **2** μm, Staphylococcus is **1** μm. [L15 p05]

More sizes: red blood cell **12** μm, rhinovirus **0.03** μm (**30 nm**). [L15 p05]

Ebola virus (**1.2** μm) is longer than Staphylococcus (**1** μm). [L15 p05]

Watch out: the size list gives viruses as **0.01**-**0.1** μm, but the size figure shows Ebola virus at **1.2** μm, so a virus is not always smaller than a bacterium. [L15 p05]

Bacterial shapes



Bacterial shapes and groupings: coccus, rod, vibrio and spiral forms [L15 p06]

On the figure: Coccus · bacillus · vibrio · spirilla · spirillum · cocci

Four shapes of bacteria: **cocci** *(round cells)*, **bacillus** *(rod cells)*, **vibrio** *(curved rods)*, spiral. [L15 p06]

Coccus is a sphere and **bacillus** (plural bacilli) is a rod. [L15 p06]

Vibrio is a curved rod and **spirillum** (plural **spirilla**) is a spiral. [L15 p06]

Some bacteria grow in clusters or filaments. [L15 p06]

Group	Size
Eukaryotic microbes	**10-100** µm wide
Bacteria	**0.4-10** µm
Viruses	**0.01-0.1** µm (**10-100 nm**)

Table source: [L15 p05]

Item in the size comparison	Size	Magnification where it appears
Human hair	no size given	**200**x
Ragweed pollen	no size given	**2000**x and **20,000**x
Lymphocyte	no size given	**2000**x
Yeast cell	no size given	**2000**x
E. coli	**2** µm	**2000**x and **20,000**x
Red blood cell	**12** µm	**20,000**x (also at **2000**x)
Staphylococcus	**1** µm	**20,000**x (also at **2000**x)
Ebola virus	**1.2** µm	**20,000**x
Rhinovirus	**0.03** µm (**30 nm**)	**20,000**x

Table source: [L15 p05]

Shape or arrangement	Description
Coccus	sphere
Diplococci	cocci in pairs
Neisseriae	coffee-bean shape in pairs
Tetrads	cocci in packets of **4**
Sarcinae	cocci in packets of **8, 16, 32** cells
Streptococci	cocci in chains
Micrococci and staphylococci	large cocci in irregular clusters
Rod or bacillus	rod
Vibrios	curved rods
Spirilla and spirochetes	spiral forms
Mycobacteria, corynebacteria, spore-forming rods	mycobacteria: thin, slightly curved rods; corynebacteria: palisades arrangement, granules; spore-forming rods: spores at the end or middle of the rod
Streptomycetes	moldlike, filamentous bacteria

Table source: [L15 p06]

Shape	What it looks like
Mycobacteria	thin, slightly curved rods
Corynebacteria	palisades arrangement; granules
Spore-forming rods	spores at the end or middle of the rod
Coccobacilli	short oval rods
Streptomycetes	moldlike, filamentous bacteria
Spirilla	spiral with flagella in tufts at the ends
Spirochetes	a tight, flexible spiral shape; flagella in the periplasm

Table source: [L15 p06]

B. External Structures of Bacteria

Book: 3.6 Specialized Structures (chapter 3 PDF, p. 119).

⚠ **Do not mix up: Fimbriae *(short sticky hairs)* help adhesion *(sticking to a surface)*; a pilus *(thin hair for sticking or DNA swap)* is hollow and transfers DNA *(cell genetic instruction molecule)*; flagella *(whip tails that spin)* give motility *(ability to move)*.** [L15 p04]

What external structures are

External structures:

> Protein filaments that project out from the cell.
>
> Are not enclosed by the cell membrane *(thin skin around the cell)* or cell wall *(stiff layer around the cell membrane)*. [L15 p07]

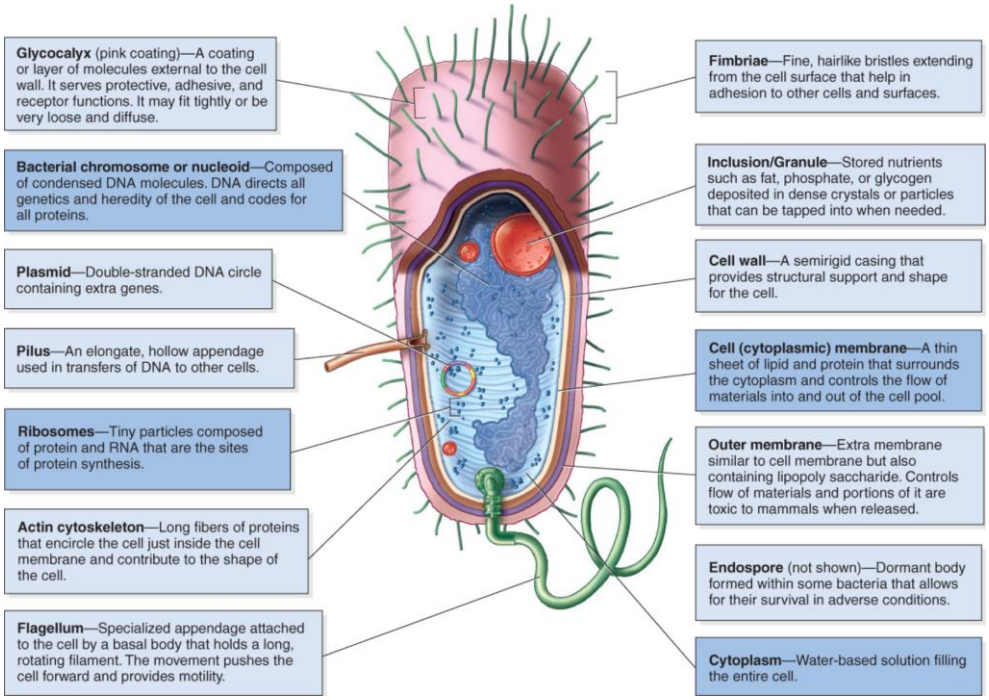
Appendages *(parts that stick out)* are flagella, pili *(thin hairs on the cell)* and fimbriae. [L15 p03]

Flagella (type **1** of **2** main types): used for motility. [L15 p07]

Pili and fimbriae (type **2** of **2** main types): used for adherence. [L15 p07]

Other external structures are in textbook section 3.5. [L15 p07]

Flagellum



Bacterial cell with each external and internal part named and described [L15 p04]

On the figure: Flagellum · Fimbriae · pilus · Glycocalyx · outer membrane · cell wall · ribosomes · actin cytoskeleton

> **Flagellum** *(whip tail that spins)*: attached to the cell by a basal body *(anchor of the whip in the envelope)* that holds a long, rotating filament. [L15 p04]
>
> The **flagellum** provides motility; its movement pushes the cell forward. [L15 p04]

Fimbriae

> **Fimbriae**:
>
> > Fine, hairlike bristles extending from the cell surface.
> >
> > Help in adhesion to other cells and surfaces. [L15 p04]
> >
> > And common pili are thinner than flagella: **3-10 nm** wide versus **14-20 nm** for a flagellum.

Pilus

> **Pilus**: an elongate, hollow appendage used in transfers of DNA to other cells. [L15 p04]

A pilus is built of straight filaments of protein monomers called pilin *(protein that builds a hair)*; short attachment pili are also called **fimbriae** (textbook).

Glycocalyx, envelope and internal parts

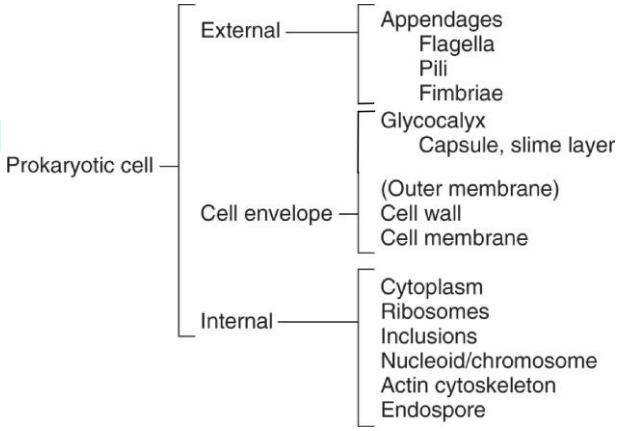
Glycocalyx *(sugary coat)* has two forms: capsule *(firm sugar coat outside the cell)* and **slime layer** *(loose sticky coat outside)*. [L15 p03]

Cell envelope *(layers wrapped around the cell)* parts: **outer membrane** (**Gram-negative only**), **cell wall**, cell membrane. [L15 p03]

Outer membrane holds **lipopolysaccharide** (LPS) *(sugar and fat molecule)*; portions of it are toxic to mammals when released. [L15 p04]

Internal parts: cytoplasm *(jelly inside the cell membrane)*, **ribosomes** *(protein building machine)*, inclusions *(clumps of protein and other material)*, nucleoid *(DNA region without a membrane)* or chromosome *(one long DNA molecule)*, actin *(protein of eukaryote thin filaments)* cytoskeleton *(inner scaffold of the cell)*, endospore *(tough dormant survival form)*. [L15 p03]

Watch out: the structure chart puts the glycocalyx (capsule, slime layer) with the external structures, but the cell envelope list includes cell membrane, cell wall, outer membrane and glycocalyx/capsule. [L15 p03]



Prokaryotic cell parts sorted into external, cell envelope and internal [L15 p03]

On the figure: Appendages · Glycocalyx · Cell envelope · internal · slime layer

Part	Description
Glycocalyx	coating or layer of molecules external to the cell wall; serves protective, adhesive and receptor functions; may fit tightly (capsule) or be very loose and diffuse (slime layer)
Outer membrane	extra membrane similar to the cell membrane but also containing lipopolysaccharide; controls flow of materials; portions of it are toxic to mammals when released
Cell wall	semirigid casing that gives structural support and shape
Cell membrane	thin sheet of lipid and protein that surrounds the cytoplasm and controls the flow of materials into and out of the cell
Cytoplasm	water-based solution filling the entire cell
Ribosomes	tiny particles of protein and RNA; sites of protein synthesis
Inclusions (granules)	stored nutrients such as fat, phosphate or glycogen, in dense crystals or particles that can be tapped when needed
Nucleoid (chromosome)	condensed DNA; directs all genetics and heredity; codes for all proteins
Plasmid	double-stranded DNA circle containing extra genes
Actin cytoskeleton	long fibers of proteins that encircle the cell just inside the cell membrane and contribute to the shape of the cell
Endospore	dormant body formed within some bacteria; lets them survive adverse conditions

Table source: [L15 p04]

1. Flagella and motility (3.6 6e)

Book: 3.6 Specialized Structures, Rotary Flagella (chapter 3 PDF, p. 126).

⚠ **Do not mix up: Flagellin *(protein that builds the whip)*** is added at the filament TIP, NOT the base (the rings, rod and hook are built first).

What flagella are

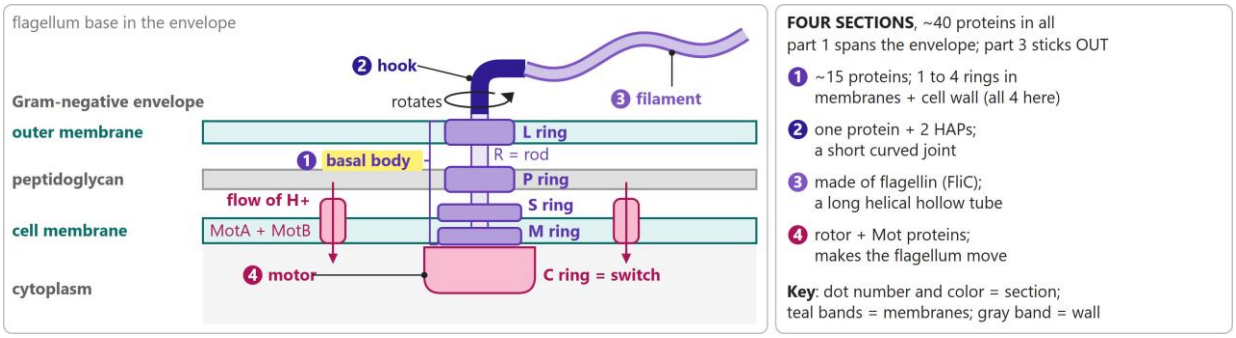
Flagella *(whip tails that spin)*: a complex structure of about **40 proteins**. [L15 p07, L15 p12]

Some sections of the flagellum *(whip tail that spins)* sit in the membrane *(thin lipid layer)*. [L15 p07, L15 p12]

The filament portion sticks out from the cell. [L15 p07, L15 p12]

Flagellar motility *(ability to move)* makes the population disperse, decreasing competition, and lets cells swim toward a favorable habitat (textbook).

Parts and growth



Flagellum base in the envelope with its four sections and about 40 proteins [L15 p13]

On the figure: basal body · hook · filament · motor · Flagellin

Four major sections: **basal body** *(anchor of the whip in the envelope)*, **hook**, **filament**, **motor**. [L15 p13]

Filament growth: **flagellin** subunits *(building block piece)* are added at the **tip**, not the **base**. [L15 p18]

Number and location

Number per cell is **0** to many. [L15 p08, L15 p09]

Number and location are a characteristic of a species. [L15 p08, L15 p09]

Location: one end, both ends or all over. [L15 p10]

Some cells can lose and regain their flagella. [L15 p08, L15 p09]

Spirochete flagella

Spirochetes *(long corkscrew shaped bacteria)* have their flagella in the periplasm *(space between the two membranes)*. [L15 p11]

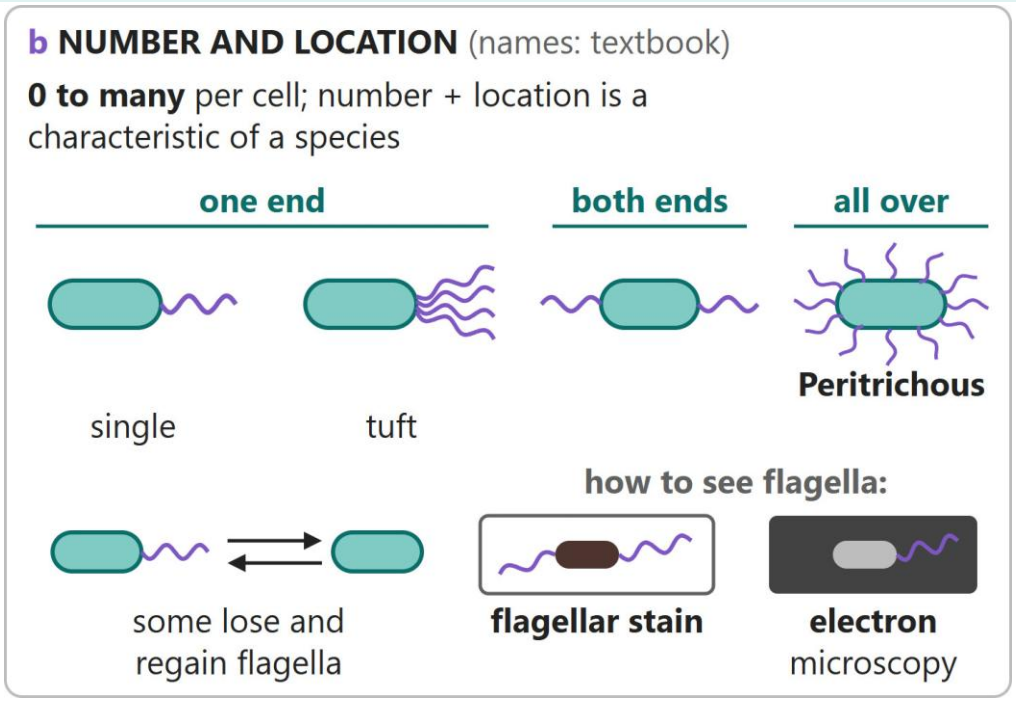
In spirochetes the flagella extend from each pole and wrap around the cell. [L15 p11]

Arrangements observed

Book: 3.6 Specialized Structures, Rotary Flagella (chapter 3 PDF, p. 126).

⚠ **Do not mix up: Polar means flagella *(whip tails that spin)* at an end of the cell (one or several at one end, or one at each end); peritrichous *(flagella all over the cell)* means flagella all over the cell.** [L15 p10]

Arrangement names



Flagella at one end, both ends or all over, and how to see them [L15 p09]

On the figure: Single · peritrichous · Flagellar stain · electron microscopy

Single polar *(one flagellum at one end)* is one flagella arrangement. [L15 p27]

Peritrichous *(flagella all over the cell)* is the name for the many flagella type. [L15 p28]

Several flagella at one end form a **tuft** *(small cluster)* at one pole. [L15 p09]

Found in bacteria

Found in bacteria:

- A single polar flagellum *(whip tail that spins)*.
- One flagellum on each end.
- Multiple polar flagella all out of one end.
- Many flagella over the whole body.

Never found

Never found: rod shaped bacteria with all their flagella enclosed inside the cell or inner membrane *(the skin around the cytoplasm)*.

This differs from spirochetes *(long corkscrew shaped bacteria)*, whose flagella sit in the periplasm *(space between the two membranes)*, beneath the outer sheath.

Seeing flagella

Flagellar stain and electron microscopy are used to see the flagella. [L15 p08, L15 p40]

Arrangement	What it looks like
Single flagellum at one end (polar)	a single polar flagellum (at one end)
Several flagella at one end	multiple polar flagella (all stick out of one end)
Flagella at both ends	a single flagellum on each end
Flagella all over the cell (peritrichous)	multiple flagella spread over the entire body
Periplasmic (spirochetes)	located in the periplasm; flagella extend out from each pole and wrap around the cell

Table source: [L15 p09, L15 p10, L15 p11, L15 p28]

Parts and features of flagella

Book: 3.6 Specialized Structures, Rotary Flagella (chapter 3 PDF, p. 126).

⚠ **Do not mix up: Filament is flagellin *(protein that builds the whip)*; hook is hook protein plus 2 HAPs *(hook associated proteins)*; motor has Mot proteins *(motor proteins that turn the flagellum)*.** [L15 p14, L15 p15, L15 p16]



Flagellin filament: helical tube of subunits, 14 nm across, hollow core [L15 p15]

On the figure: Salmonella typhimurium · helical · 14 nm · 40,000 daltons · flagellin

Filament and flagellin

Flagellin subunits *(building block piece)*:

- Self polymerize *(assemble on their own)* in a **helical** or spiral arrangement.
- Form a hollow tube. [L15 p15]

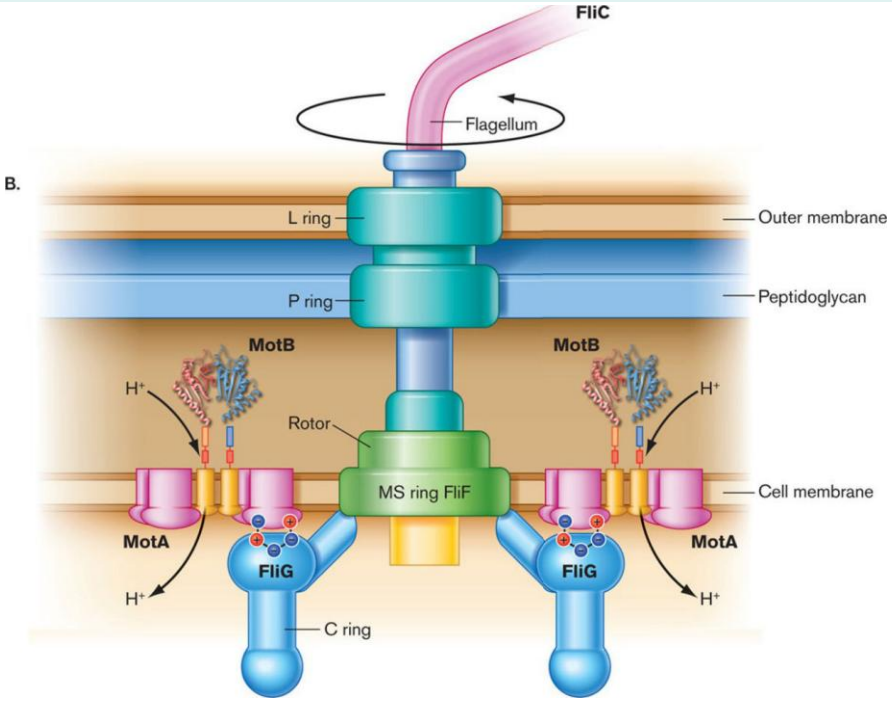
Filament:

- A cell may have several different **flagellin** genes.
- The cell can change the flagellin gene it uses. [L15 p15]

Salmonella typhimurium filament: helical, **14 nm** in diameter (within the **14-20 nm** range). [L15 p15]

Salmonella typhimurium flagellin: **40,000 daltons** *(unit of molecule weight)*. [L15 p15]

Basal body parts



Motor: rotor, MS ring, C ring, MotA and MotB with proton flow [L15 p16]

On the figure: L ring · P ring · MS ring · C ring · MotA · MotB · H+ · Rotor

Position of the rings (**Gram-negative** flagellum): **L ring** at the outer membrane *(extra membrane outside the wall)*. [L15 p12, L15 p14, L15 p16]

P ring is at the peptidoglycan *(sugar and peptide mesh of the wall)*. [L15 p12, L15 p14, L15 p16]

Rotor and MS ring (FliF) are in the cell membrane *(thin skin around the cell)*. [L15 p12, L15 p14, L15 p16]

C ring (with FliG) is below the MS ring, inside the cell; **FliG** *(switch protein in the C ring)* sits at the top of the C ring under **MotA** *(motor protein in the membrane)*, and its + and - charges make contact with MotA. [L15 p12, L15 p14, L15 p16]

The **C ring** is also called the **switch** (C ring/switch). [L15 p14]

Hook (H): hook protein and **2** HAPs; the filament (F) comes after it. [L15 p13, L15 p14]

MotA is in the cell membrane, and **MotB** sits beside it in the cell membrane and reaches into the periplasm *(space between the two membranes)*. [L15 p12, L15 p14, L15 p16]

How the flagellum moves

How the flagellum *(whip tail that spins)* **moves**: the motor section mediates movement of the flagellum. [L15 p19, L15 p20, L15 p16]

The motor section is the rotor plus the Mot proteins. [L15 p19, L15 p20, L15 p16]

H+ flows from the periplasm side through MotA and MotB into the cytoplasm *(jelly inside the cell membrane)*; this proton flow powers the rotation. [L15 p16]

The motor is driven by the transmembrane proton current, the same proton potential that drives the membrane-embedded ATP *(cell energy molecule)* synthase (textbook).

The **filament** rotates by means of the motor at the **base** (rotor plus Mot proteins). [L15 p16]

The motor is embedded in the layers of the cell envelope *(layers wrapped around the cell)* and has an axle and rotary parts made of specific proteins (textbook).

Stuck flagellum: when the flagellum is stuck to the glass slide, the motor turns the whole cell. [L15 p19]

A cell turned by a stuck flagellum spins in place. [L15 p19]

Section	Parts and numbers
Basal body	spans the membrane; about **15** different proteins; **1-4** rings in the membranes and cell wall (L, P, S, M); central rod (R)
Hook	hook protein and **2** HAPs
Filament	**14-20 nm** wide; up to **5-10** µm long; usually a single protein called flagellin; may have a different protein on the **tip** (cap protein)
Motor	rotor section plus Mot proteins; mediates movement of the flagellum

Table source: [L15 p13, L15 p14, L15 p15, L15 p16]

Part	Where it sits in the flagellum
MotA	in the cell membrane
MotB	in the cell membrane and reaching into the periplasm; forms part of the ion channel whose flux of hydrogen ions powers rotation (textbook)
H+ arrows	flow through MotA and MotB across the cell membrane
FliG	part of the C ring; forms part of the device that generates torque (rotary force) (textbook)
FliC	flagellin, the protein of the filament, which sticks out from the cell
Rotation	the whole flagellum rotates

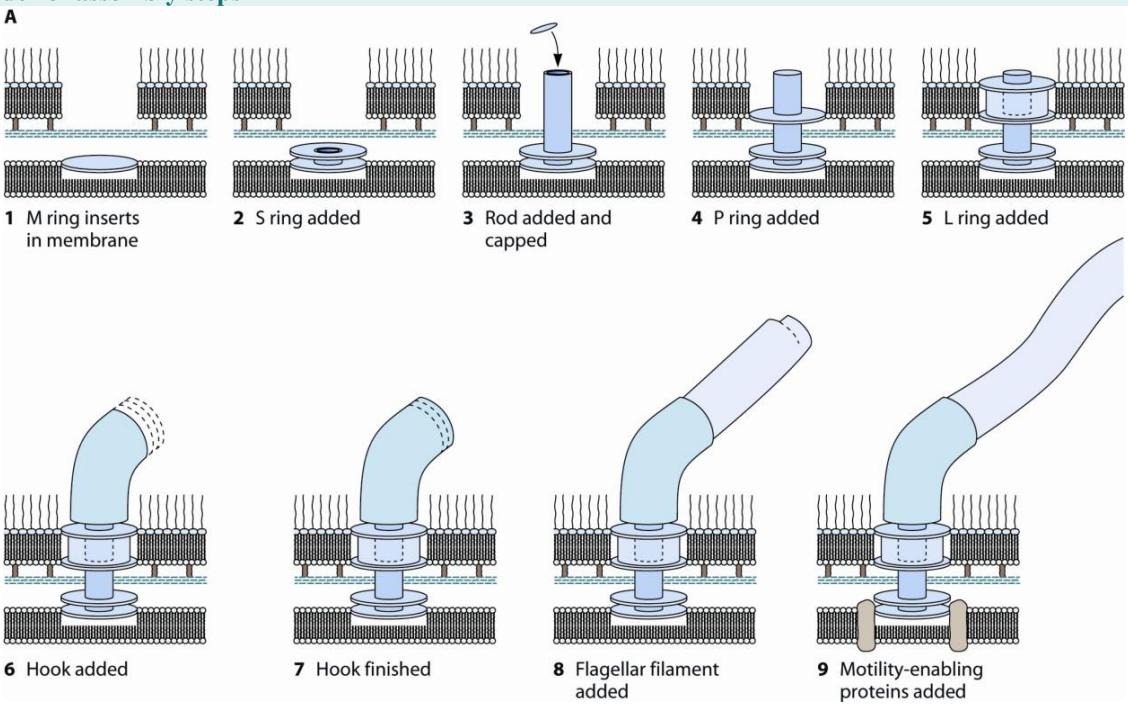
Table source: [L15 p12, L15 p16]

Order of assembly of flagellum

Book: 3.6 Specialized Structures, Rotary Flagella (chapter 3 PDF, p. 126).

⚠ **Do not mix up: Order: M, S, rod, P, L, hook, filament, Mot proteins *(motor proteins that turn the flagellum)* last.** [L15 p18]

Order of assembly steps



Nine assembly steps from M ring to motility proteins [L15 p17]

On the figure: M ring · S ring · rod · P ring · L ring · hook · filament · motility enabling

Order of assembly (steps **1**-**9**): **1** **M ring** inserts in the membrane. [L15 p17, L15 p18]

Where each ring goes: the M ring inserts into the cell membrane *(thin skin around the cell)*, the **S ring** stacks on top of it; the **P ring** sits at the peptidoglycan *(sugar and peptide mesh of the wall)* above the S ring; the **L ring** sits in the outer membrane *(extra membrane outside the wall)*. [L15 p16, L15 p18]

Order of assembly:

2 **S** ring added. **3** **rod** added and capped. **4** P ring added.
5 L ring added. **6** **hook** added. **7** hook finished.
8 flagellar **filament** added. **9** motility *(ability to move)* enabling (Mot) proteins added. [L15 p17, L15 p18]

Short summary of the steps

In short: rings of the basal body *(anchor of the whip in the envelope)* go into the cell membrane (**1** and **2**). [L15 p18]

In short: then the rod (**3**), then two outer membrane rings (**4** and **5**). [L15 p18]

Watch out: This summary calls both outer membrane rings, but the flagellum *(whip tail that spins)* diagram puts the P ring at the peptidoglycan and the L ring at the outer membrane. [L15 p18]

In short: then the hook (**6** and **7**), then the filament (**8**). [L15 p18]

In short: last, the motility proteins in the cell membrane (**9**). [L15 p18]

Assembly in plain terms

Assembly:

Two ring structures form in the cell membrane.
Two more rings (the P ring and the L ring) are then added.
The rings go in the cell wall *(stiff layer around the cell membrane)* layer or outer membrane.
The hook section is added.
The filament is formed.

Filament growth

Filament growth:

Flagellin *(protein that builds the whip)* subunits *(building block piece)* travel up through the core (hollow center) of the flagellum and are added at the **tip**.
Is by **extrusion** *(pushing out)* of flagellin subunits through the core of the flagellum. [L15 p18]

Assembly step	What happens
1 M ring	M ring inserts in membrane
2 S ring	S ring added
3 rod	rod added and capped
4 and 5 P ring, L ring	P ring added, then L ring added
6 and 7 hook	hook added, then hook finished
8 filament	flagellar filament added
9 Mot proteins	motility enabling (Mot) proteins added in the cell membrane, last

Table source: [L15 p17, L15 p18]

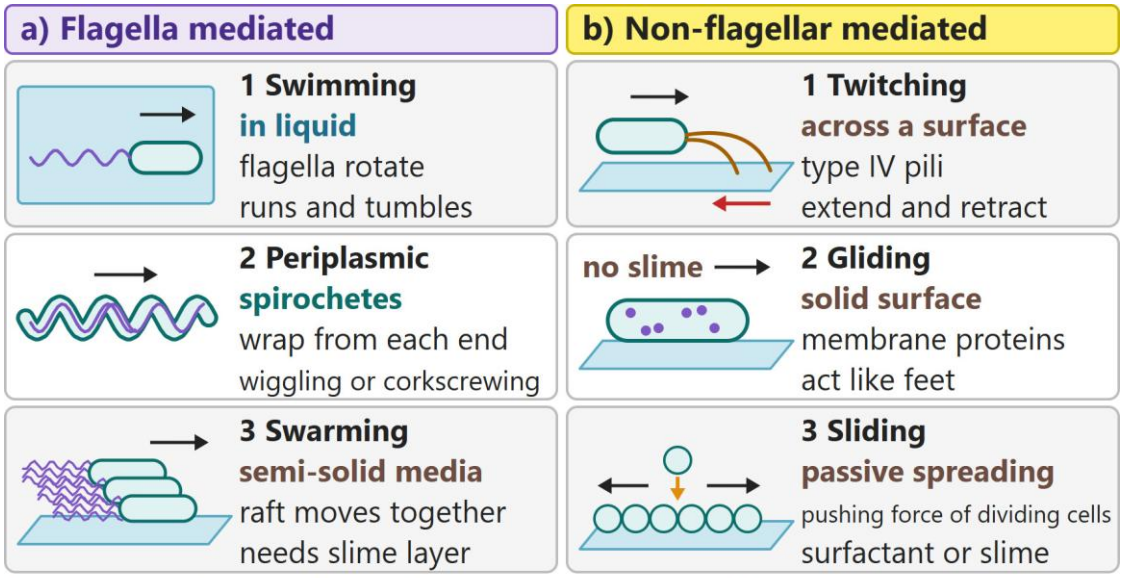
Types of motility observed in bacteria: know how each is mediated

Book: 3.6 Specialized Structures, Rotary Flagella (chapter 3 PDF, p. 126); 3.6 Specialized Structures, Pili and Stalks (chapter 3 PDF, p. 123).

⚠ **Do not mix up: Twitching *(jerky crawl using pili)*, gliding *(smooth crawl on a surface)* and sliding *(passive spreading by pushing)* are NOT flagella *(whip tails that spin)* mediated; swarming *(group moving on a surface using flagella)* and periplasmic *(in the space between the two membranes)*** flagella are.

What motility is

Motility *(ability to move)*: purposeful movement in a liquid or across a surface. [L15 p22, L15 p25]



Six motility types split into flagella mediated and non-flagellar mediated [L15 p25]

On the figure: flagella mediated · non-flagellar mediated · swimming · swarming · Twitching · gliding · sliding · periplasmic

Motility splits into **flagella mediated** and **non-flagellar mediated** types. [L15 p22, L15 p25]

Flagella mediated

Flagella mediated: (**1**) typical flagellar **swimming**, (**2**) **periplasmic** flagella, (**3**) **swarming** on a surface. [L15 p25, L15 p34]

Corkscrew swimming of spirochetes *(long corkscrew shaped bacteria)* is flagella mediated.

Not flagella mediated

Non-flagellar mediated:

(**1**) **twitching** on a surface.

(**2**) **gliding** on a surface, (**3**) **sliding** on a surface. [L15 p25, L15 p34]

Not flagella mediated: twitching, gliding and sliding.

Type	Key feature
Swimming	in a liquid; typical flagella
Swarming	on a surface; flagella; a group (raft) moves together
Twitching	on a surface; pilus retraction
Gliding	on a surface; focal-adhesion complexes
Sliding	on a surface; spreading by growth

Table source: [L15 p25]

Type	Mediated by	Where and key facts
Swimming	typical flagella rotating	liquid; runs and tumbles; direction controlled by length of runs
Periplasmic flagella	flagella in the periplasm	spirochetes; flagella out from each end; wiggling or corkscrewing; good for burrowing into thick mucus
Swarming	flagella (position may change to lateral)	surface or semi-solid media; a group (raft) moves together; requires a slime layer
Twitching	type IV pili	surface; type IV pili thought to extend, attach and then shorten to pull the cell forward; several **Gram-negative** species
Gliding	thought to be motility proteins in the membrane that act like feet (mechanism not understood in all genera)	solid surface; over **12** genera; Myxococcus, Flavobacterium; no slime involved in Flavobacterium
Sliding	powered by the pushing force of dividing cells	passive spreading across a surface; needs surfactants or exopolysaccharide or protein slime layer; also described as spreading by growth

Table source: [L15 p25, L15 p29, L15 p31, L15 p33, L15 p35, L15 p36, L15 p37, L15 p38, L15 p39]

▸ Swimming motility mediated by flagella

Book: 3.6 Specialized Structures, Rotary Flagella (chapter 3 PDF, p. 126).

What swimming is

Swimming motility *(ability to move)*:

> Directional movement (taxis *(moving toward or away from a stimulus)*); examples of swimming cells are Escherichia coli and Pseudomonas aeruginosa.
>
> Is mediated by controlling the length of runs (flagella on). [L15 p26]

Cells sense a change in concentration. [L15 p26]

Then cells decide to keep the flagella *(whip tails that spin)* on or turn them off. [L15 p26]

How flagella turn

Motility comes from the turning or spinning of the flagellum *(whip tail that spins)*.

Most flagella can turn in either direction.

Single polar flagellum

Single polar flagellum:

> The cell turns it counterclockwise (**CCW**) or clockwise (**CW**) for runs.
>
> To stop (tumble), it either stops turning or turns in the opposite direction. [L15 p27]

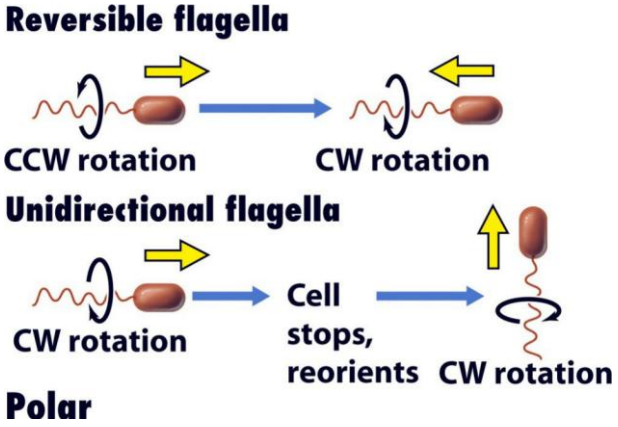
Reversible flagella: run **CCW** then **CW** (cell moves back the other way). [L15 p27]

Unidirectional flagella

Unidirectional flagella: one polar flagellum that turns one way **only**. [L15 p27]

It runs **CW**, the cell stops, reorients, then runs again with **CW**. [L15 p27]

This differs from multiple flagella, where **CCW** is the run. [L15 p27]



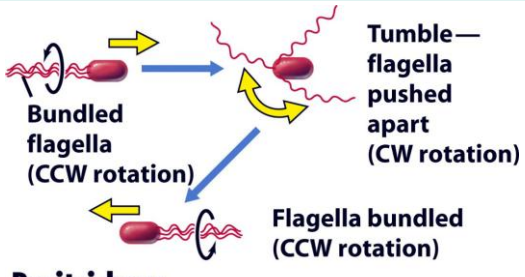
Single polar flagellum: reversible runs, or one direction then reorient [L15 p27]

On the figure: Reversible flagella · Unidirectional flagella · CCW · CW

Multiple flagella

Multiple flagella:

> Turning is coordinated.
>
> **CCW** gives forward movement (slower than a cell with a single flagellum).
>
> The opposite direction (**CW**) gives a stop (**tumble**).
>
> **CCW rotation** bundles the flagella for a run.
>
> **CW rotation** pushes them apart for a tumble *(stop and turn to a new direction)*. [L15 p28]



Many flagella: bundled for a run, pushed apart for a tumble [L15 p28]

On the figure: tumble · CCW rotation · CW rotation

▸ Periplasmic flagella in spirochetes

Book: 3.6 Specialized Structures, Rotary Flagella (chapter 3 PDF, p. 126).

⚠ **Do not mix up: Opposite rotation at the two ends gives translational swimming; same rotation gives nontranslational forms.** [L15 p30]

Spirochetes and their flagella

Periplasmic *(in the space between the two membranes)* **flagella** *(whip tails that spin)*: motility *(ability to move)* seen in spirochete bacteria. [L15 p11, L15 p29, L15 p30]

Spirochetes *(long corkscrew shaped bacteria)* have a **tightly coiled** spiral shape. [L15 p29]

Outer membrane *(extra membrane outside the wall)* **sheath** (**outer sheath**): surrounds the plasma membrane *(thin lipid layer)* and cell wall *(stiff layer around the cell membrane)* of a spirochete. [L15 p30]

The flagella sit in the periplasm *(space between the two membranes)* and extend out from each pole. [L15 p11, L15 p29, L15 p30]

Spirochete flagella wrap around the cell from each end.

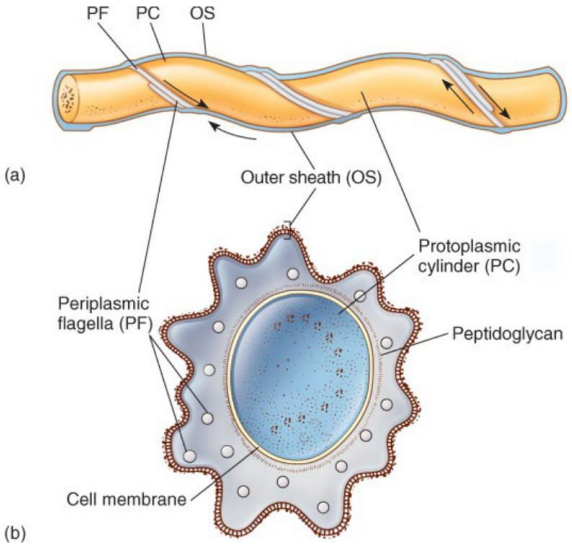
How the flagella move the cell

Turning of the flagella causes a wiggling or corkscrewing locomotion. [L15 p31]

Spirochete flagella produce a wiggling swimming motility.

This motility is good for burrowing into thick mucus. [L15 p31]

Direction of rotation of the flagella at each end determines the direction of motility. [L15 p30]

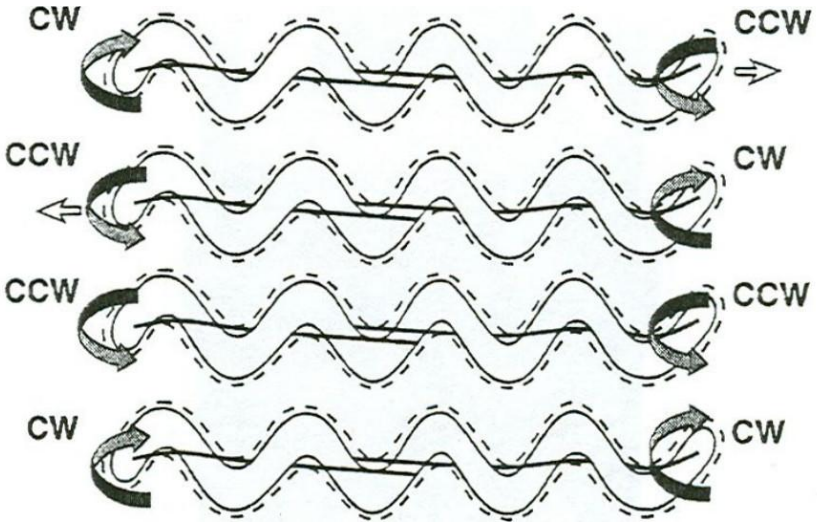


Spirochete with outer sheath and periplasmic flagella around the cell [L15 p11]

On the figure: outer sheath · Periplasmic flagella

B. burgdorferi

B. burgdorferi has between **7** and **11** **periplasmic flagella** attached at each end of the cell; the diagram shows **only** one per end, for simplicity. [L15 p30]



Rotation at each end and the direction the spirochete swims [L15 p30]

On the figure: CW · CCW

B. burgdorferi: opposite rotation at the two ends gives translational *(moving forward)* swimming. [L15 p30]

Opposite rotation means **CW** at one end with **CCW** at the other. [L15 p30]

Translational swimming goes toward the **CCW** end; the reverse pattern swims the other way. [L15 p30]

Same rotation at both ends (**CCW** and **CCW**, or **CW** and **CW**) gives nontranslational forms. [L15 p30]

Part of a spirochete	What it is
Outer sheath (OS)	outer sheath that surrounds the plasma membrane and cell wall
Periplasmic flagella (PF)	located in the periplasm, beneath the outer sheath; wrap around the cell
Protoplasmic cylinder (PC)	inner part of the cell (PC); the flagella wrap around the cell
Peptidoglycan	layer next to the cell membrane
Cell membrane	the cell membrane of the spirochete

Table source: [L15 p11, L15 p31]

Rotation (left end, right end)	Direction of swimming	What the cell does
CW, CCW	right	swims toward the **CCW** end (right)
CCW, CW	left	swims toward the **CCW** end (left)
CCW, CCW	none	nontranslational: no net swimming
CW, CW	none	nontranslational: no net swimming

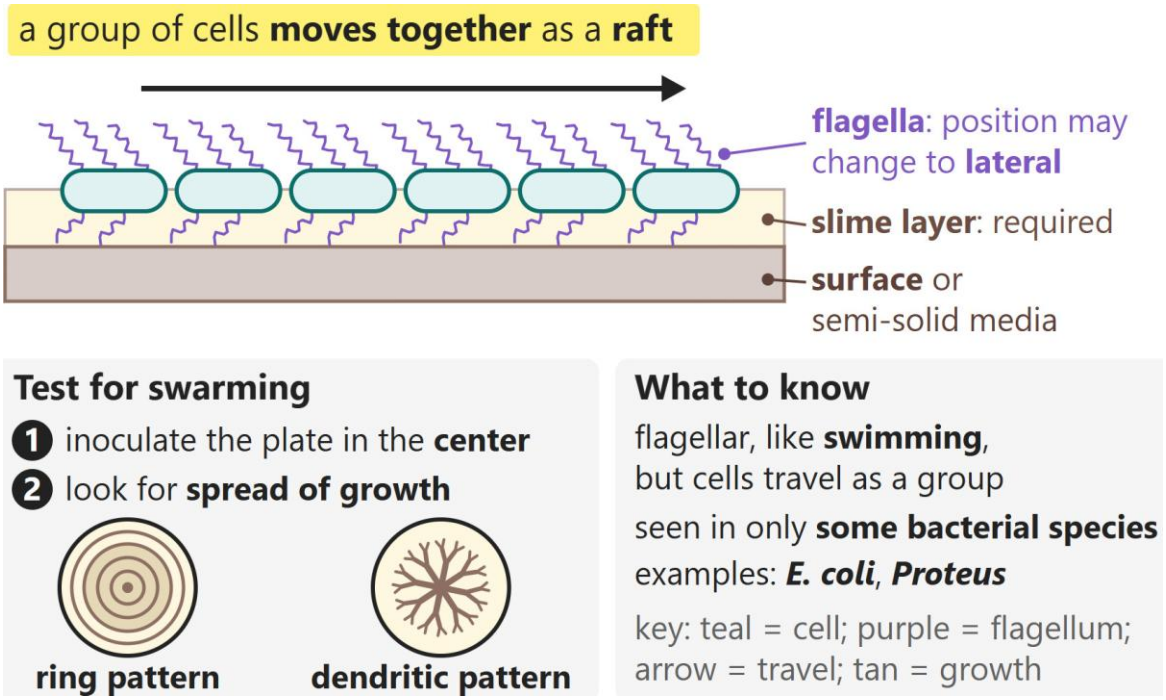
Table source: [L15 p30]

Swarming motility

Book: Not in the assigned sections (3.6, 25.2).

⚠ **Do not mix up: Swarming *(group moving on a surface using flagella)* is a group (raft) moving on a surface and needs a slime layer *(loose sticky coat outside)*.** [L15 p33]

What swarming is



Swarming raft on a slime layer, and ring and dendritic plate patterns [L15 p33]

On the figure: raft · lateral · slime layer · ring pattern · dendritic pattern · semi-solid media

Swarming:

Movement across a surface or **semi-solid media**.
Is mediated by flagella *(whip tails that spin)*, and their position may change to **lateral** *(along the side of the cell)*.
A group (**raft**) of bacteria moves together.
Requires a **slime layer**.
Is observed in some bacterial species. [L15 p33]
Examples: Escherichia coli and Proteus. [L15 p32]

Swarming Proteus

Swarming E. coli

Swarming test

Test: inoculate a plate in the center and look for spread of growth. [L15 p33]
Patterns shown: **ring pattern** and **dendritic pattern**. [L15 p33]

Gliding motility

Book: Not in the assigned sections (3.6, 25.2).

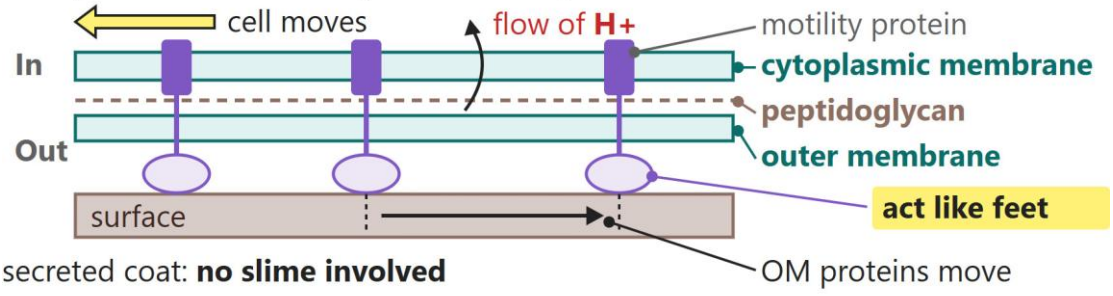
⚠ **Do not mix up: Gliding *(smooth crawl on a surface)* is NOT flagella *(whip tails that spin)* mediated, and Flavobacterium uses no slime.** [L15 p37, L15 p38]

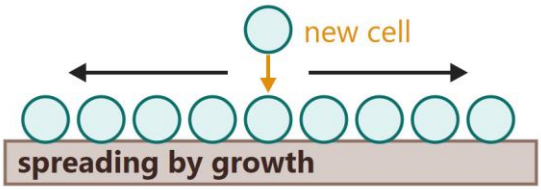
What gliding is

Gliding: across a **solid surface**; seen in over **12 genera**

example: *Myxococcus*; mechanism **not understood** in all genera

example: ***Flavobacterium*** **(Bacteroidetes)**





Sliding: a **passive** spreading powered by the pushing force of **dividing cells**; needs surface factors: **surfactants** or **exopolysaccharide** or **protein slime layer**

key: teal = cell parts; purple = proteins

Flavobacterium gliding on membrane proteins, and sliding by growth [L15 p38]

On the figure: Flavobacterium · cytoplasmic membrane · peptidoglycan · outer membrane · H+ · feet · surfactants · exopolysaccharide

Gliding:

- Motility *(ability to move)* across a solid surface. [L15 p37]
- Is not flagella mediated. [L15 p25]
- Is observed in over **12** genera of bacteria. [L15 p37]

The mechanism is not understood in all genera. [L15 p37]

Gliding examples

Gliding examples: Myxococcus and the Bacteroidetes **Flavobacterium**. [L15 p37, L15 p38]

Flavobacterium layers from inside to outside: **cytoplasmic membrane** *(thin lipid layer)*, **peptidoglycan** *(sugar and peptide mesh of the wall)*, **outer membrane** *(extra membrane outside the wall)*, then the surface. [L15 p38]

In **Flavobacterium**, **H+** flows through proteins in the cytoplasmic membrane. [L15 p38]

In **Flavobacterium**, motility proteins in the membrane are thought to act like **feet**. [L15 p37, L15 p38]

In Flavobacterium, no slime is involved. [L15 p37, L15 p38]

In **Flavobacterium**, outer membrane proteins move along the surface. [L15 p38]

In **Flavobacterium**, the movement of the cell is in the opposite direction from the movement of the outer membrane proteins. [L15 p38]

Sliding

Sliding *(passive spreading)* across a surface is powered by the pushing force of dividing cells and requires synthesis of additional **surface factors**: **surfactants** *(soap-like molecules)* or **exopolysaccharide** *(sugar chains outside the cell)* or a protein slime layer *(loose sticky coat outside)*. [L15 p39]

▸ Twitching motility

Book: 3.6 Specialized Structures, Pili and Stalks (chapter 3 PDF, p. 123).

⚠ **Do not mix up: Twitching *(jerky crawl using pili)* uses type IV pili *(thin hairs on the cell)*, NOT flagella *(whip tails that spin)*.**

What twitching is

Twitching:

- Movement across a surface.

Is mediated by a type of pili (type IV).
Is observed in several **Gram-negative** *(thin wall plus outer membrane)* bacteria species. [L15 p35]
Is not flagella mediated.

Twitching example: Pseudomonas aeruginosa moves across a surface using its type IV pili. [L15 p35]

Type IV pilus cycle

Type IV pili are thought to extend, attach and then shorten to pull the cell forward. [L15 p36]

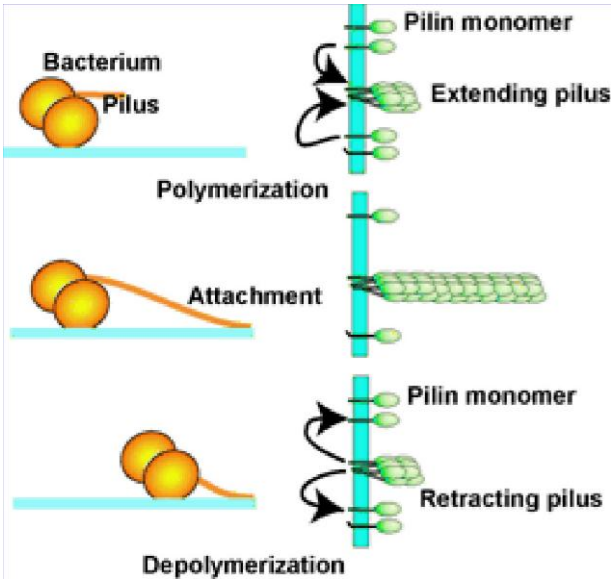
In twitching, the pili act as limbs that walk the bacterium across a substrate (textbook).

Type IV pilus *(thin hair for sticking or DNA swap)* **extension**: **polymerization** adds pilin *(protein that builds a hair)* monomers at the **base** of the pilus and extends it. [L15 p36]

Type IV pilus attachment: the pilus attaches. [L15 p36]

Type IV pilus retraction: **depolymerization** retracts *(pull back in)* the pilus. [L15 p36]

Retracting pilus: **pilin monomers** *(protein subunits)* are removed from the **base** of the pilus, so it shortens. [L15 p36]



Type IV pilus extends, attaches and retracts to pull the cell [L15 p36]

On the figure: pilin monomers · polymerization · depolymerization · attachment · Retracting pilus

What pili do

Pili:

Mediate attachment to surfaces.
Mediate transfer of DNA *(cell genetic instruction molecule)* between cells.

Sex pili of **Gram-negative** enteric bacteria attach a donor cell to a recipient cell for DNA transfer, called conjugation (textbook).

Pili mediate a form of motility *(ability to move)*.

Chemotaxis: what it

Book: 3.6 Specialized Structures, Rotary Flagella (chapter 3 PDF, p. 126).

⚠ **Do not mix up: Cells can do chemotaxis *(moving toward or away from chemicals)*** toward food but cannot move in a straight line to it.

Taxis and stimuli

Taxis *(moving toward or away from something)*:

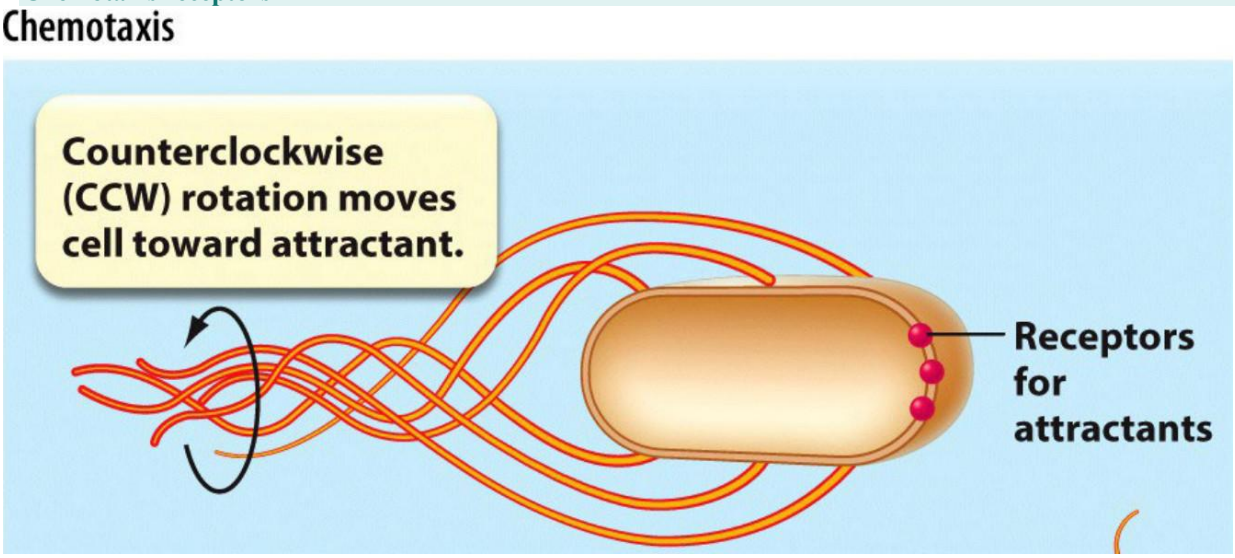
Movement in response to an external stimulus or effector *(outside signal that triggers a response)*.
Can be movement toward or away. [L15 p22, L15 p23]

A **wide variety** of substances and conditions affect motility *(ability to move)* and taxis. [L15 p23]

Stimuli that affect motility and taxis: chemicals (some nutrients), metals (many are toxic). [L15 p22, L15 p23]

More stimuli: light, temperature, pH, oxygen level. [L15 p22, L15 p23]

Chemotaxis receptors



Receptors for attractants at one pole; CCW rotation moves the cell toward the attractant [L15 p24]

On the figure: receptors for attractants · CCW rotation · chemotaxis

Chemotaxis:

> *(moving toward or away from chemicals)*: cells have receptors *(proteins a signal or virus binds to)* for attractants *(chemical that pulls cells in)* and repellents *(chemical that pushes cells away)*.
> The receptors send a signal that affects whether the flagella *(whip tails that spin)* turn. [L15 p24]

Chemoreceptors act like a nose, telling the bacterium when it is swimming toward a source of attractant (textbook).

Chemotaxis: CCW rotation moves the cell toward an attractant. [L15 p24]

Receptors for attractants sit at one pole of the cell, the front end as it swims toward the attractant. [L15 p24]

Arrays of chemoreceptors near a cell pole detect the attractant and repellent molecules (textbook).

The **CCW** flagella trail behind as one bundle. [L15 p24]

Runs and tumbles

No attractant or repellent: a series of runs (R) and tumbles (T). [L15 p26]

Path shape: runs (R) are the straight segments and tumbles (T) are the turns. [L15 p26]

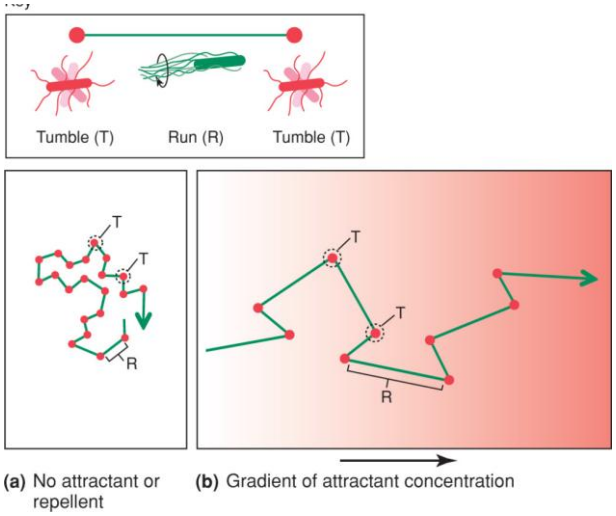
No attractant or repellent: the tumbles reorient the cell randomly. [L15 p26]

Gradient of attractant

Gradient *(gradual change in amount)* **of attractant**: the path ends up where the attractant is most concentrated, the highest concentration. [L15 p26]

In a gradient of attractant there are fewer tumbles and longer runs than with no attractant. [L15 p26]

Runs up the gradient last longer than runs down it. [L15 p26]



Runs and tumbles with no attractant and in an attractant gradient [L15 p26]

On the figure: No attractant or repellent · Gradient of attractant · tumbles · runs

Reaching food

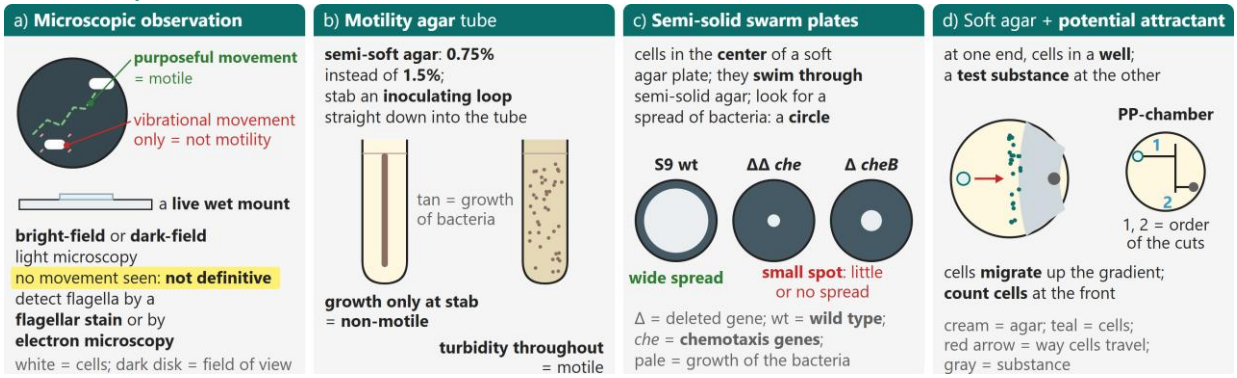
Chemotaxis: bacteria can move toward a desired food source.

Straight line: they cannot move continuously in a straight line to food.

How one could determine if a bacterium is motile and if it has flagella

⚠ **Do not mix up: Motility *(ability to move)* agar: growth only at the stab means non-motile; turbidity *(cloudiness of liquid)* throughout means motile.** [L15 p41]

Four assays



Four motility assays: microscope, agar tube, swarm plate, soft agar with attractant [L15 p41]

On the figure: microscopic observation · Motility agar · semi-solid swarm plates · soft agar · potential attractant · PP-chamber · turbidity · stab

Four assays:

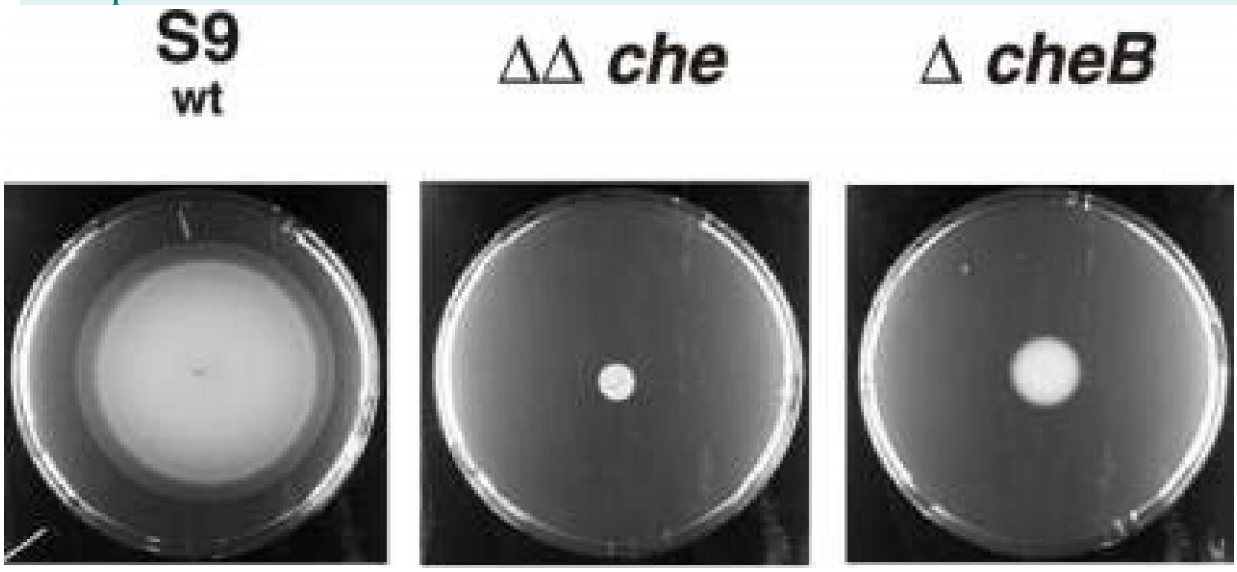
(a) **microscopic observation**, (b) **motility agar**.

(c) **semi-solid swarm plates**, (d) agar plates with **soft agar** and a **potential attractant** *(chemical that pulls cells in)*. [L15 p40, L15 p41, L15 p42, L15 p43]

Motility agar tubes

Motility agar tubes: growth **only** at the **stab** means non-motile; **turbidity** throughout means motile. [L15 p41]

Swarm plate results



Swarm plates: wild type spreads wide, che mutants stay a small spot [L15 p42]

On the figure: S9 wt · ΔΔche · ΔcheB

Swarm plate:

The wild type (**S9 wt**) spreads out in a large circle.

The che mutants (**ΔΔche** and **ΔcheB**) stay as a small spot. [L15 p42]

Agar plate techniques

PP-chamber version: the agar has cuts made in a sequence (**1, 2**) between the cells and the test substance. [L15 p43]

Agar-plate techniques: cells are counted at the test substance end. [L15 p43]

Soft agar plate with an attractant: cells are put in a well at one end and the test substance at the other; if it attracts them, the cells migrate toward the substance. [L15 p43]

Assay	How	Result and caution
Microscopic observation	bright field or dark-field light microscopy of live wet mounts	make sure the movement is purposeful and not just vibrational; lack of observed movement is not definitive
Seeing flagella	flagellar stain or electron microscopy	part of microscopic observation; shows whether flagella are present
Motility agar	semi-soft agar (**0.75%** instead of **1.5%**); stab an inoculating loop into a tube of media	growth **only** at the stab means non-motile; turbidity throughout means motile; not sure it detects all forms of motility
Semi-solid swarm plates	put cells in the center of a soft agar plate (bacteria can swim through semi-solid agar)	look for spread of bacteria as a circle; a wild type strain spreads widely, while che mutants stay as a small spot at the center
Soft agar with potential attractant	put cells in a well at one end and the test substance at the other end	count cells moving toward the test substance

Table source: [L15 p40, L15 p41, L15 p42, L15 p43]