What is life like at low Reynolds number?

Readings for today

- Berg, H. C. (Ed.). (2004). E. coli in Motion. New York, NY: Springer New York.

Topics

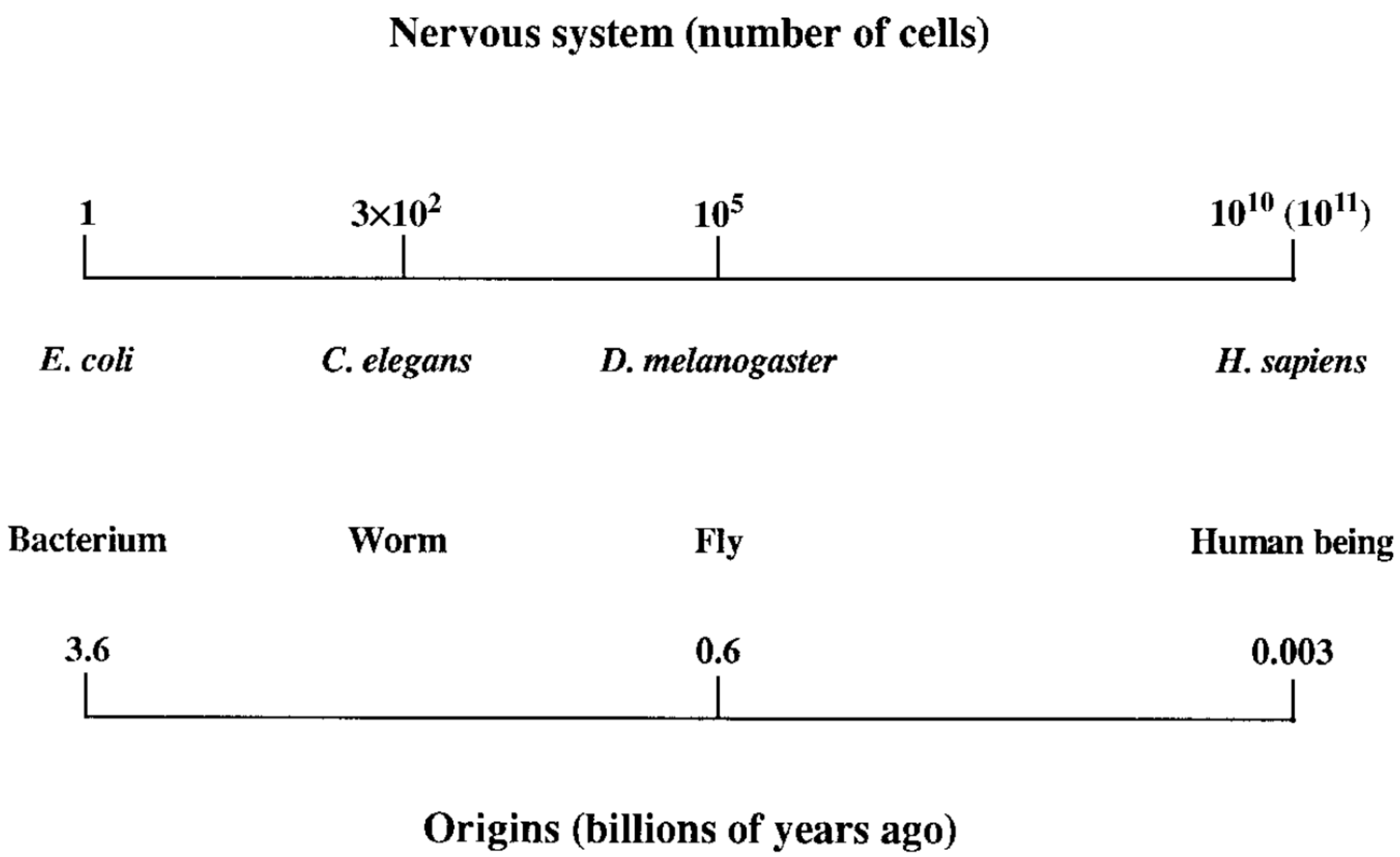
- An *e. coli's* world
- The motility of *e. coli*
- The simple behavior of *e. coli*

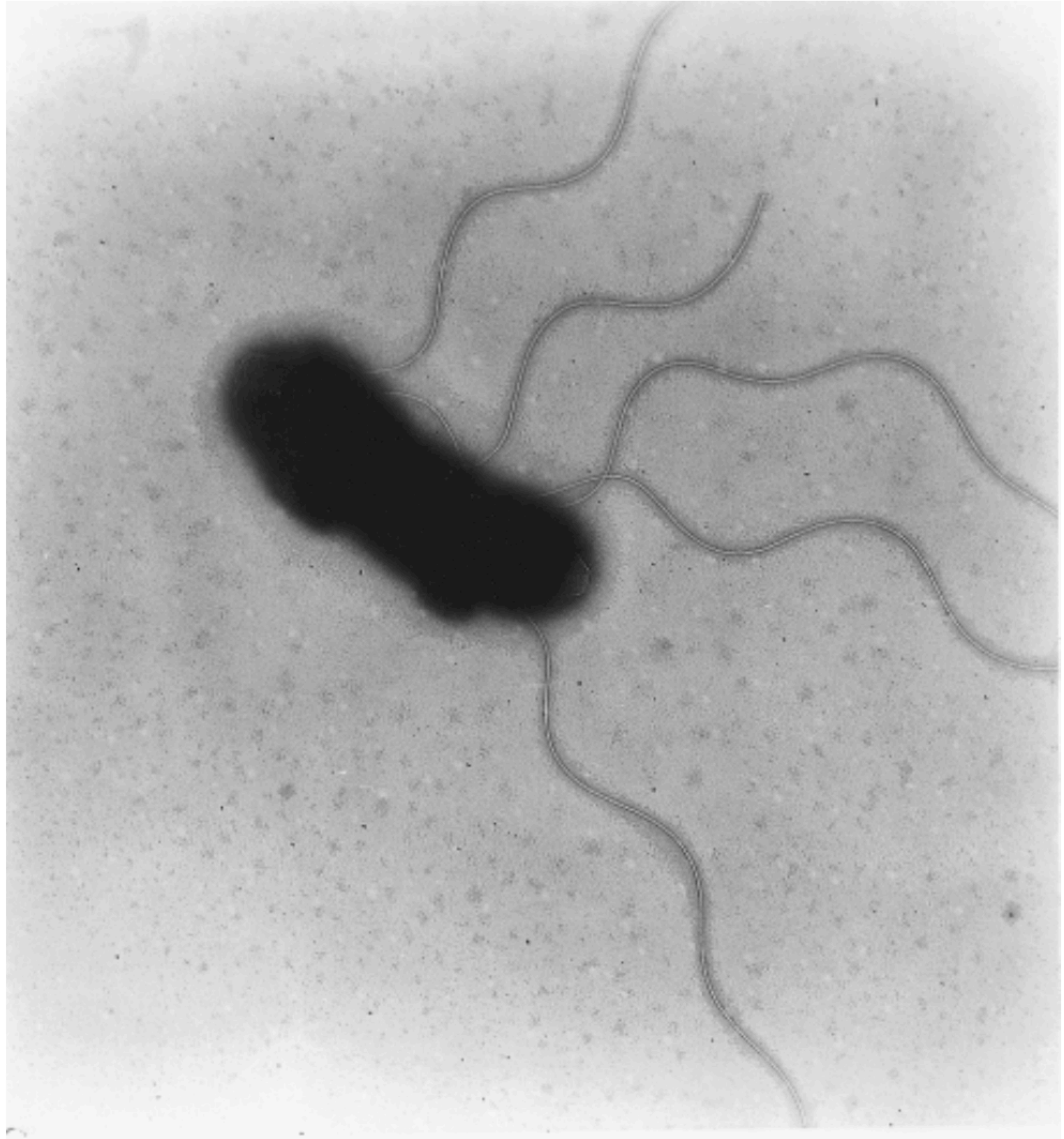
An e. coli’s world

The e. coli bacteria

Escherichia coli (E. coli)

- A rod-shaped bacteria commonly found in the intestines of humans and other animals.
- Most strains are harmless and a normal part of the gut flora

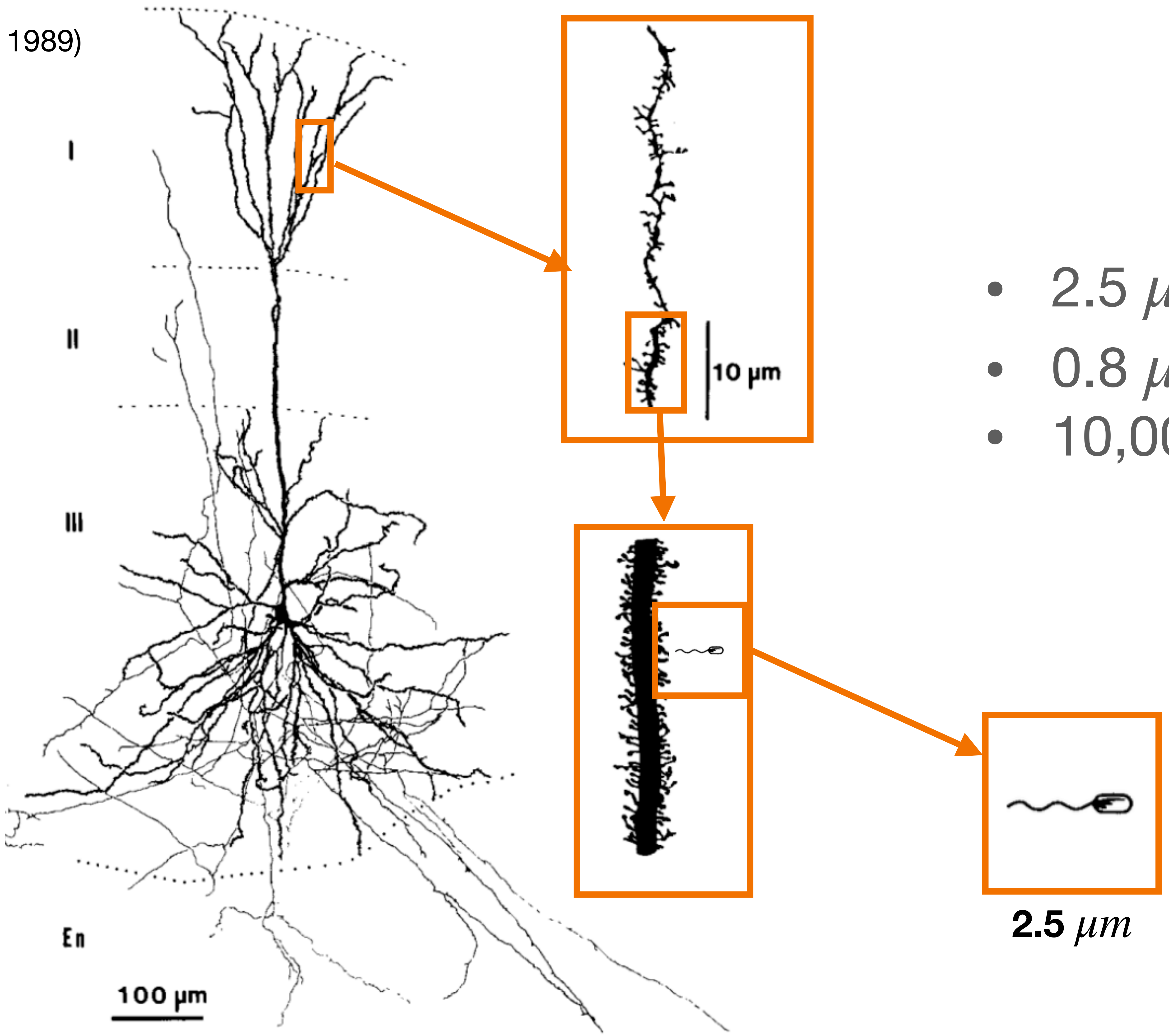




(Adler 1965)

E. coli are very very small

(Tseng & Haberli, 1989)



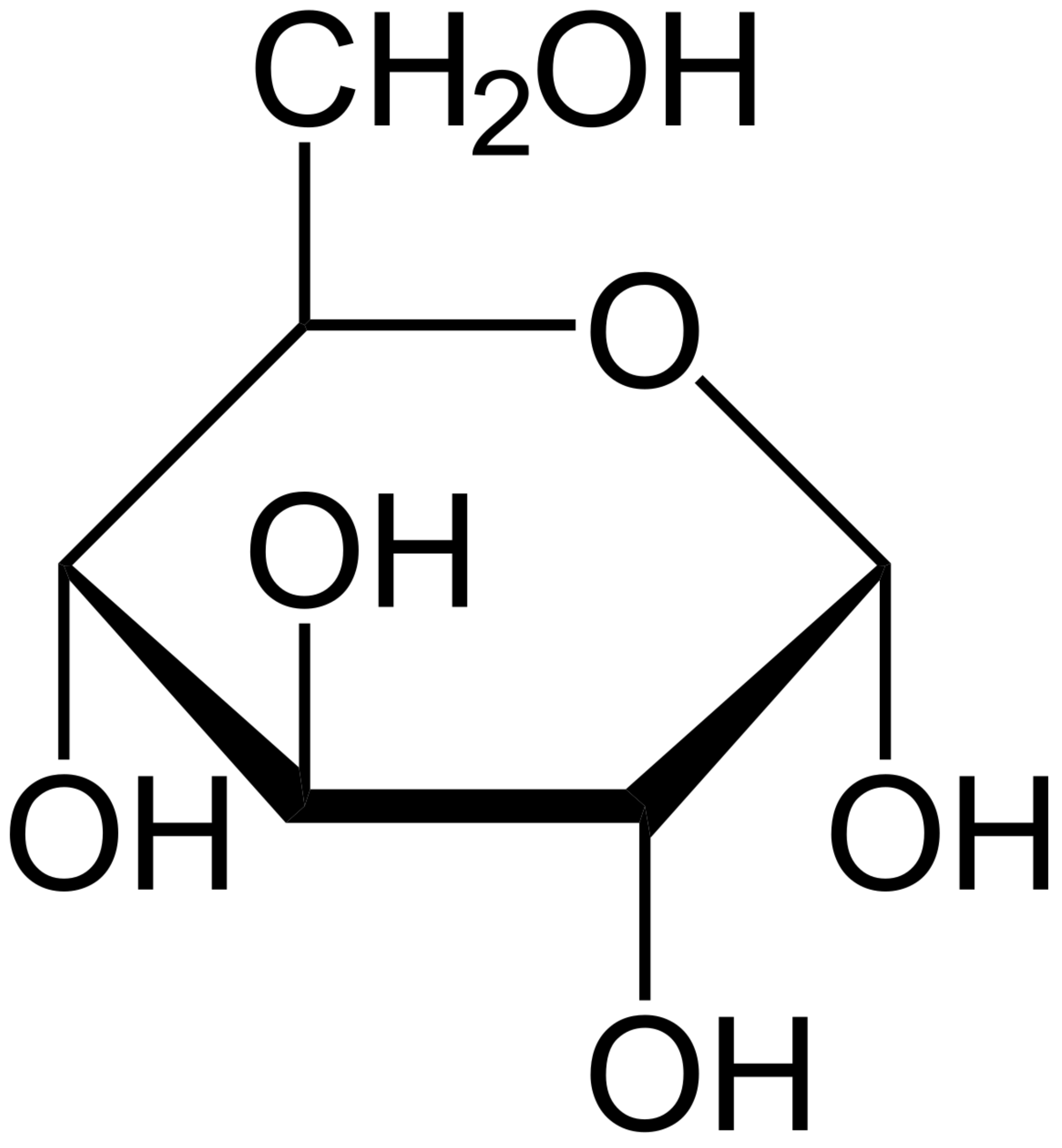
2.5 μm

- 2.5 μm in length
- 0.8 μm in diameter
- 10,000 end-to-end span 1 inch

Food sources

- **Sugars**: *E. coli* primarily consumes glucose, a simple sugar, as its main source of carbon and energy. Other sugars can also be consumed.
- **Amino acids**: *E. coli* can use certain amino acids as both carbon and nitrogen sources.
- **Organic acids**: *E. coli* can sometimes metabolize organic acids, such as acetate, succinate, and lactate, as alternative carbon sources.

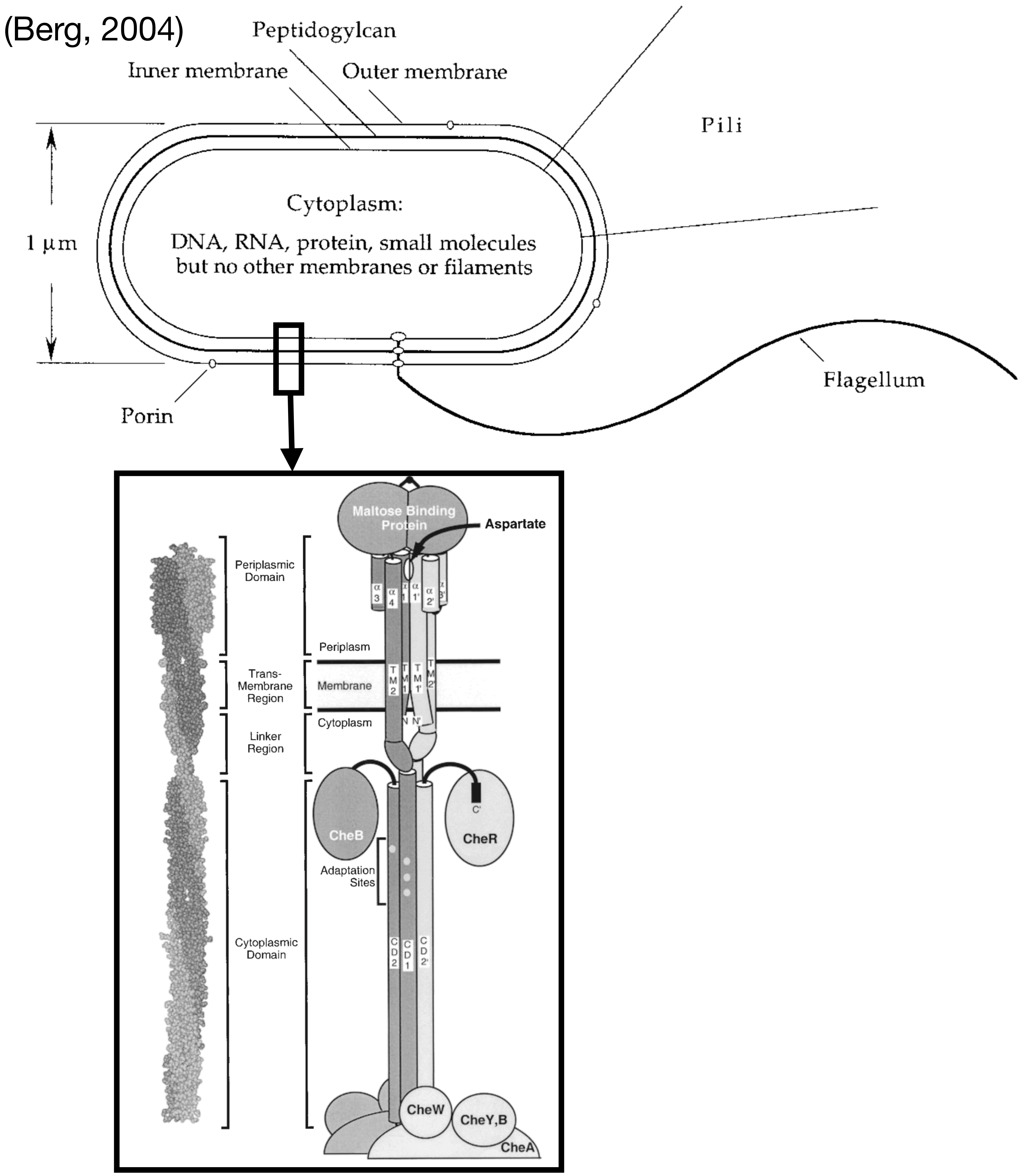
Glucose

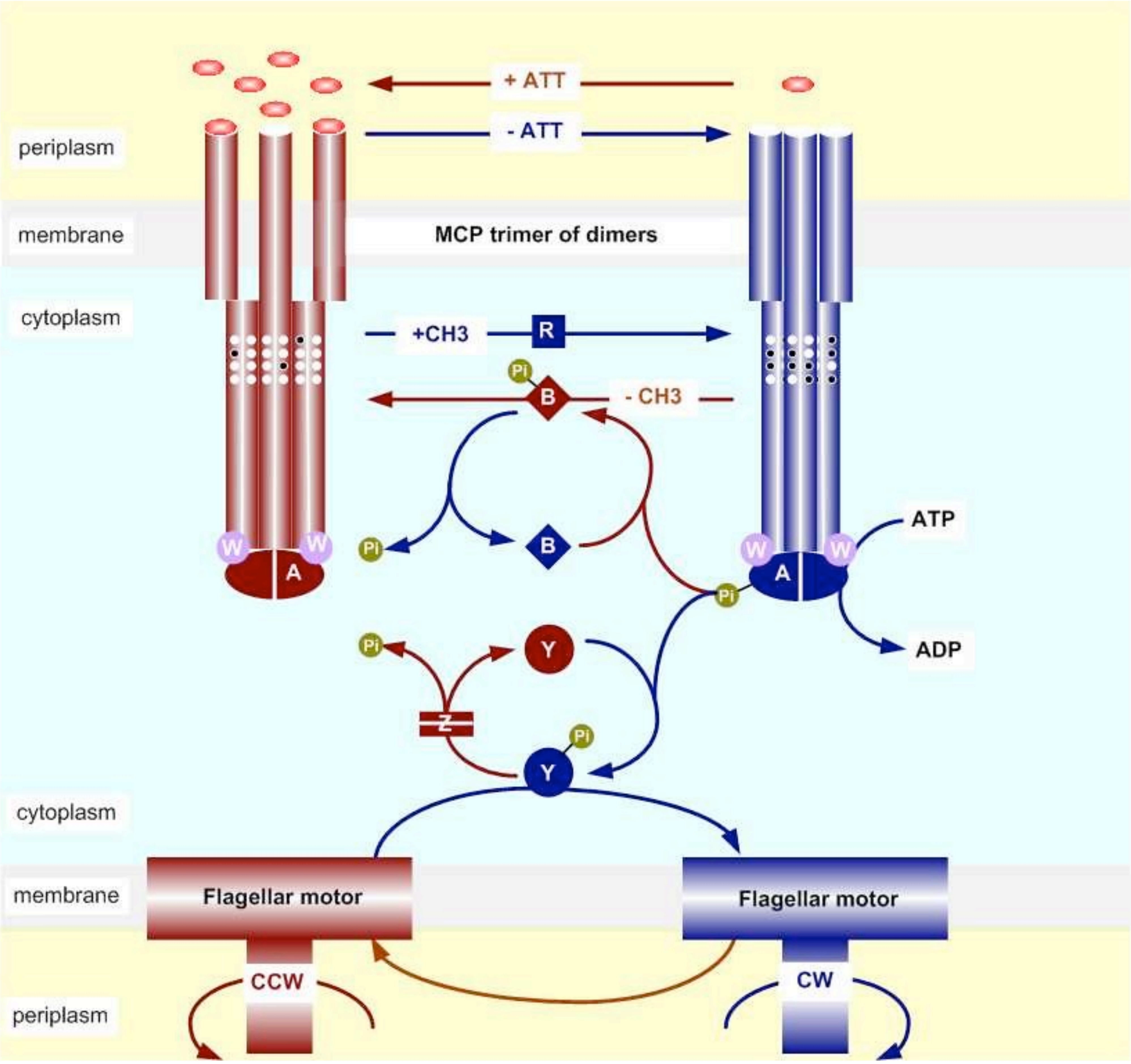


https://en.wikipedia.org/wiki/Glucose

E. coli anatomy

(Berg, 2004)





(Othmer et al., 2013)

Life at low Reynold's number

Reynolds number, R

ν : velocity

l : size

ρ : density of medium

$$R = \frac{l\nu\rho}{\eta}$$

← **inertial forces**

← **viscous forces**

η : viscosity of medium

Human (in pool):

$R = 10^5$ (100,000)

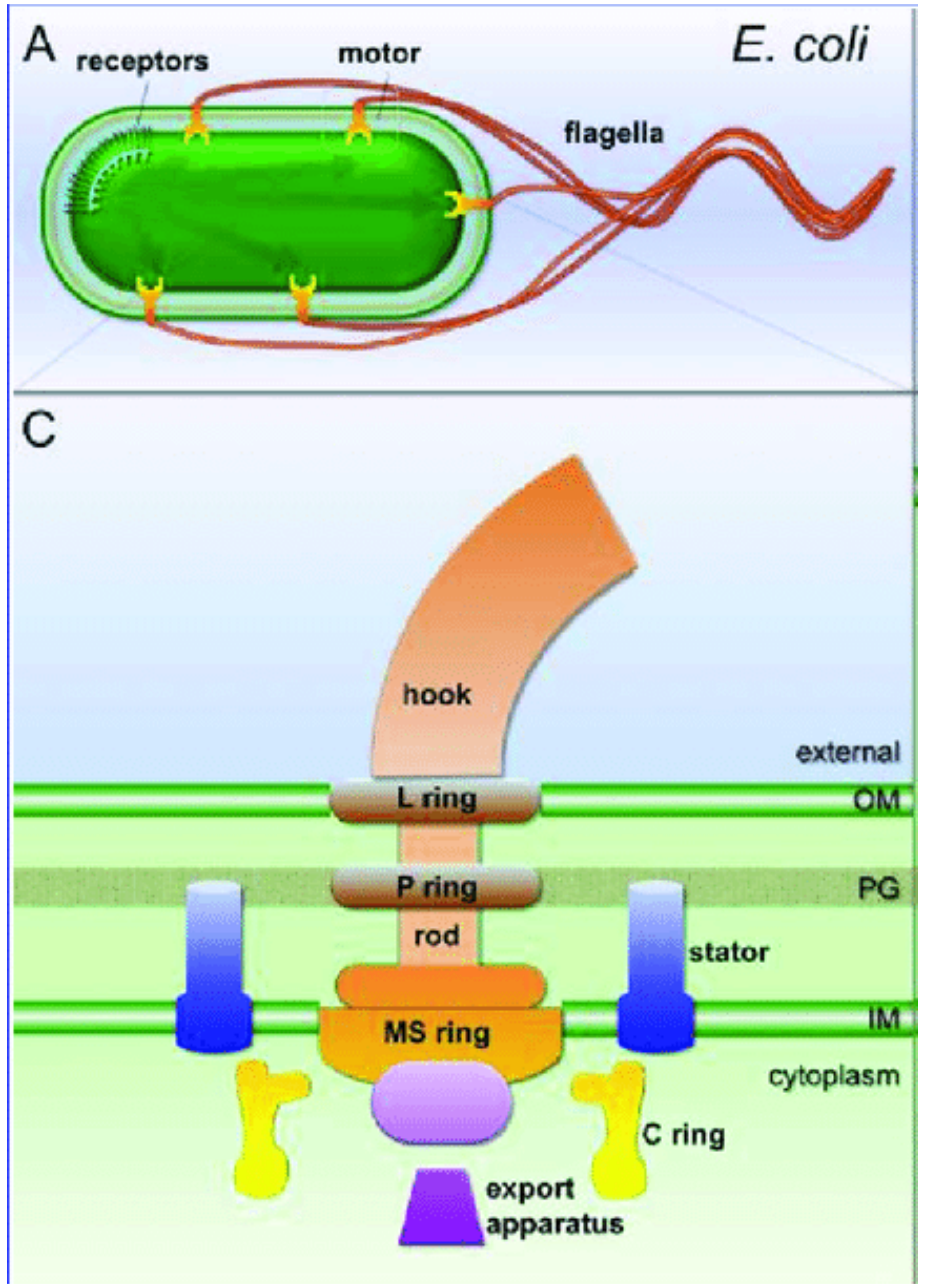
E. coli (in water):

$R = 10^{-5}$ (1/100,000)

"Suppose, for example, that you are immersed in a swimming pool full of molasses and are allowed to move parts of your body no faster than the hands of a clock? According to Purcell, 'If under those ground rules you are able to move a few meters in a couple of weeks, you may qualify as a low Reynolds number swimmer.'" - Berg, 2004

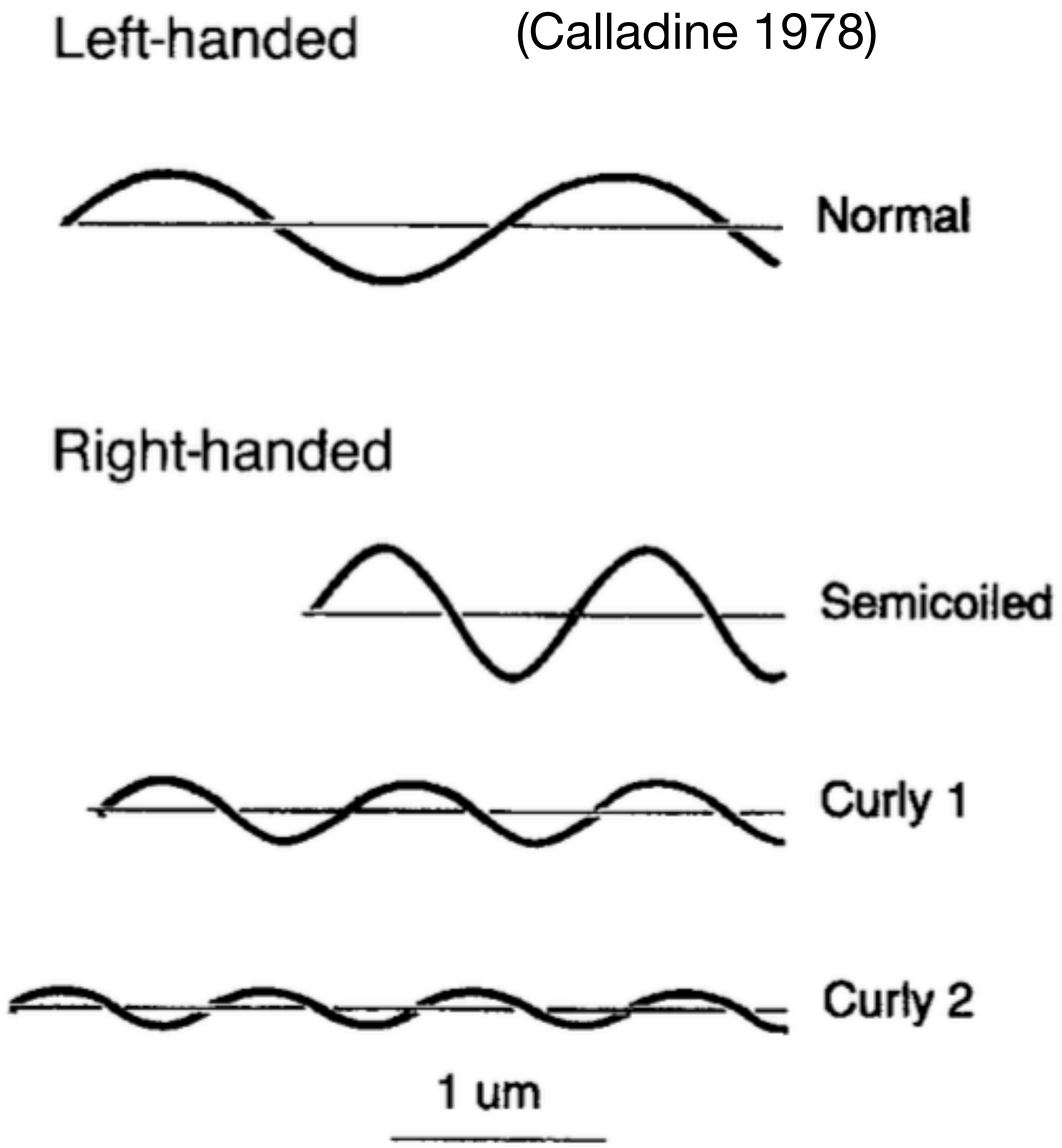
The motility of *e. coli*

Moving in high vicious environments



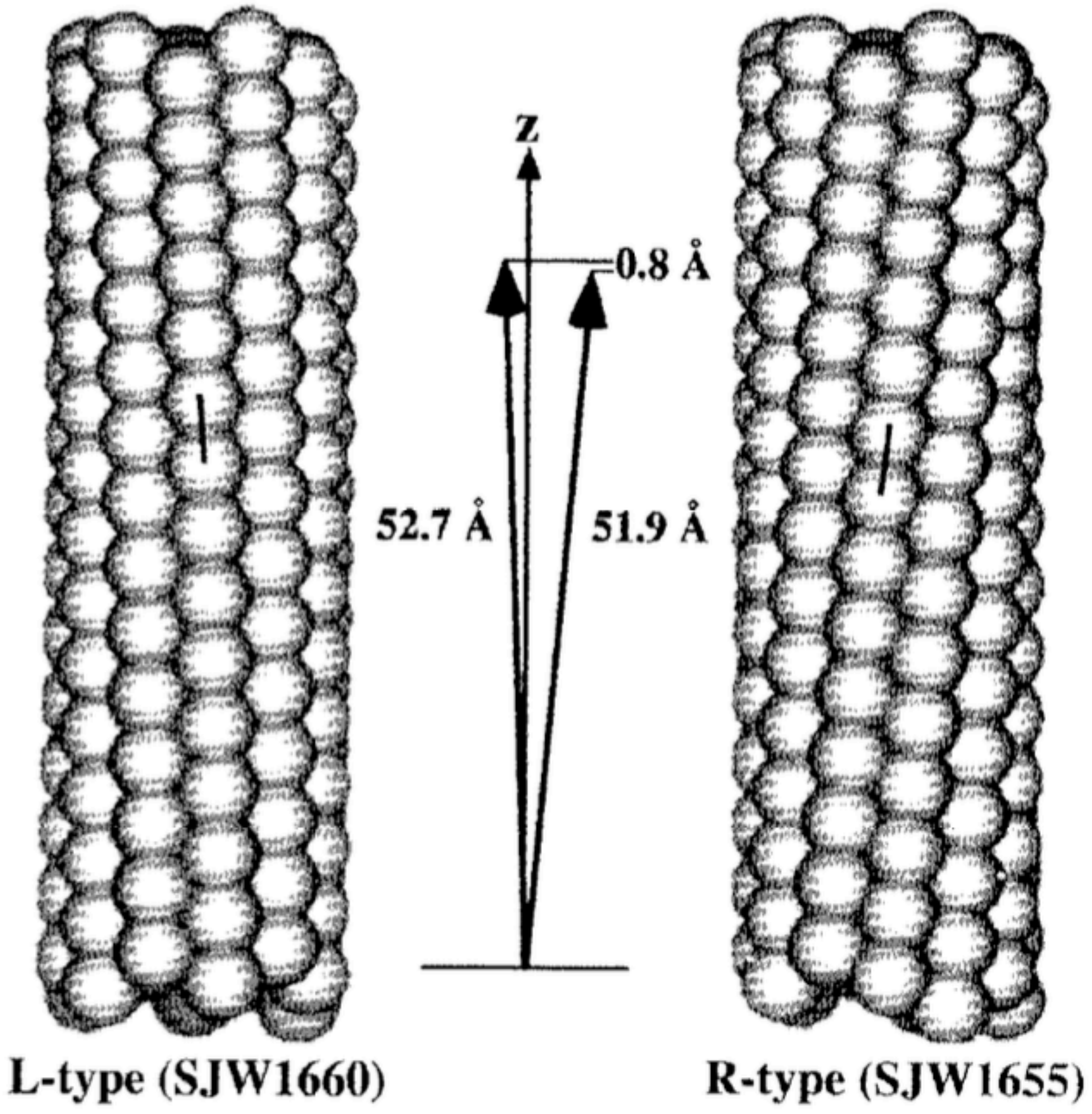
(Zhao et al., 2014)

Flagellar waveforms



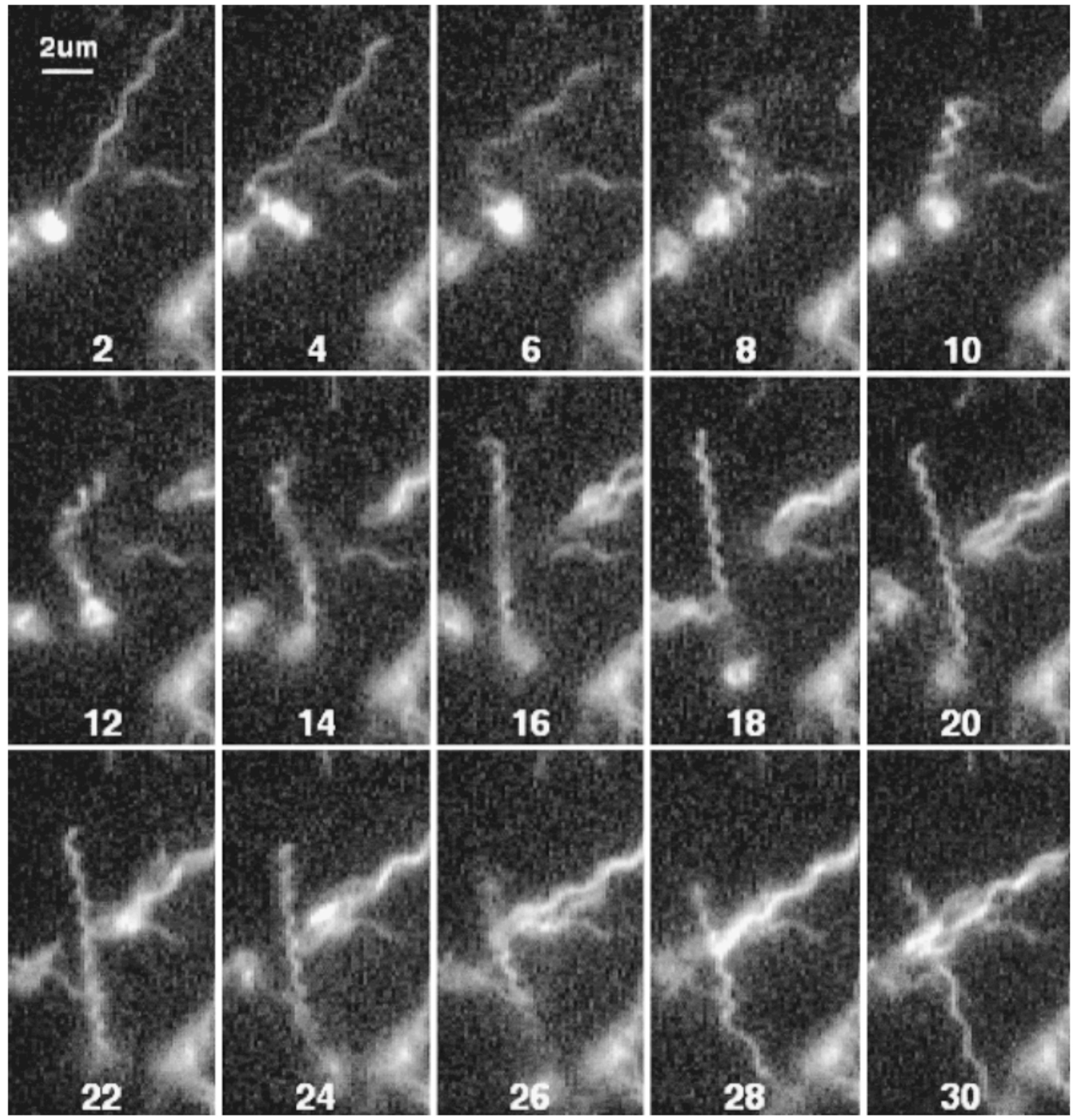
- 4-10 flagella per bacterium
- Whip-like, single-helix structures
- Distributed throughout the surface

Surface lattices of filaments



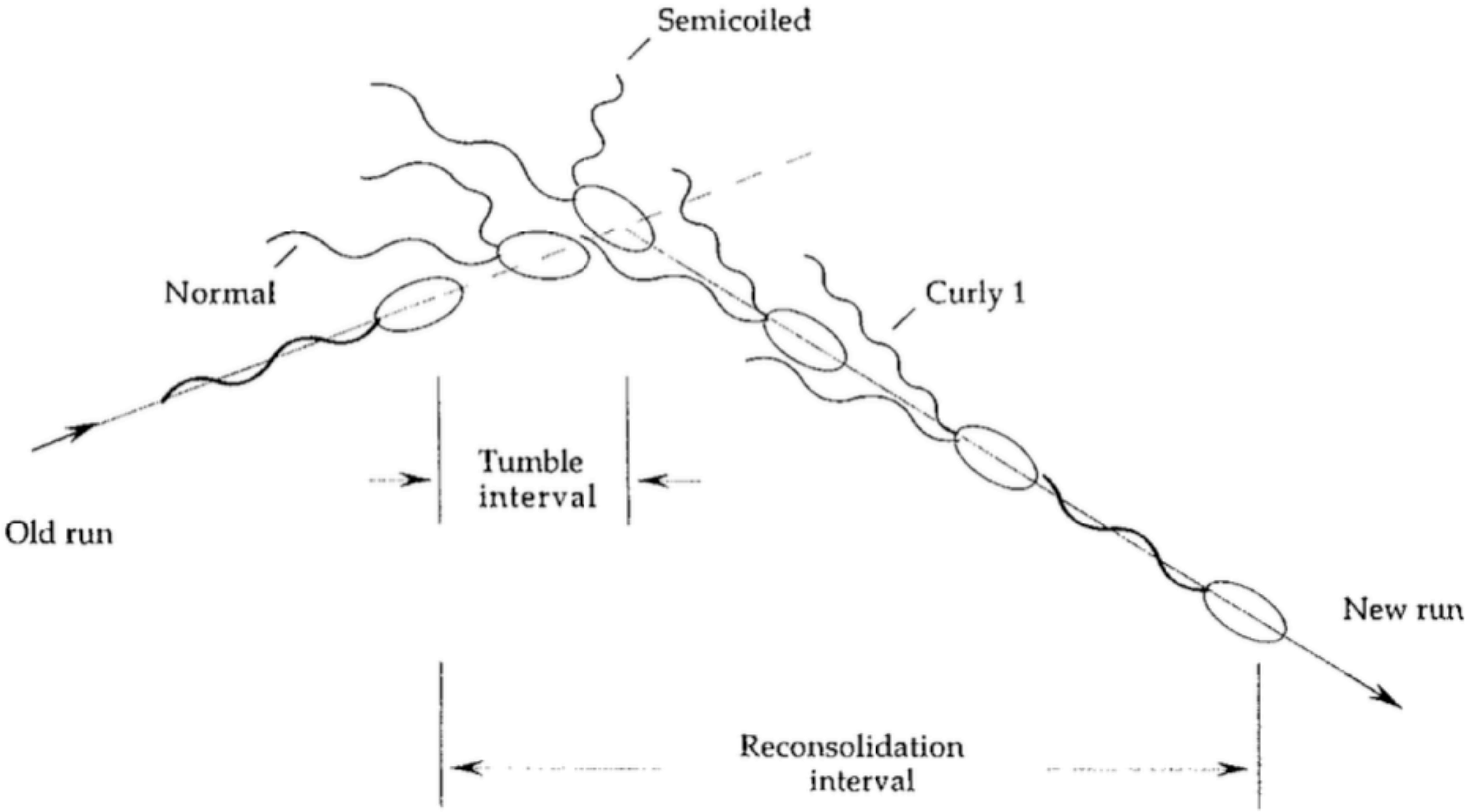
(Namba & Vonderviszt, 1997)

Runs and tumbles



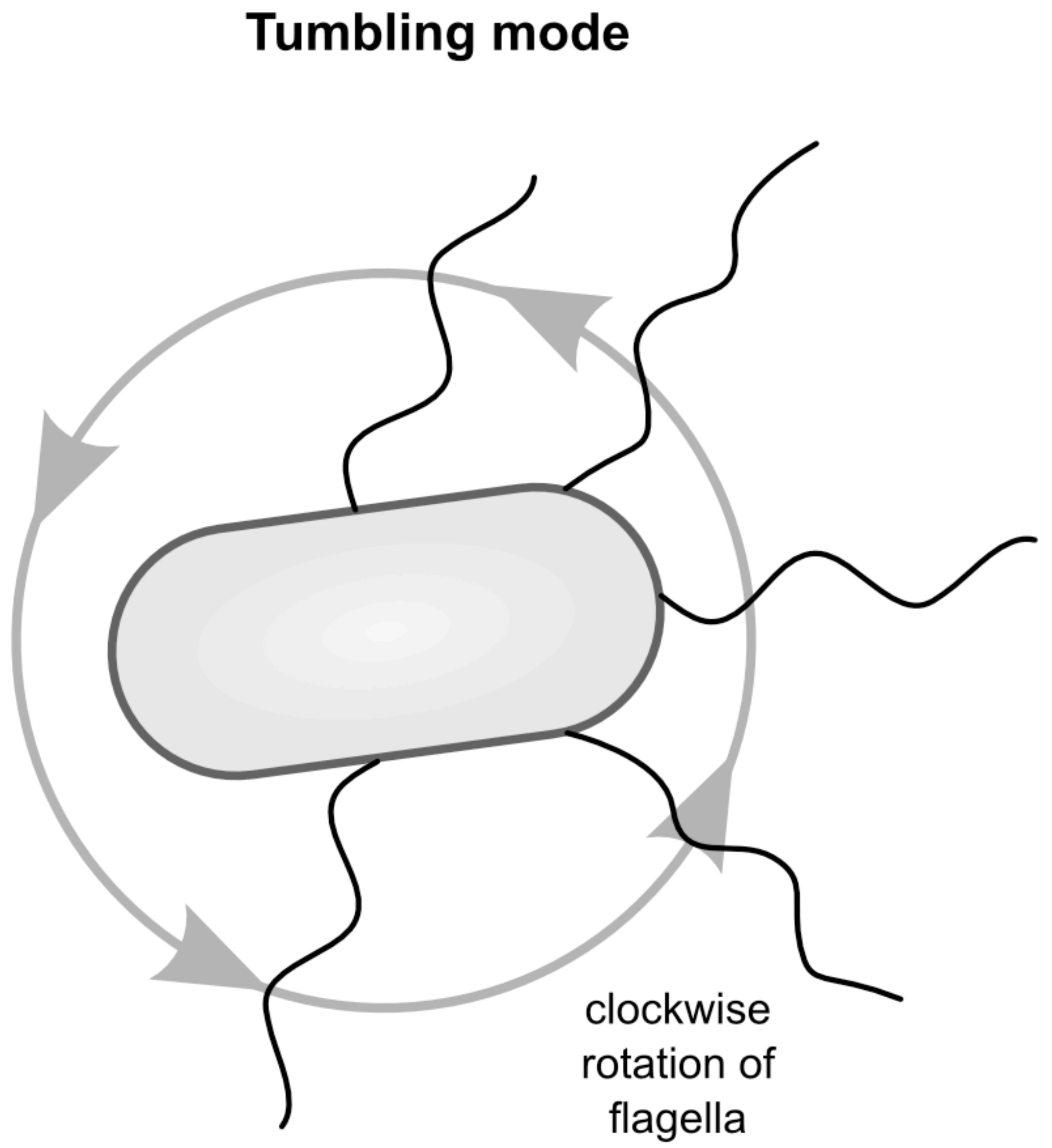
(Tuner et al. 2000)

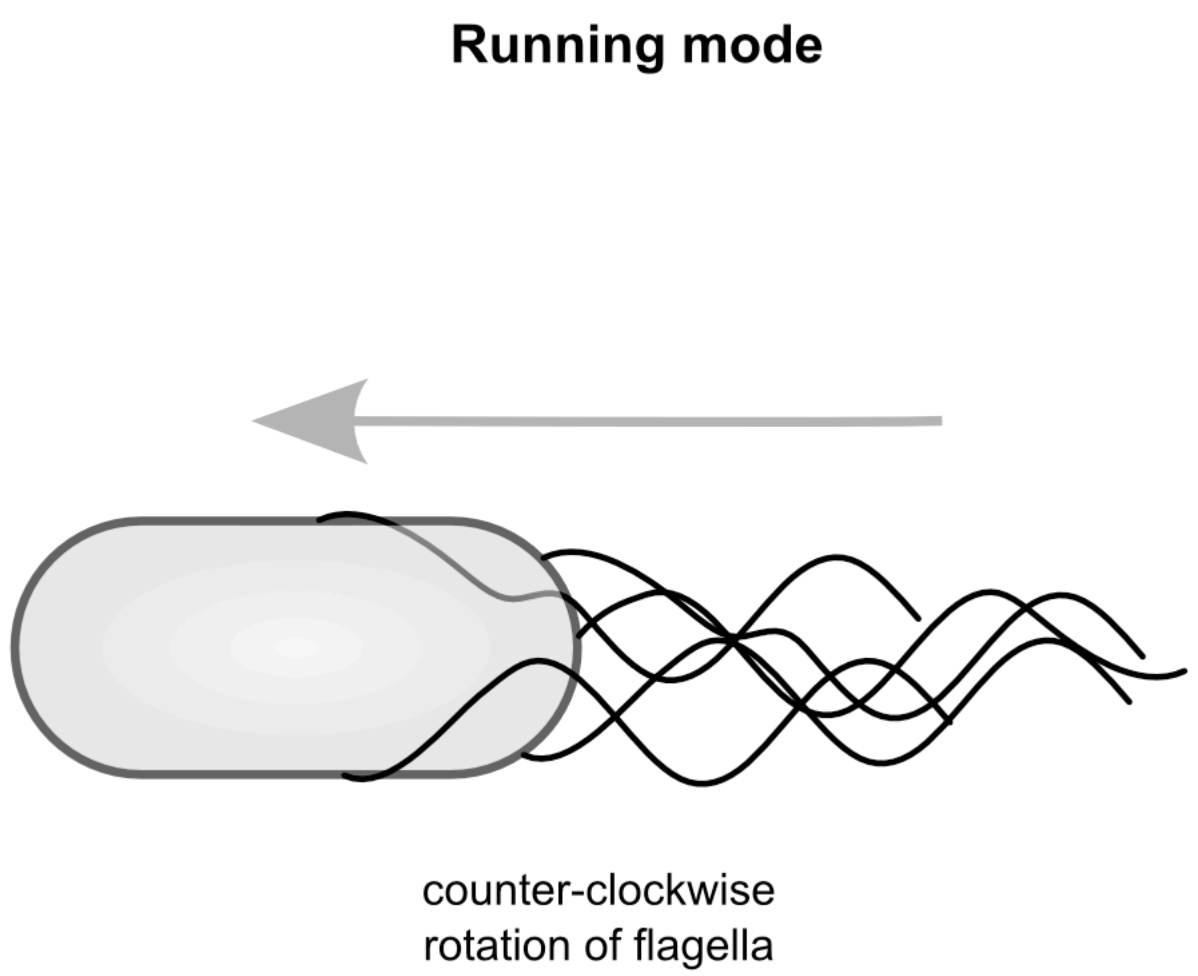
Counterclockwise (CCW): normal **Clockwise (CW)**: semicoiled

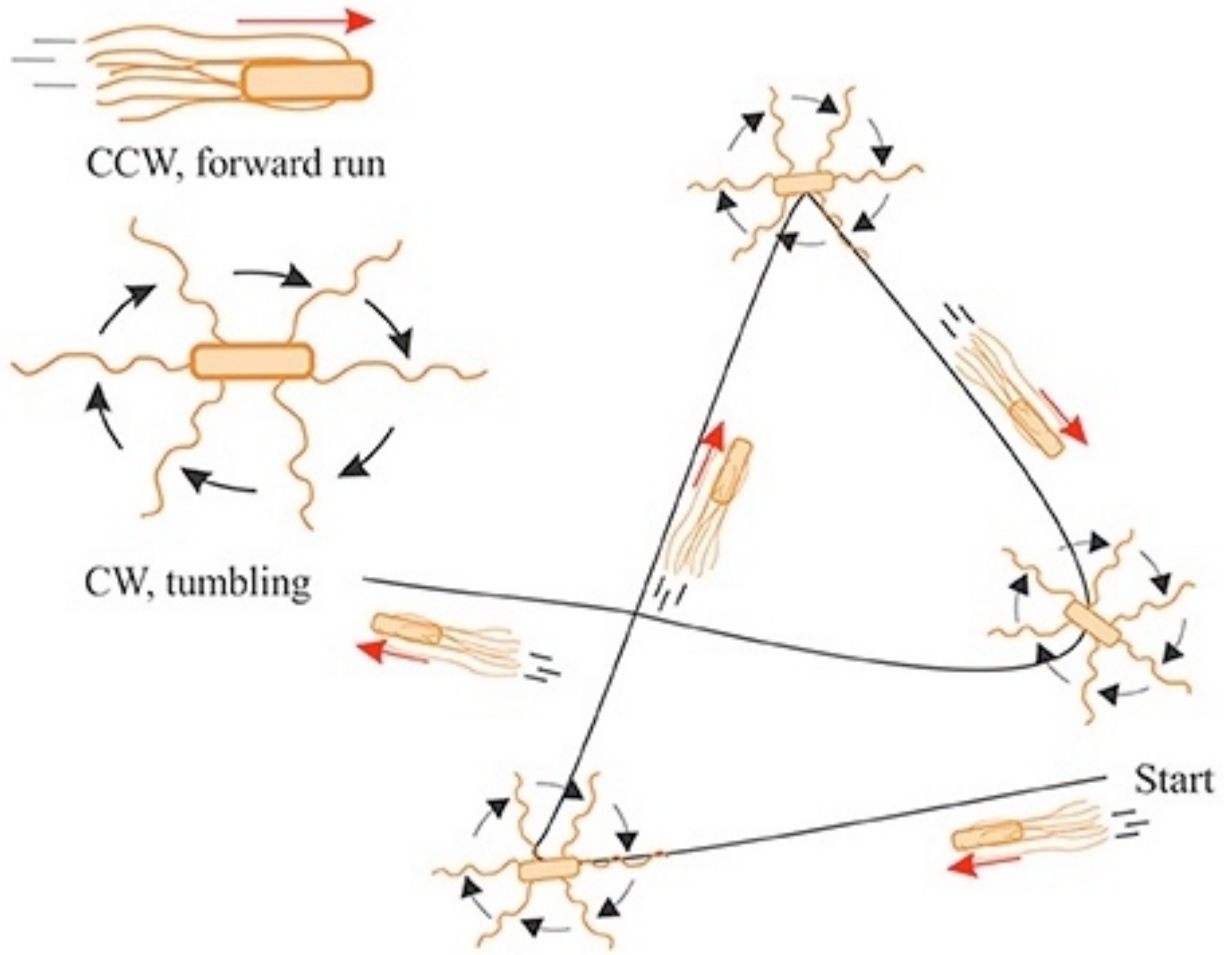


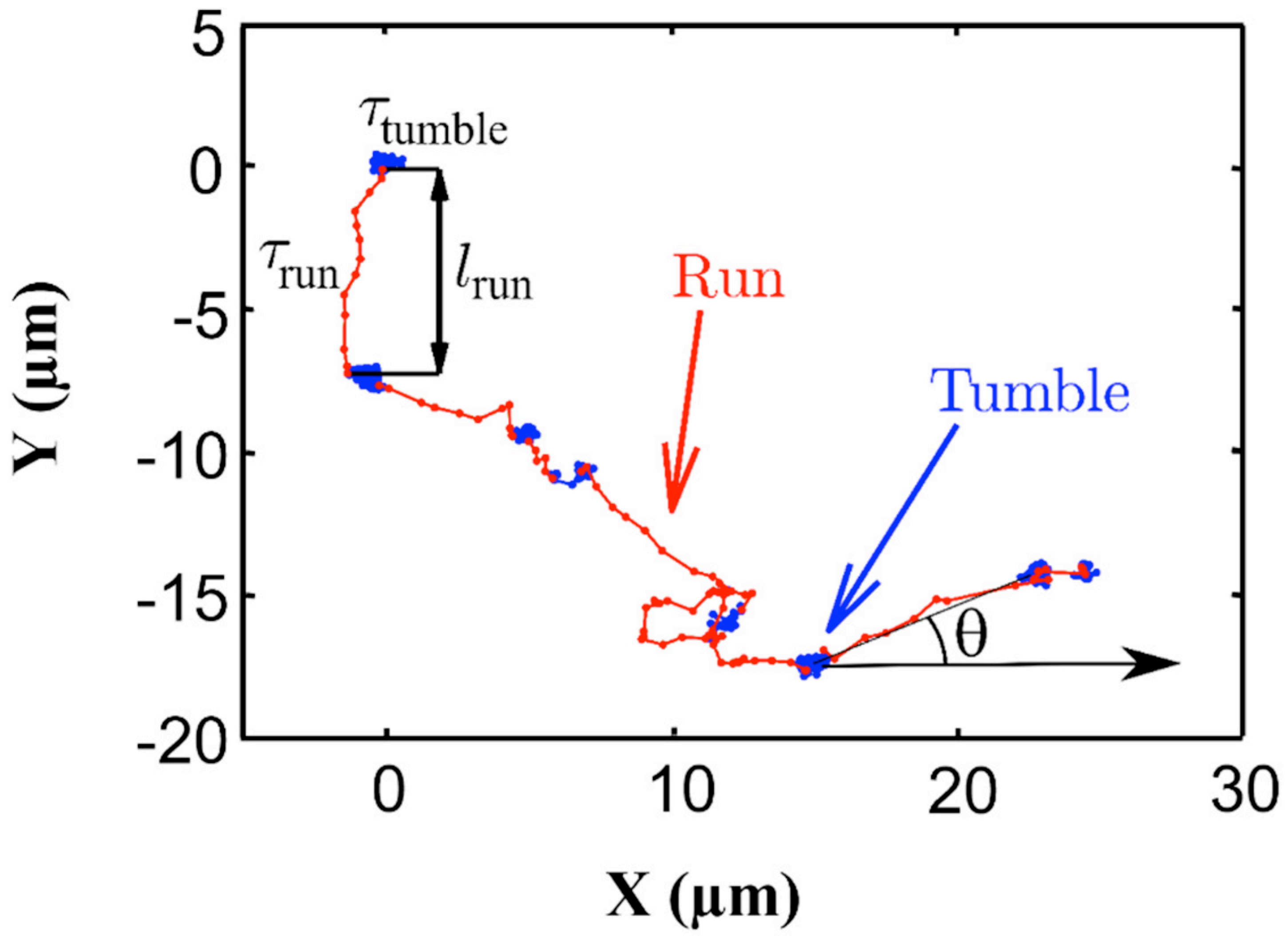
(Berg, 2004)

Runs and tumbles







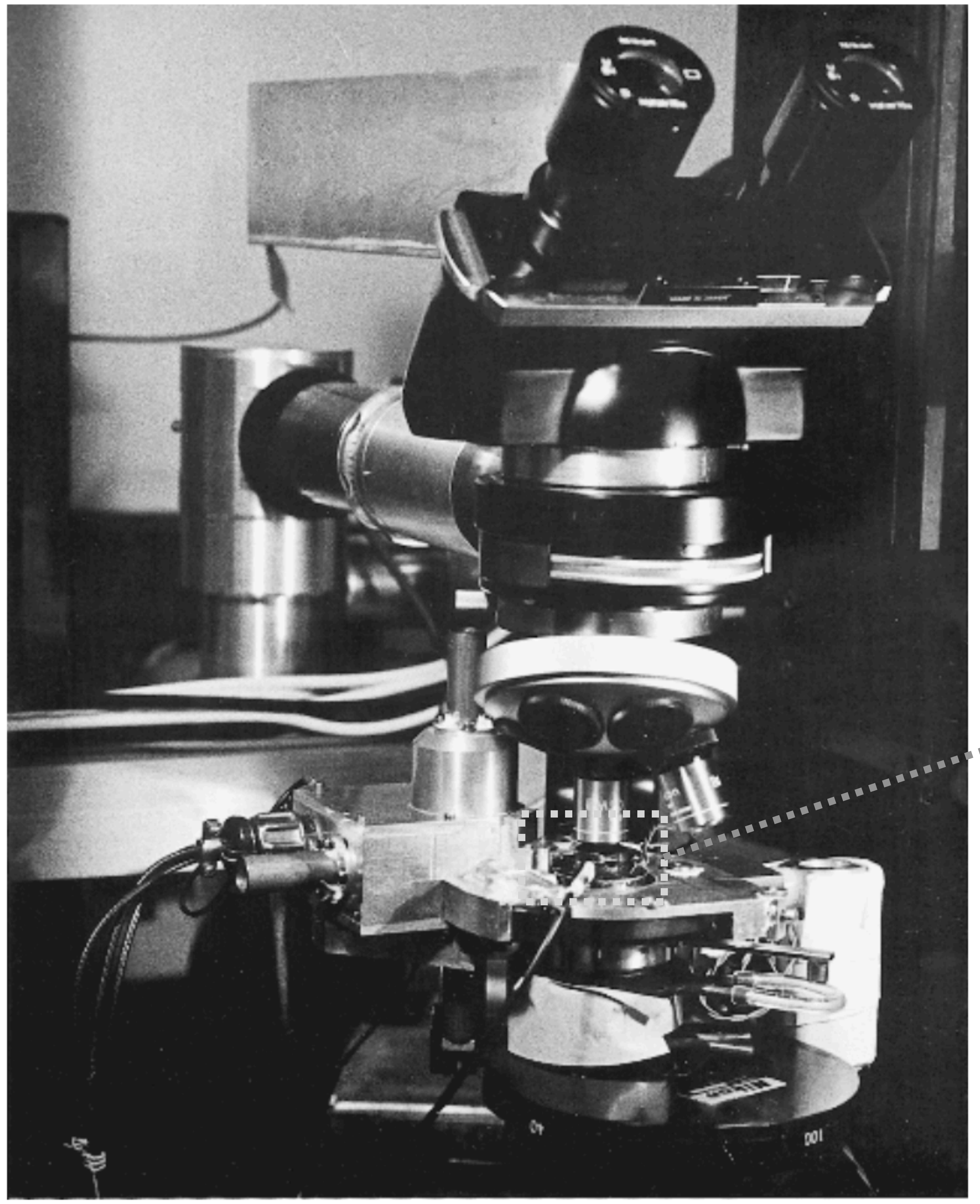


E. coli alternate between runs (CCW, coherent flagellar motion) and tumbles (CW, incoherent flagellar motion)

https://en.wikipedia.org/wiki/Run-and-tumble_motion

The simple behavior of e. *coli*

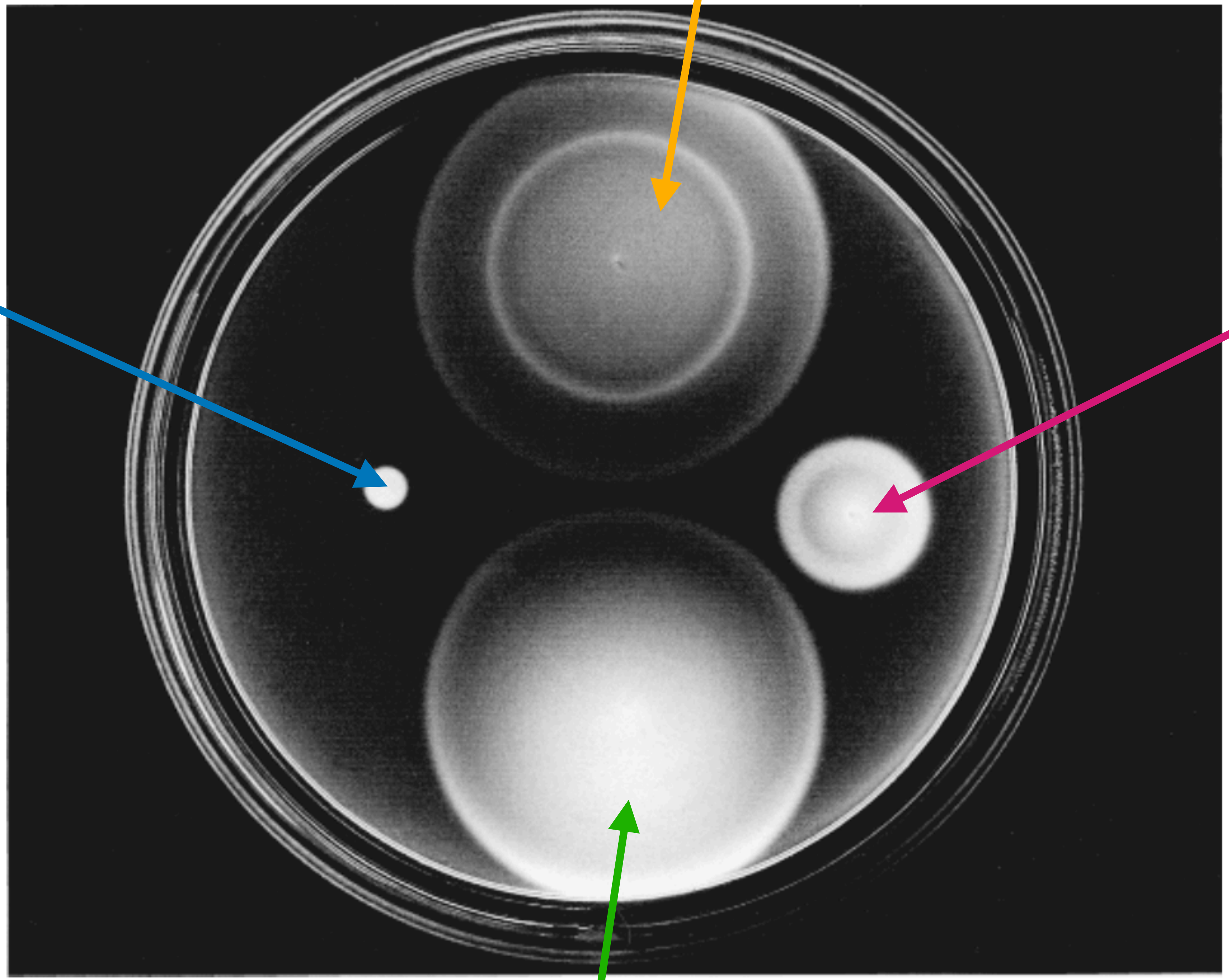
Directly measure movements



(Berg, 1978)

This allowed for characterizing the run and tumble style of movement of e. coli bacteria

Chemotactic rings

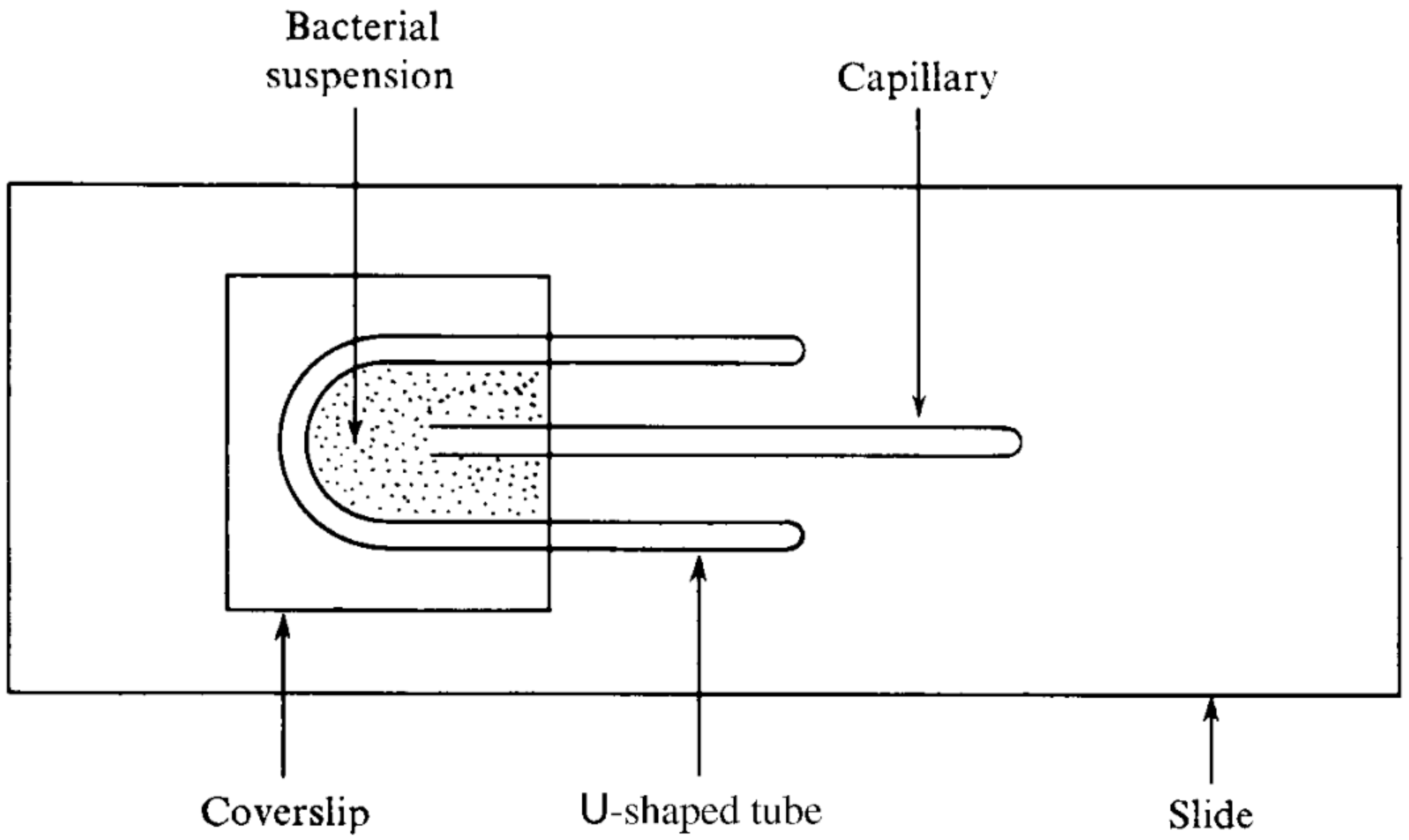


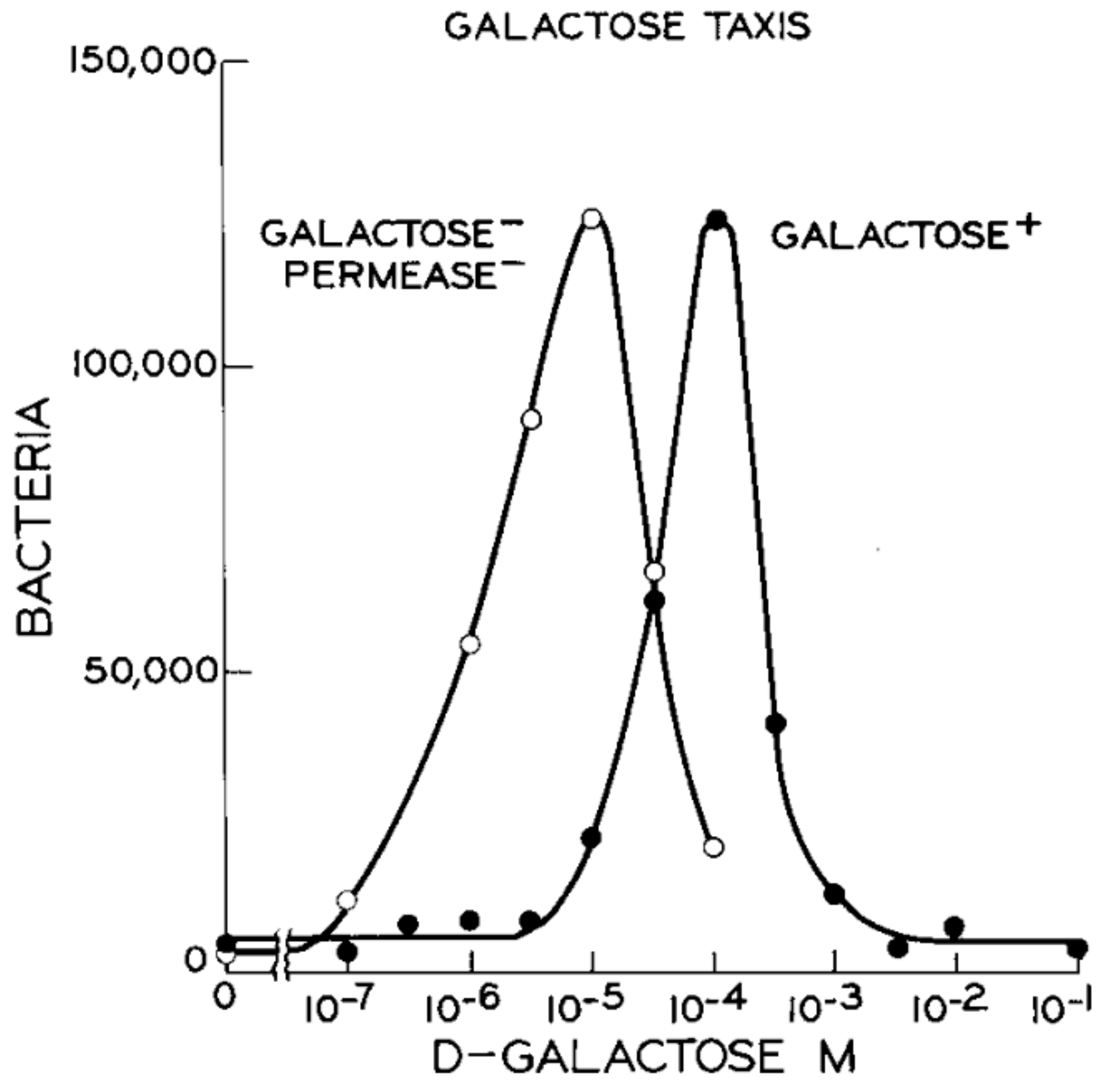
Chemotactic rings

visually observable “swarm rings” of bacterial cells as they move out from an origin point (drop) in the presence of an attractant

Adler capillary assays

Insert capillary filled with a specific substance and measure how many bacteria diffuse up the tube (or avoid it)





By counting concentrations of wild type and mutants who cannot process glucose, Adler (1987) found that bacteria move towards taste, not nutrients per se.

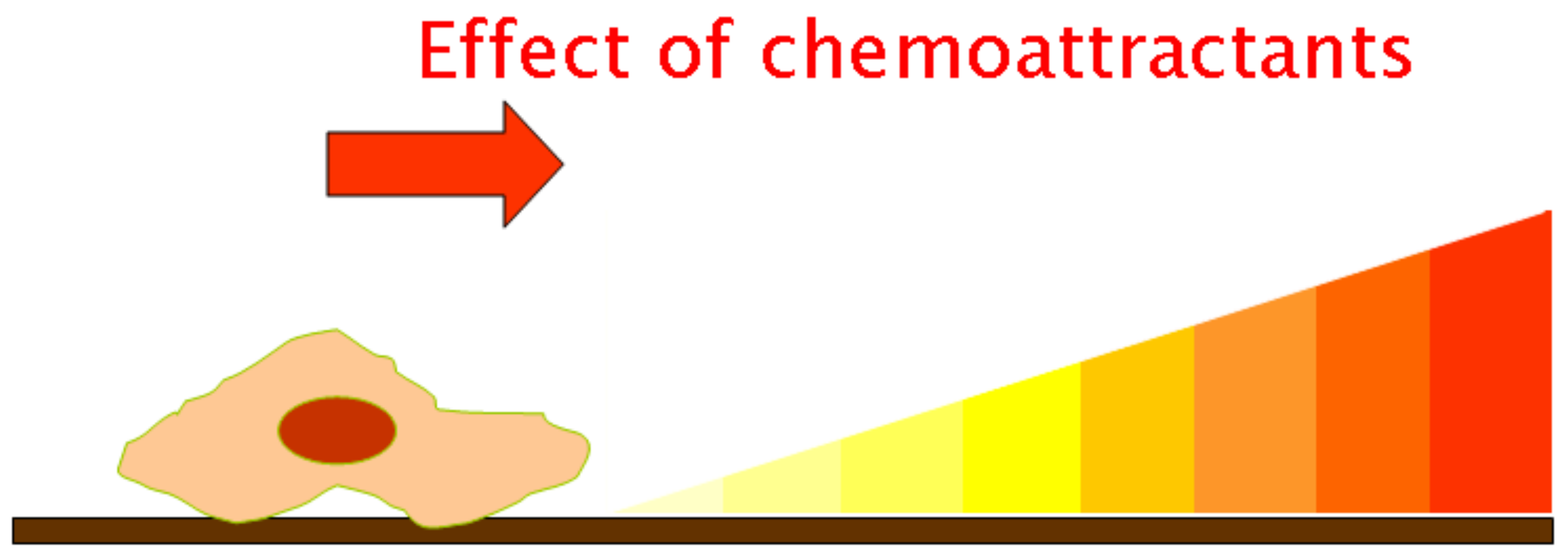
(Berg, 2004)

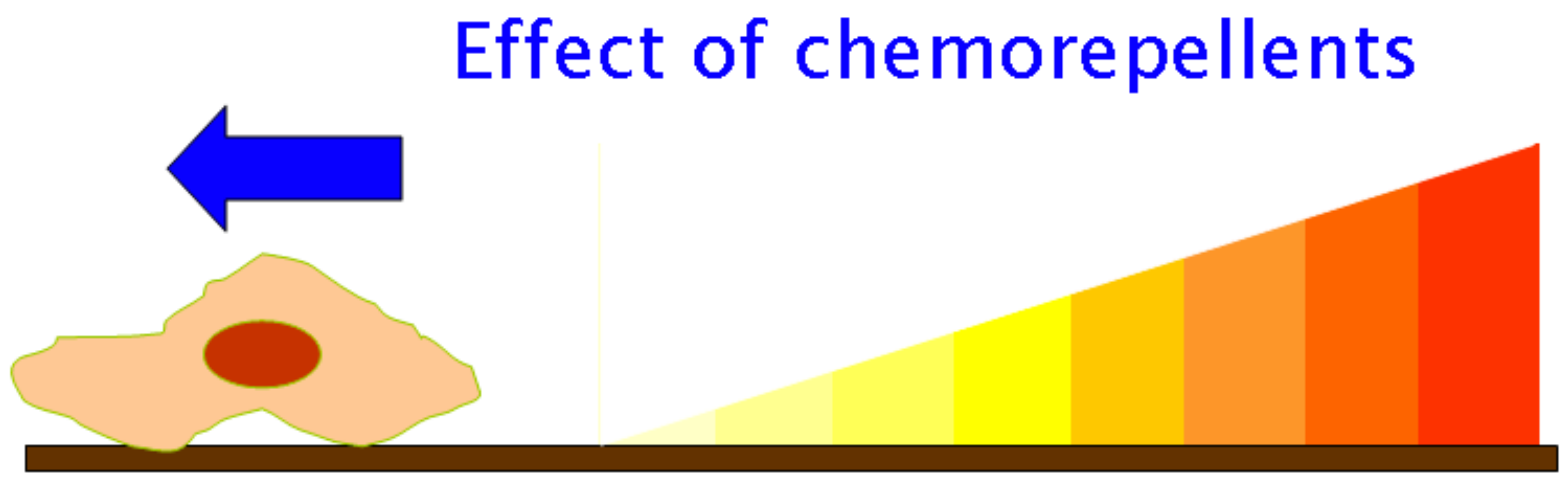
Attractors and repellants

Attractants
- Amino acids: e.g., aspartate, serine
- Dipeptides
- Electron acceptors: oxygen, nitrate, fumarate
- Membrane-permeant bases
- Salts at low concentrations
- Sugars and sugar alcohols: e.g., fructose, galacitol, galactose, glucitol, glucose, β-glucosides, maltose, mannitol, mannose, ribose, *N*-acetylglucosamine

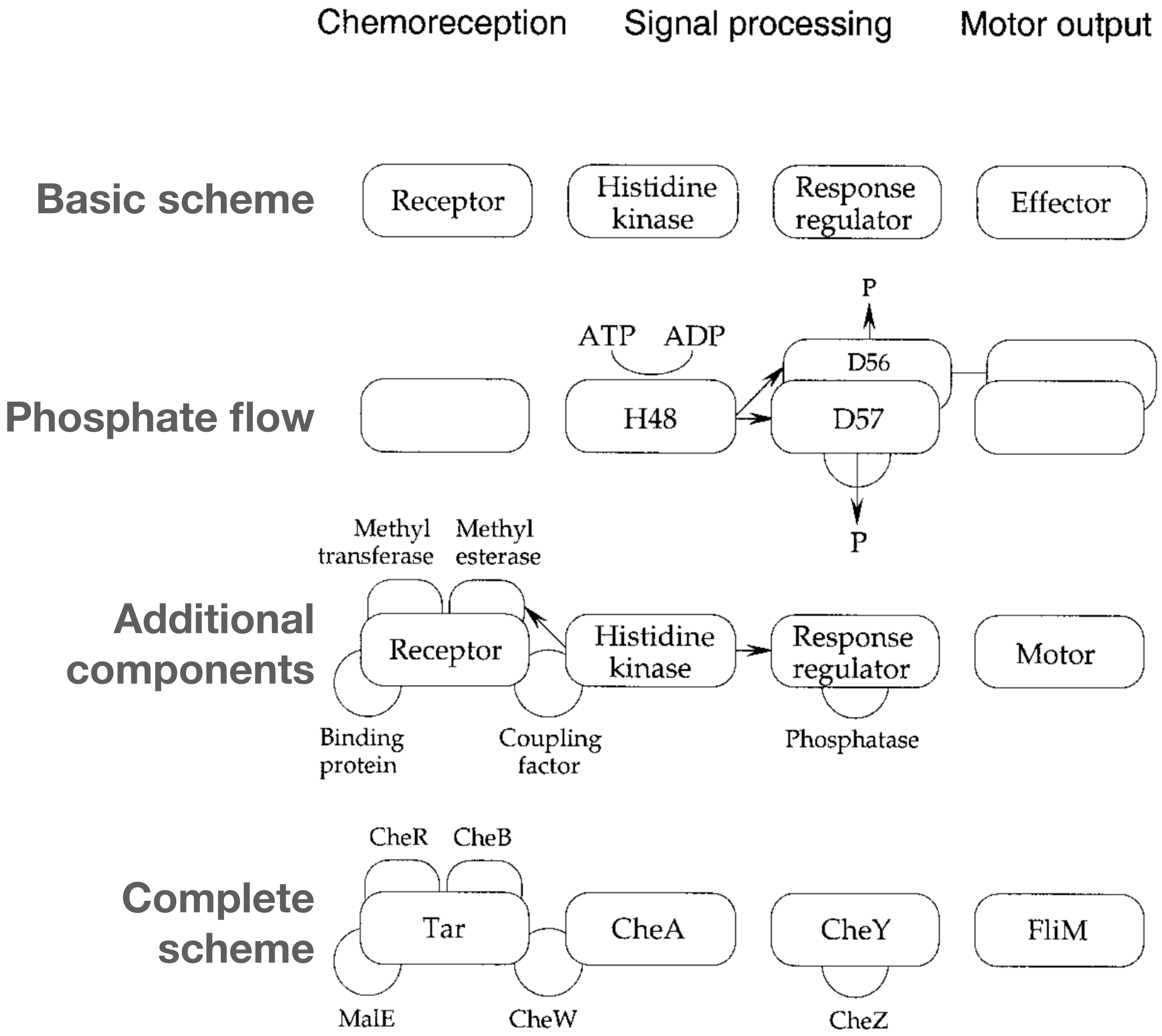
Repellents
- Alcohols: e.g., ethanol, isopropanol
- Amino acids: e.g., leucine, isoleucine, valine
- Chemicals at high osmotic strength
- Divalent cations: e.g., cobalt, nickel
- Glycerol or ethylene glycol at high concentrations
- Indole
- Membrane-permeant acids

(Berg, 1978)





From sensing to movements



The chemical sensing systems can “count” local chemical densities over short time intervals to estimate a gradient and regulate direction of flagellar motors

Take home message

- E. coli are surprisingly complex biological machines, despite their size.
- They need to constantly move to overcome vicious forces, adopting a run and tumble movement pattern.
- Chemoreceptors estimate local gradients of attractants or repellants and shift the turn of flagellar motor directions to regulate run vs. tumble frequencies.
- This quite effectively implements chemotaxis movements and simple search strategies.

Debate time!

Prompt: Given the simplicity of their behaviors & design, are e. coli a good model system for studying the mechanics of *chemotaxic* exploration?

Group A: Defend e. coli as a model

Group B: Reject e. coli as a model

Timeline:

	Thesis		Rebuttal		
Discuss →	Group A →	Group B →	Group B →	Group A →	Evaluate
15 min	5 min	5 min	5 min	5 min	