How does bacteria swim?

Studium Generale

Division of Biological Science,
Graduate School of Science,
Nagoya University
Seiji Kojima

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4. Part 2 / How does cells "smell" the chemicals?
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6. Summary / Conclusion

Vocabulary

bacteria

prokaryote

flagella

motor

chemotaxis

attractant

repellent

receptor

electron microscopy

purification

cryo-electron tomography

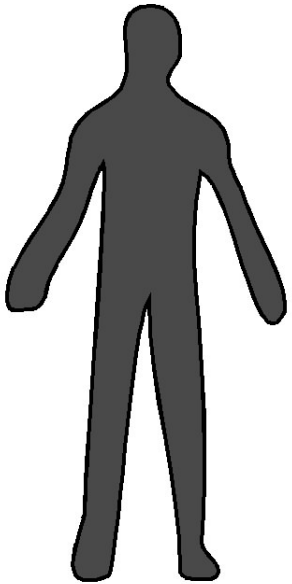
basal body

Take a minute to check the meaning!

Introduction: what is bacteria?

human

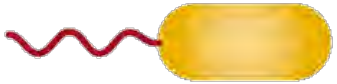
(m, meter)



size: 1/1,000,000

bacteria

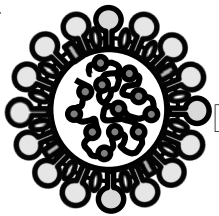
(μ m: 10^{-6} meter)



bacteria is very small, and unicellular organism

How do they swim?

size: 1/10



SARS-CoV-2

(100 nm: 10^{-7} meter)

Question 1

How can we see the bacteria? Can we see it by eye? or do we need to use microscope?

If you use microscope, then what kind?

Think about it for a minute!

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Bacteria is very small, and we cannot see by our naked eye. It is around the detection limit of light microscopy. If we use electron microscopy, we can see it clearly.

The structure of the bacterial cell

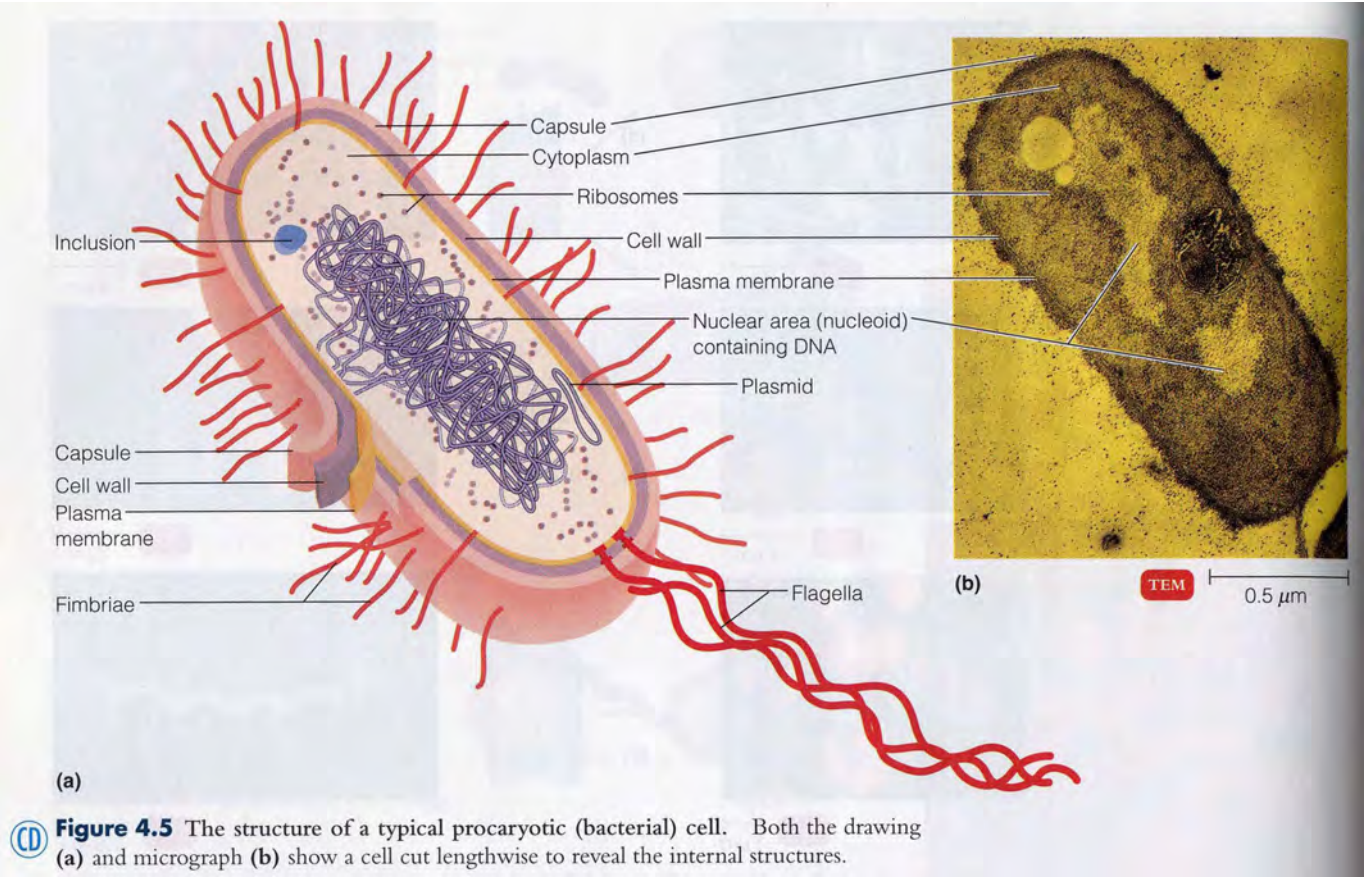


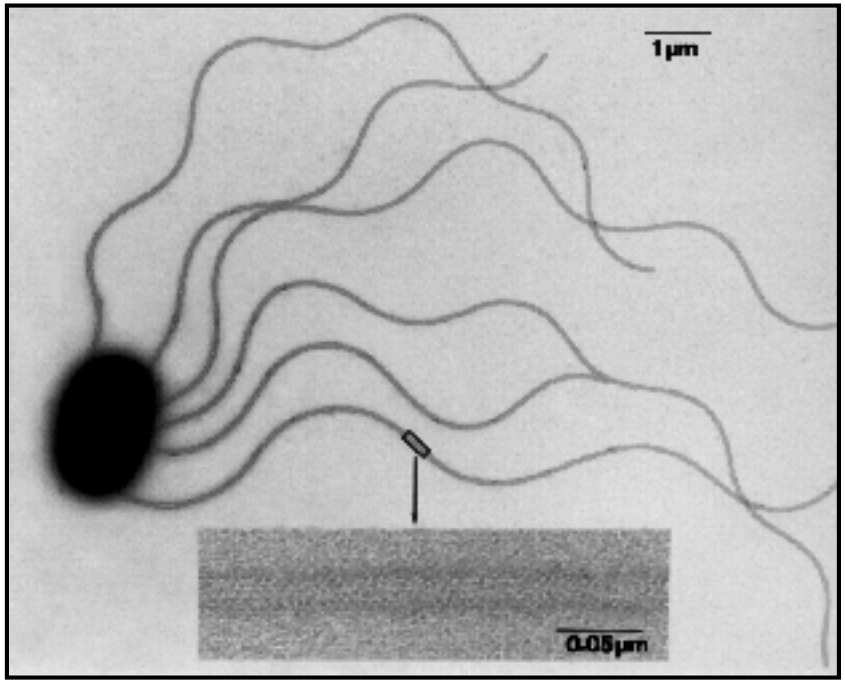
Figure 4.5 The structure of a typical procaryotic (bacterial) cell. Both the drawing **(a)** and micrograph **(b)** show a cell cut lengthwise to reveal the internal structures.

Tortora,Fukase,Case（2019）Microbiology（6th edition）

There is no nucleus in the bacterial cell. Chromosome DNA is exposed to cytoplasmic contents.

Electron microscopic picture of bacterial cell

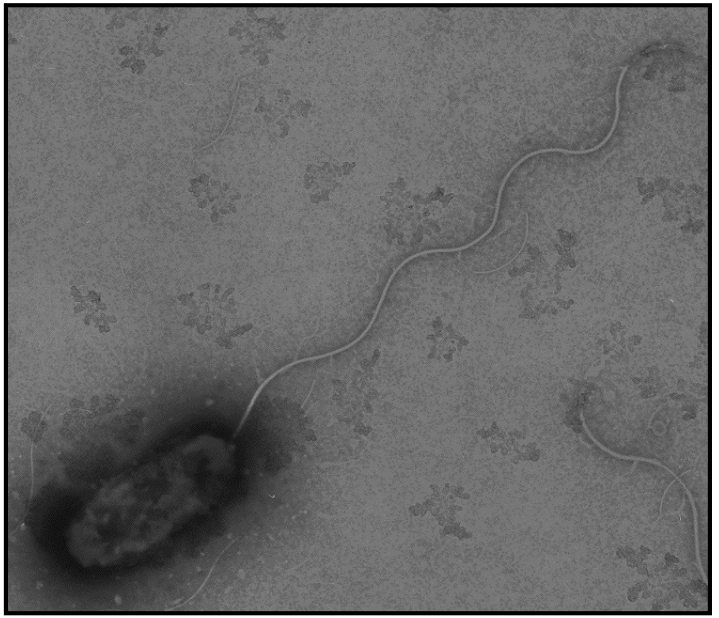
Salmonella typhimurium



Multiple flagella from a single cell

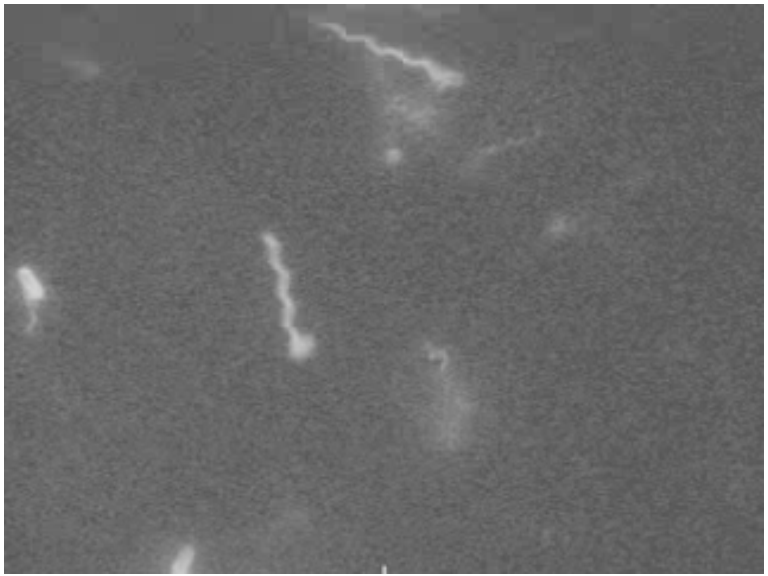
http://www.spring8.or.jp/ja/news_publications/publications/news/no_02/

Vibrio alginolyticus

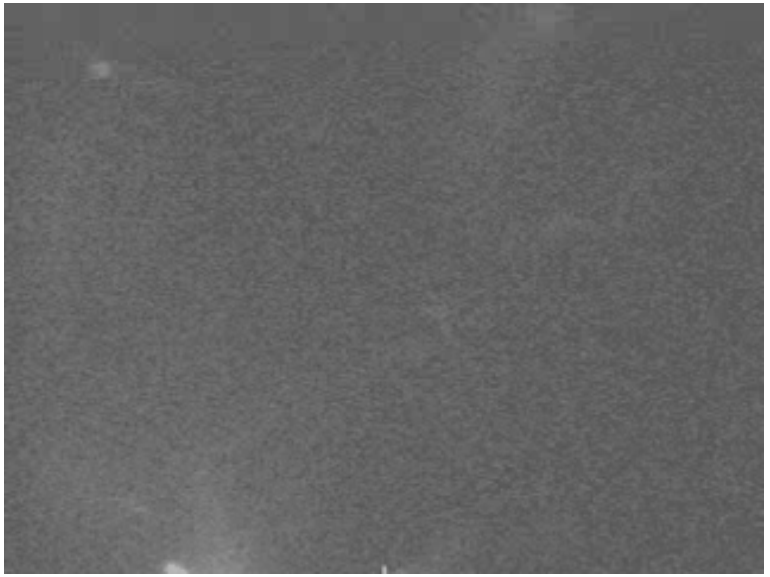


In a liquid environment, only possess a polar flagellum

Flagellar motility with fluorescent dye-stained filament



http://www.rowland.harvard.edu/labs/bacteria/movies/showmovie.php?mov=fluo_fil_leave



http://www.rowland.harvard.edu/labs/bacteria/movies/showmovie.php?mov=fluo_curly1

Pitch of the flagellar filament is changed

Laboratory of
Howard Berg
(Harvard University)

http://www.rowland.harvard.edu/labs/bacteria/people/hberg.php

Part 1: Flagella, the rotary motility organ of the cell

Question 2

OK, now you know that bacteria swim by using flagella, and there seems to exist rotary motor at its base. How do you prove "flagellar rotation"?

Think about it for a minute!

Flagellar rotation was proven by the very simple experiment published 1974!

Published: 03 May 1974

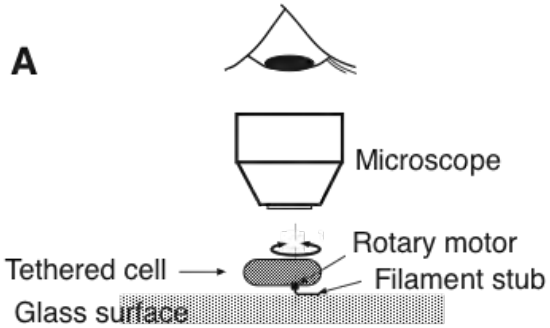
Flagellar rotation and the mechanism of bacterial motility

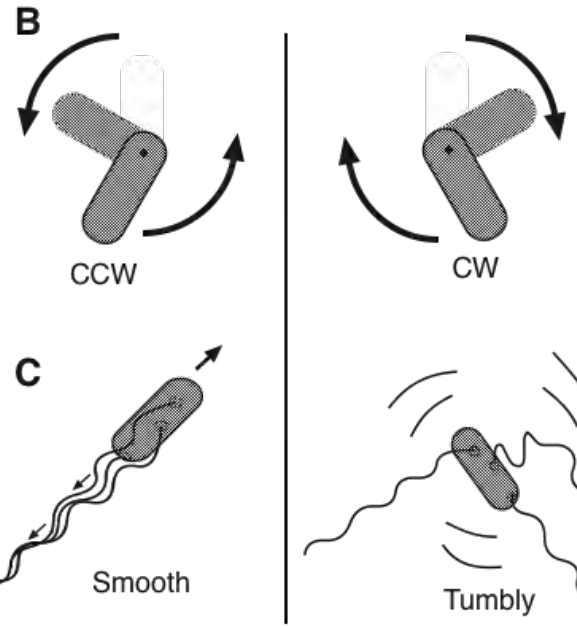
MICHAEL SILVERMAN & MELVIN SIMON

Nature **249**, 73–74(1974) | Cite this article

In department of Biological Science (School of Science), we do this experiment in the laboratory course in 3rd year student.

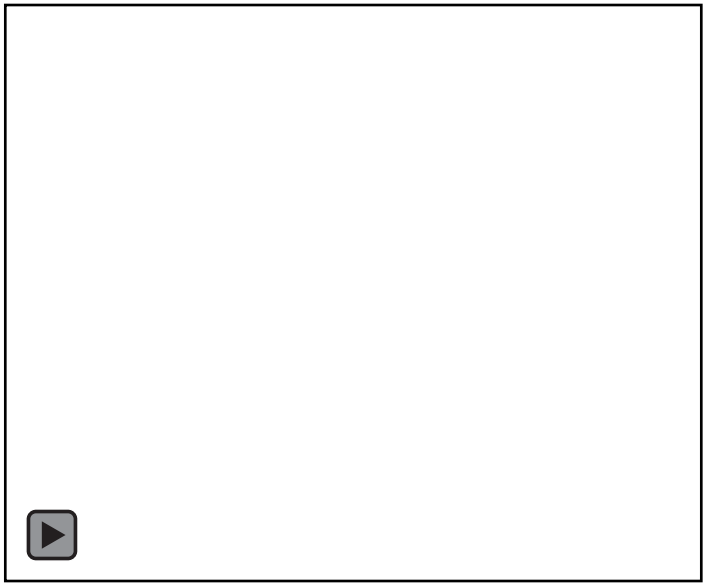
Named: Tethered cell !





Rotary motors (bacterial). Kojima S, Blair D.F. McGraw-Hill Yearbook of Science & Technology 2003 (2003). pp 363-366. The McGraw-Hill Companies, Inc. New York.

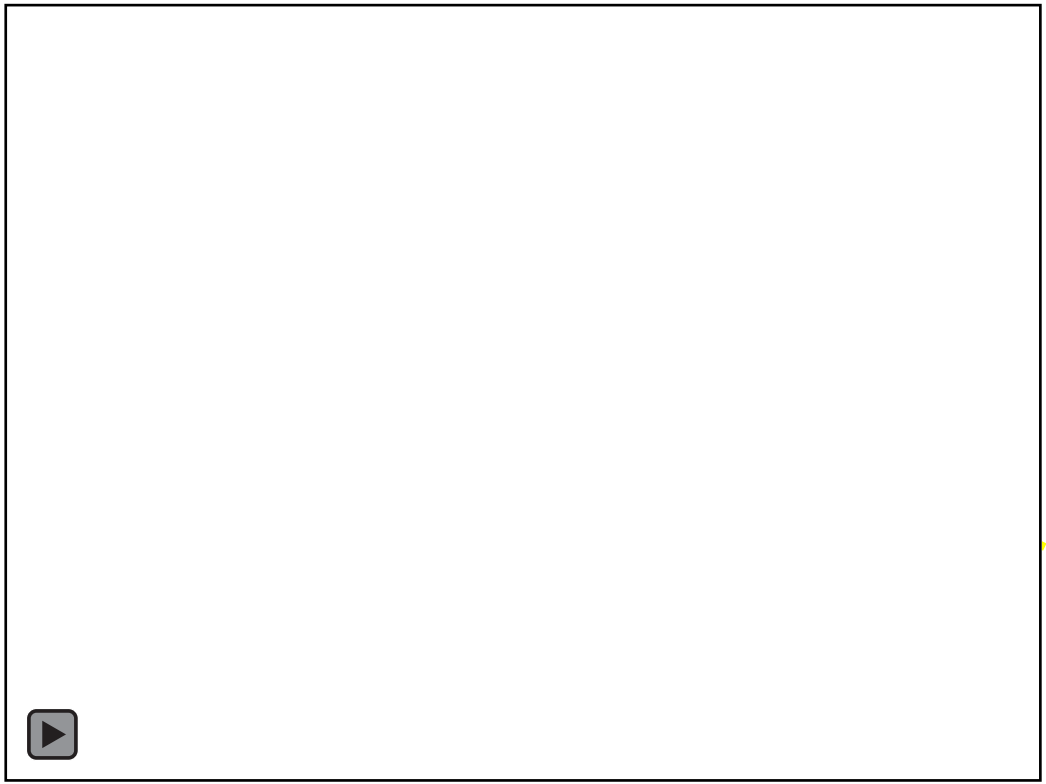
http://www.rowland.harvard.edu/labs/bacteria/movies/showmovie.php?mov=tethered_ecoli



Movie from Berg lab
Harvard University

There is a motor at the flagellar base: flagellar motor

rotor
(rotary part)



stator
(energy converter,
stationary part)

https://www.youtube.com/watch?v=hq4qrCNE1sA

The motor rotates by using the specific ion flux through the energy converter, **stator**.

Part 2: How does cells "smell" the chemicals?

Published: 03 May 1974

Change in direction of flagellar rotation is the basis of the chemotactic response in *Escherichia coli*

STEVEN H. LARSEN, ROBERT W. READER, EDWARD N. KORT, WUNG-WAI TSO & JULIUS ADLER

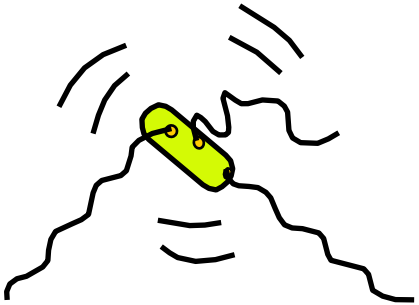
Nature **249**, 74–77(1974) | Cite this article

As shown in the previous slide, tethered cell experiment revealed that when the "flagellar motor" rotates counter-clockwise (CCW), then the cell forms flagellar bundles to swim forward.

On the other hand, when the "flagellar motor" rotates clockwise (CW), then the cell cannot form flagellar bundles and so tumbles around.

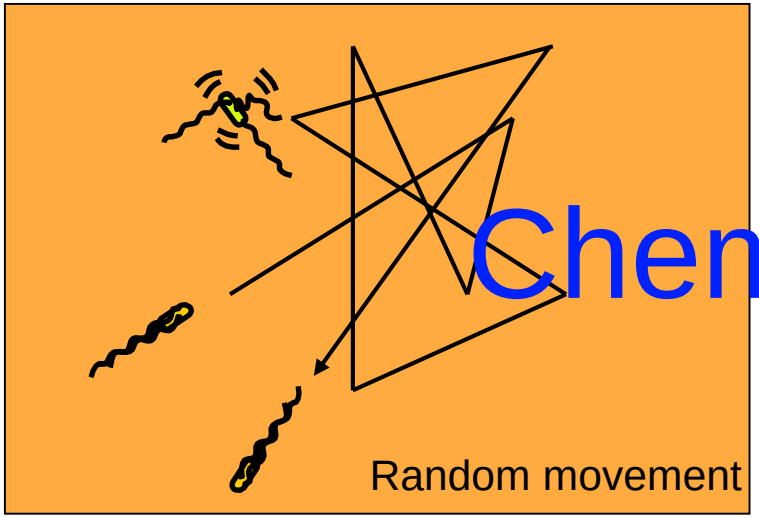
Escherichia coli cells can move by using two different mode for motility

Counter clockwise rotation: **run**

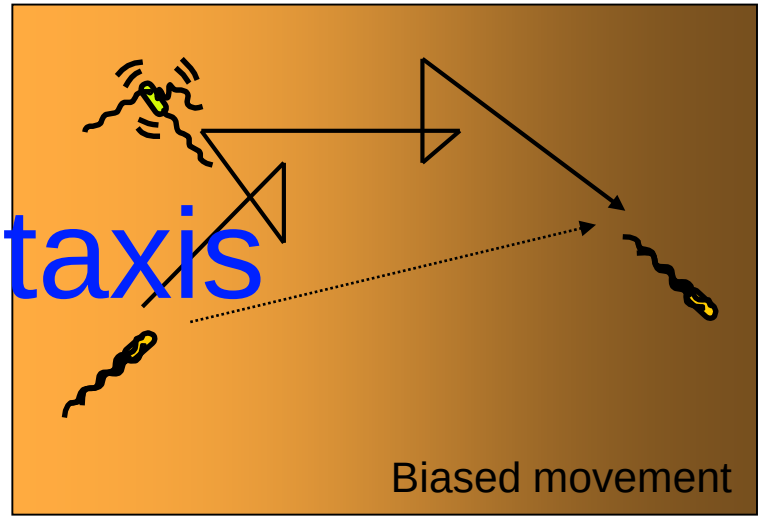


Clockwise: **tumble**

No stimulus



Attractant gradient



Chemotaxis

Question 3

OK, now bacterial cell "smells" favorite chemicals and move toward them. Then how can we know bacteria's favorite chemicals or the one it avoids?

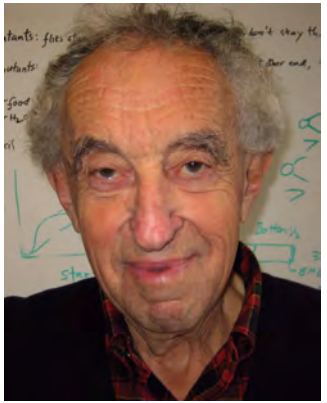
Think about it for a minute!

Grow *E. coli* cell in the liquid broth → Wash cells with buffer → A substance is packed into capillary glass tube, put into cell suspension

Figure removed due to copyright restrictions.

Capillary including subtance (e.g., Aspartate)

Cells that swim toward substance!



Julius Adler

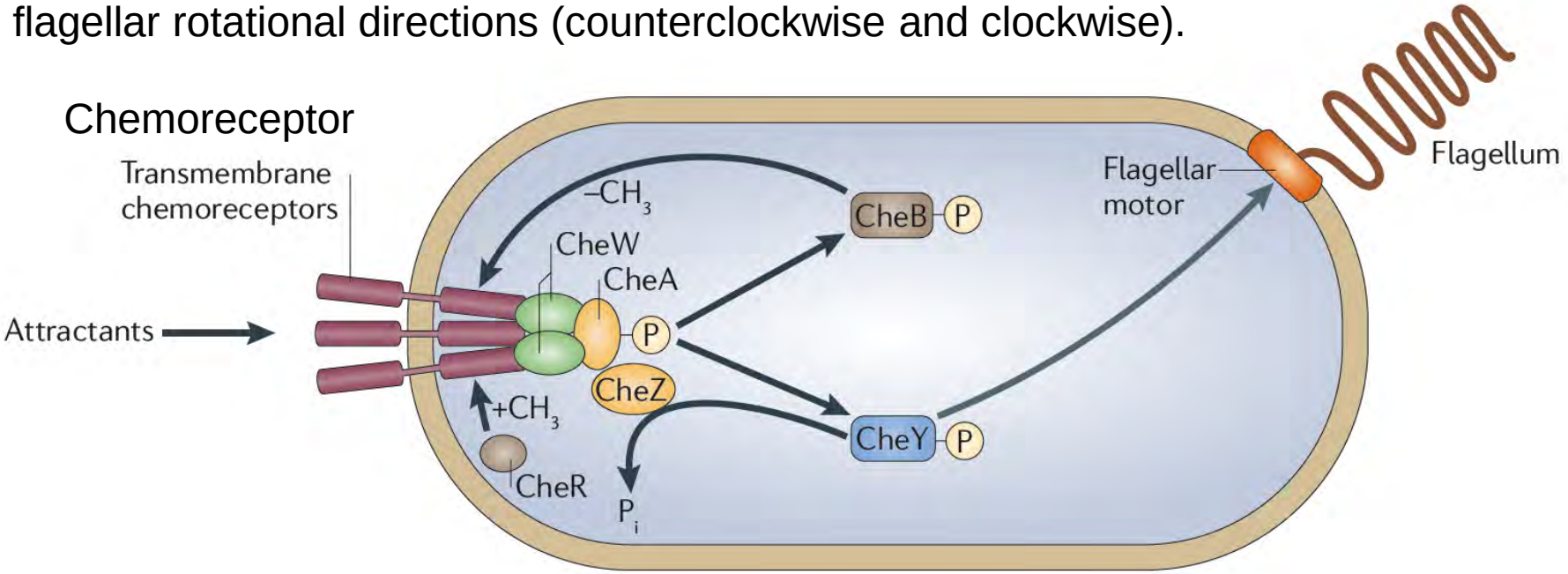
http://www.estherlederberg.com/EImages/Archive/AdlerJ/AdlerJ%20Correspondence.html

Under the microscope, we can see cells that swam toward substance leaked from capillary

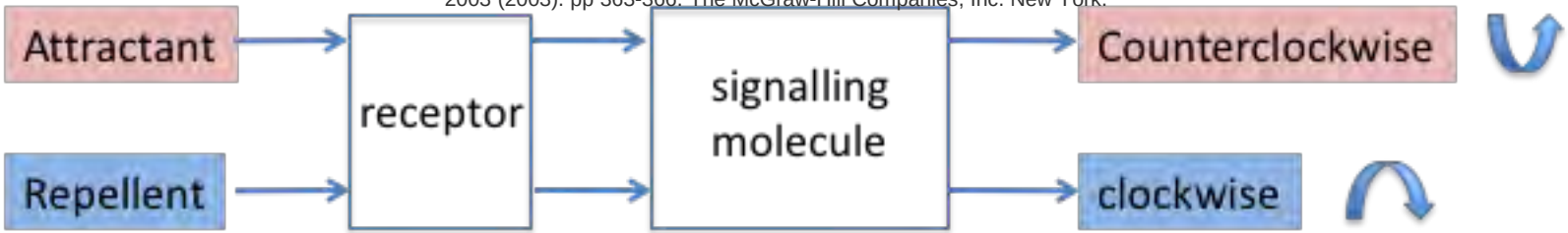
Attractant: swim toward

Repellent: swim away

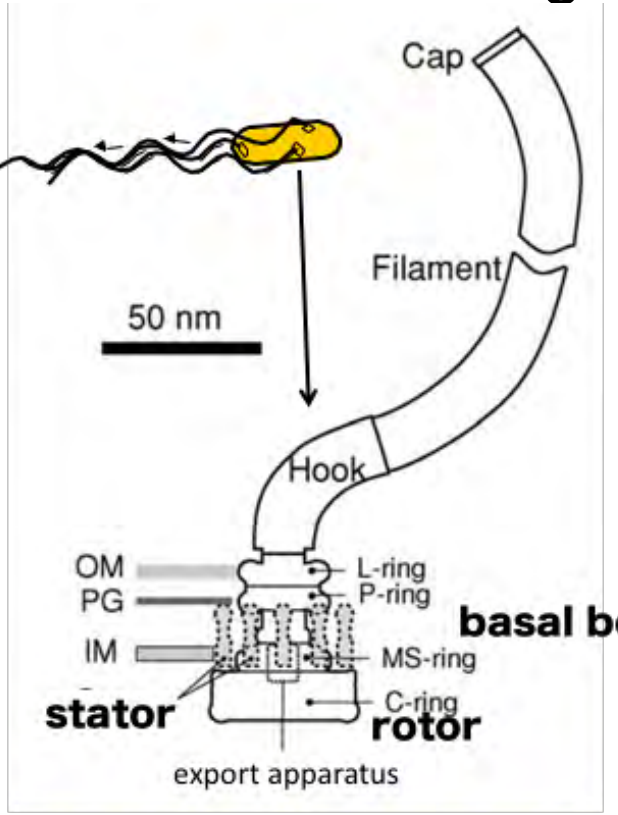
Bacterial cells can sense environmental cue, transmits that signal, then control flagellar rotational directions (counterclockwise and clockwise).



Rotary motors (bacterial). Kojima S, Blair D.F. McGraw-Hill Yearbook of Science & Technology 2003 (2003). pp 363-366. The McGraw-Hill Companies, Inc. New York.



Part 3: How does the flagellar motor look like?



https://www.youtube.com/watch?v=hq4qrCNE1sA

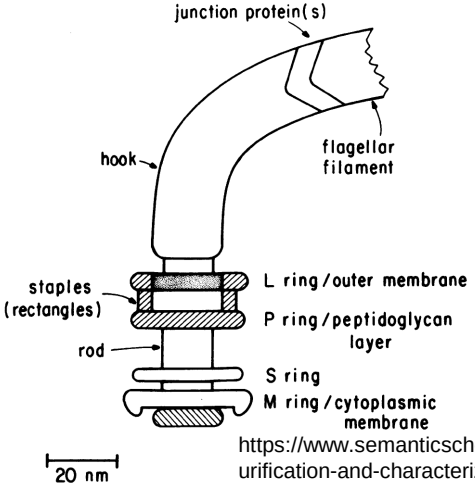
Structure, property, energy conversion

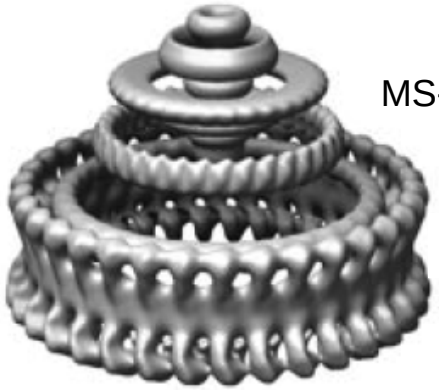
Energy source is the electrochemical gradient across the membrane

Rotation occurs when ion flows through the stator

左図：Int Rev Cytol. 2004;233:93-134. doi: 10.1016/S0074-7696(04)33003-2.

Aizawa et al, J. Bacteriol. (1985) 161: 836-849

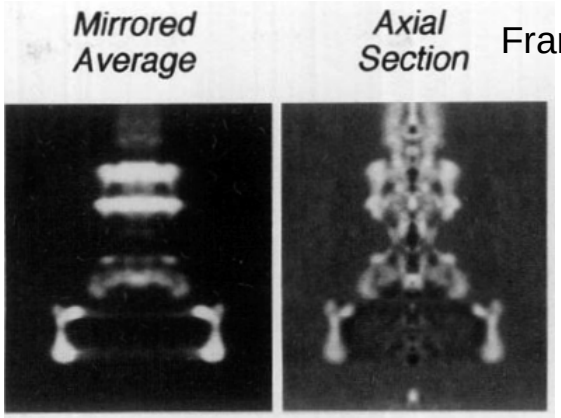




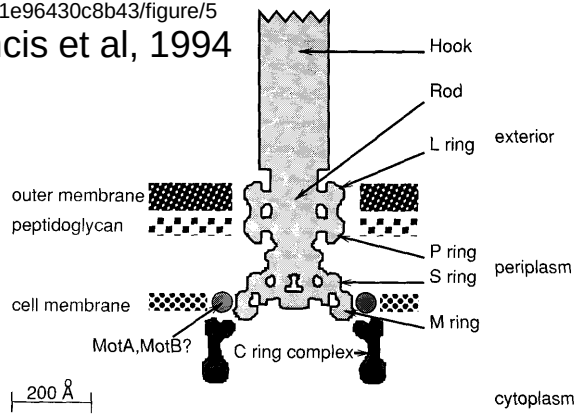
Thomas et al, 2006

https://www.semanticscholar.org/paper/Purification-and-characterization-of-the-flagellar-Aizawa-Dean/d7c015bb0c75cce56649bb2277ac1e96430c8b43/figure/5

Thomas et al, J. Bacteriol (2006) 188: 7039-748



Francis et al, 1994



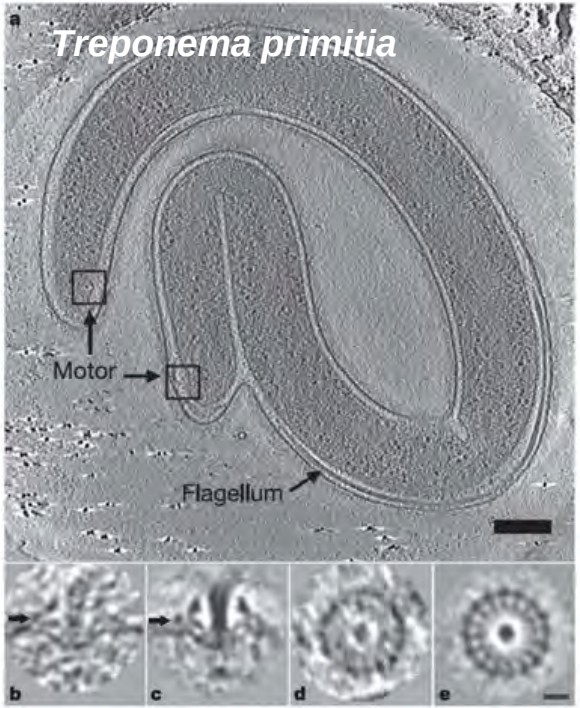
Francis et al, J. Mol. Biol. (1994) 235: 1261-1270

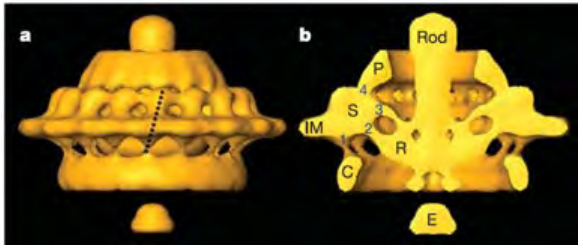
cryo-electron tomography

directly observe cell inside

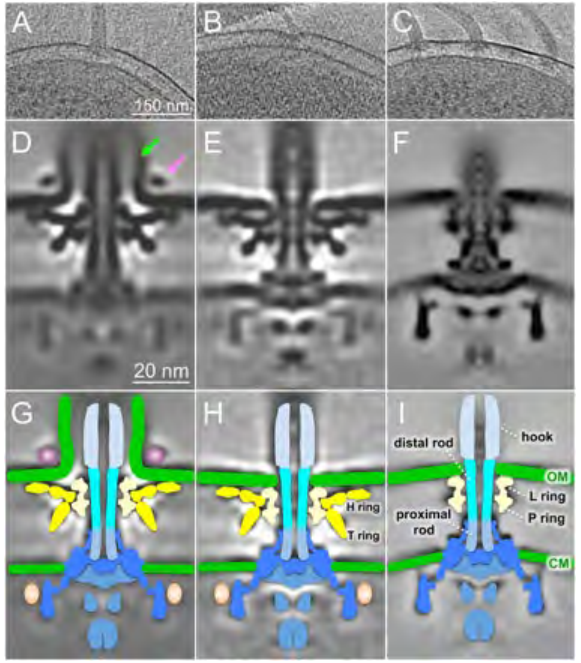
左上：http://theonematrix.com/super-technologies/down-the-rabbit-hole/

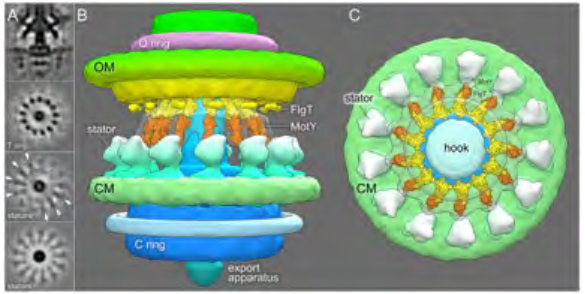
右上：https://europepmc.org/articles/PMC5642721/figure/fig01/





Vibrio alginolyticus





右下：https://europepmc.org/articles/PMC5642721/figure/fig05/

左下：Murphy et al, Nature (2006) doi:10.1038/nature05015

Zhu et al, 2017

Summary / Conclusion

1) Motile bacteria can swim by using "flagella", the filamentous organ of the cell.

2) At the base of each flagellar helical filament, there is a rotary motor.

3) The motor is powered by ion motive force across the membrane.

4) Bacterial cells can smell chemical compounds by receptor on the surface,

and sensing signal controls the flagellar rotational direction.

5) The structure of the flagellar motor can be seen by electron microscopy, especially the cryo-electron tomography.

Summary / Conclusion

Summary question(s)

How does bacterial cell move toward favourable condition?

Please explain by using terms of:

flagella, bundle, rotation, motor, chemotaxis, attractant, receptor, counter-clockwise, clockwise.

Think about it for a minute!

THANK YOU