

# Why Bacteria Don't Swim Like Fish.

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# Life at low Reynold's number.

$$\text{Re} = \frac{\text{D.V.}\rho}{\mu}$$

D = Characteristic length

V = velocity

P = Density

$\mu$  = Viscosity

- A dimensionless combination of variables that is important in the study of viscous flow is called **the Reynolds Number**.
- *RE, inertial forces visicousforces*

# Life at low Reynold's number.

- At low reynold's number
- Inertia plays no role. What you are doing is determined by the forces exerted on you at that moment.
- Time doesn't matter. Pattern of motion is the same, whether slow or fast, backward or forward.
- Motion at low Reynold's number is majestic, slow and regular.

# Feeding at low Reynold's number.

- Organisms can feed by diffusion or by stirring it's environment.

Time for transport by  
diffusion =  $l^2/\nu$

Time for transport by  
stirring =  $l/D$

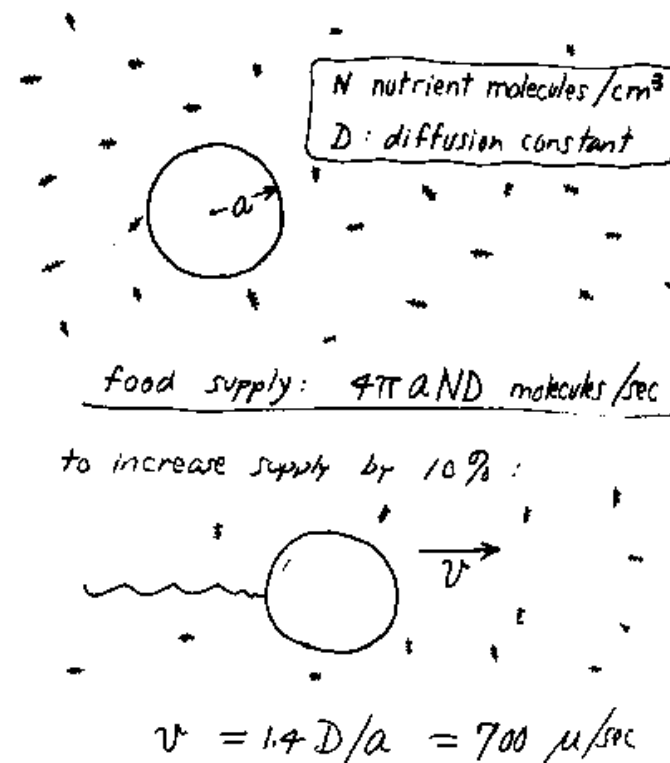
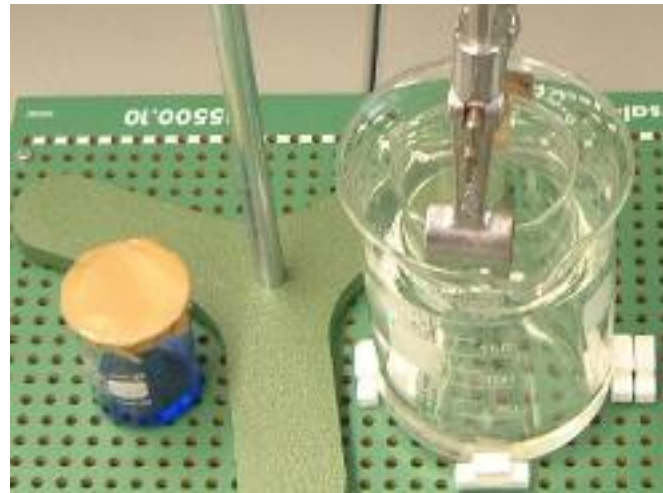


Figure 19

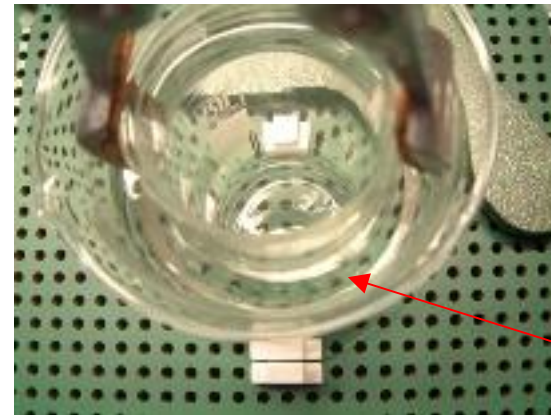
# Experiment: Low Reynolds number flow.

- In the nanoworld water behaves as a very viscous liquid



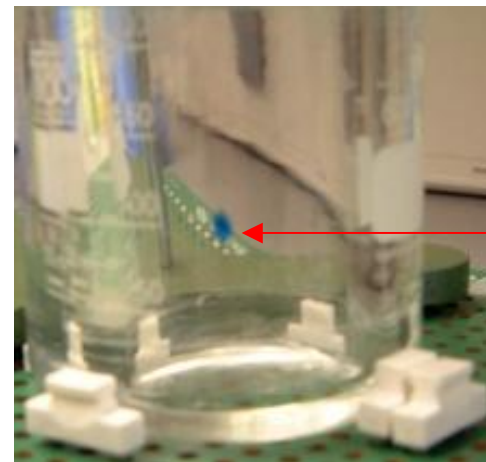
## *Low Reynolds number flow*

- Glycerin is the component simulating water



*Glycerin*

- An ink drop simulates a bacterium



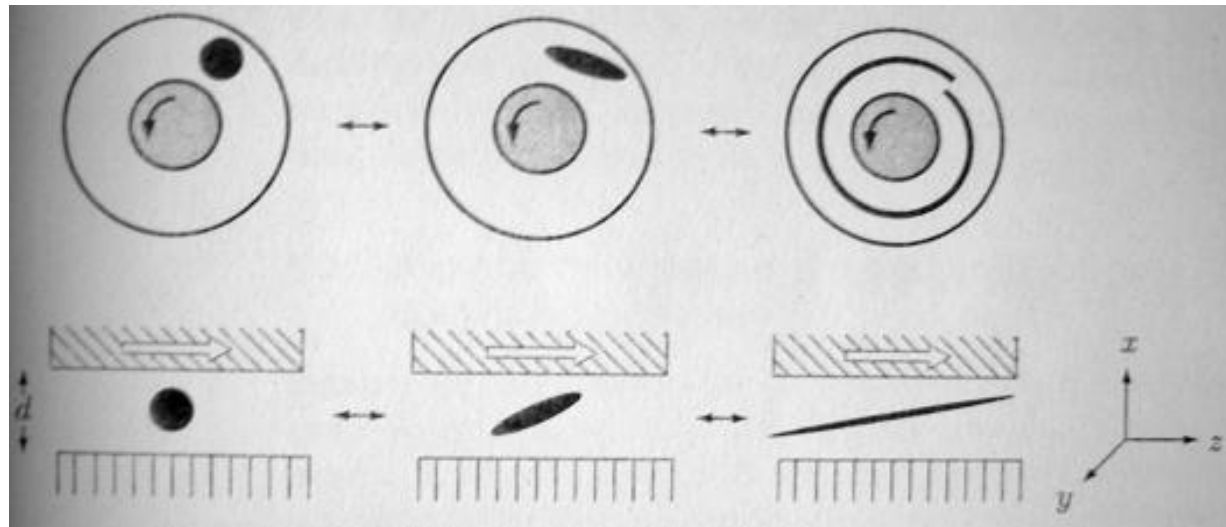
*Ink Drop*

*Low Reynolds number flow*

- The Ink drop does not diffuse away because of the large viscosity
- Example: viscosity of water 0,0009Pas; of Glycerine 1Pas
  - So the ink stays where it is and is not influenced by simple diffusion

## *Low Reynolds number flow*

- When moving the glass cylinder the layers of fluid slide over each other

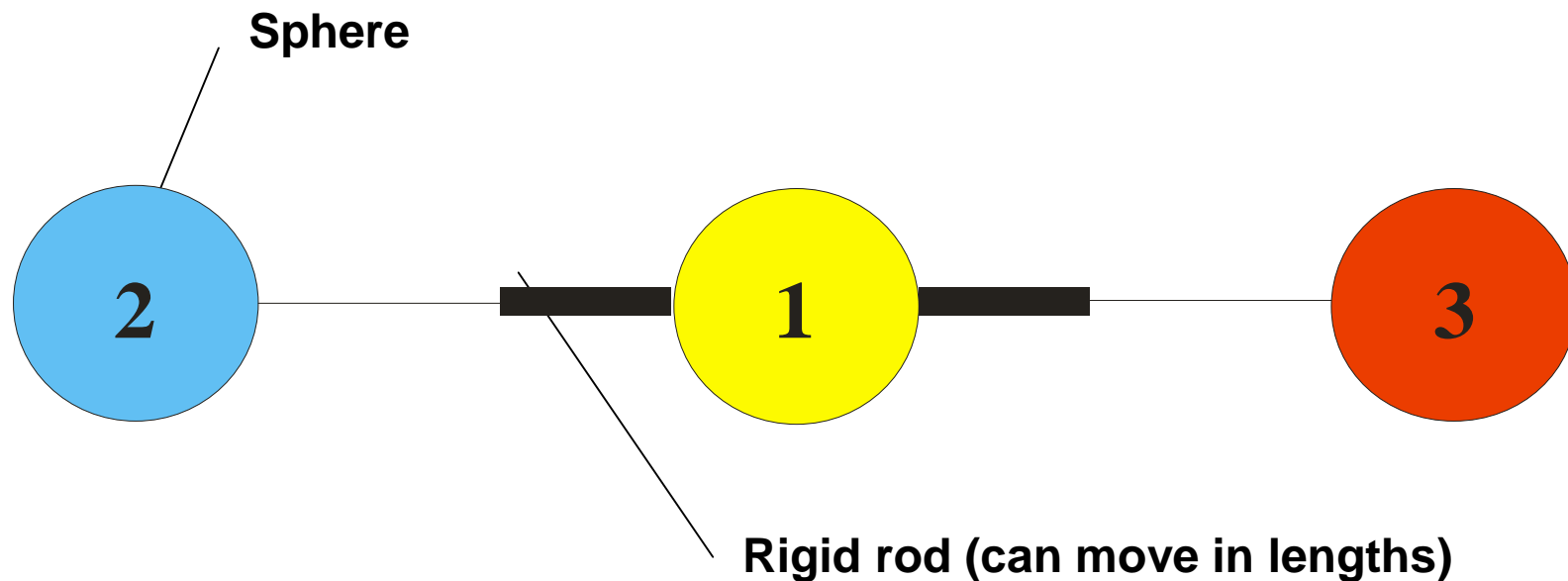


- This behavior is called laminar flow

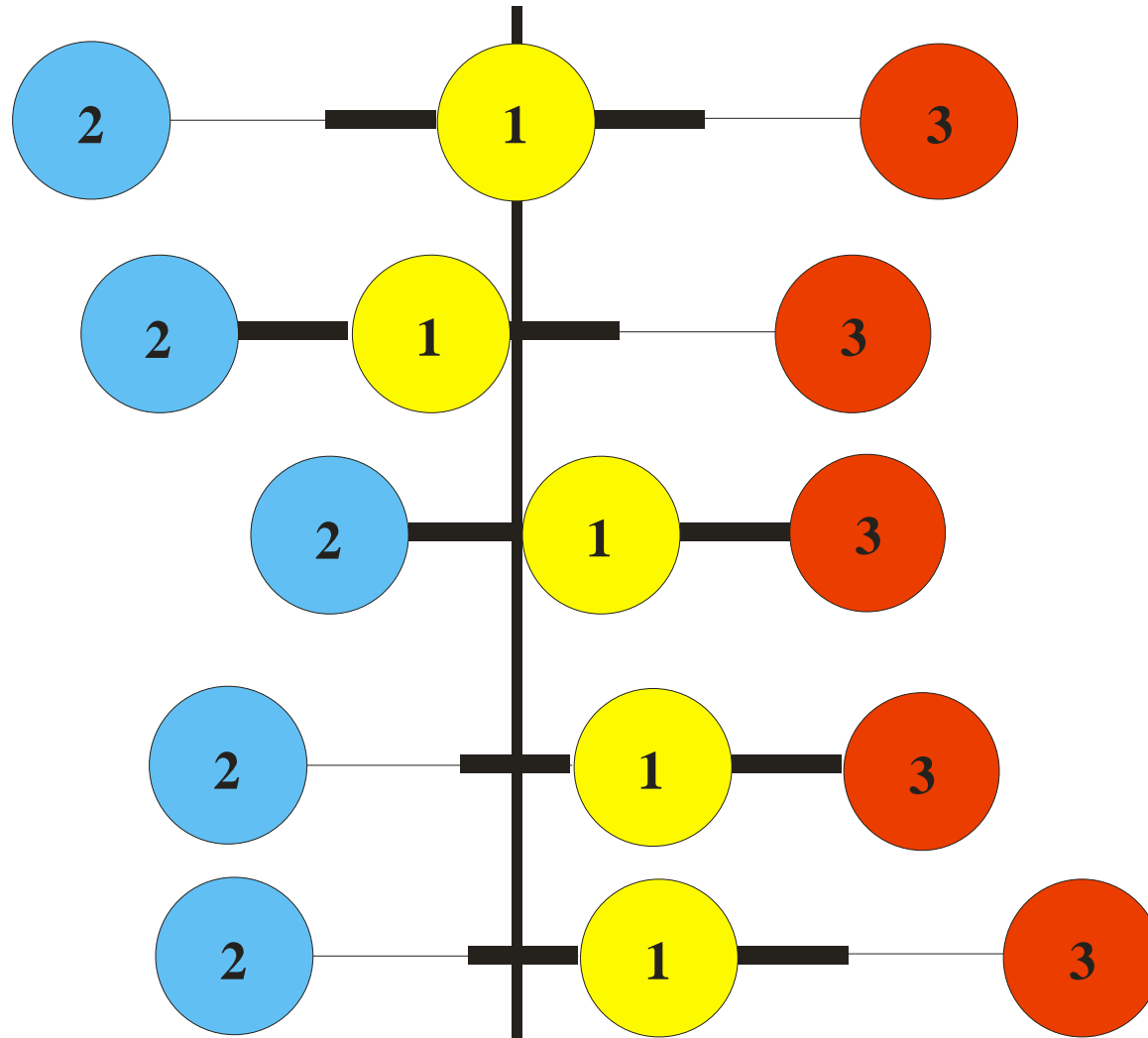


# *Simple swimmer*

- Observation of the motility at low Reynolds numbers led to the model of the simplest swimmer

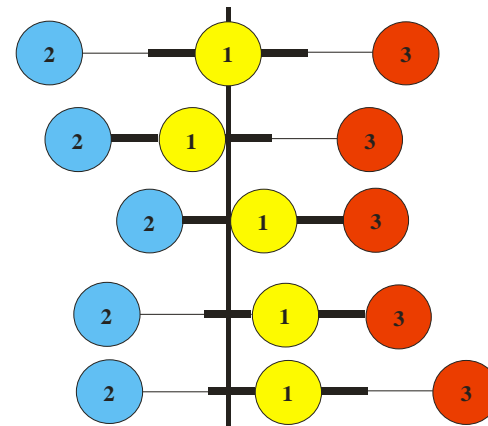


# *Simple swimmer*



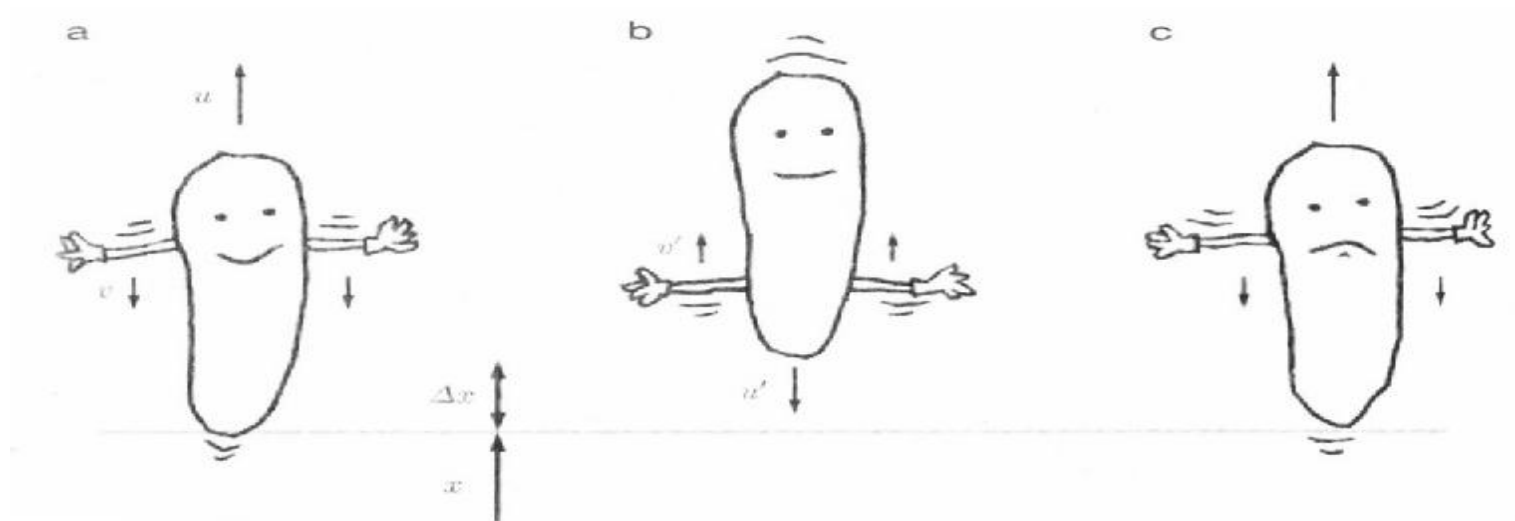
# *Simple swimmer*

In a periodic motion in a non reciprocal fashion the simple swimmer can move at low Reynolds numbers.

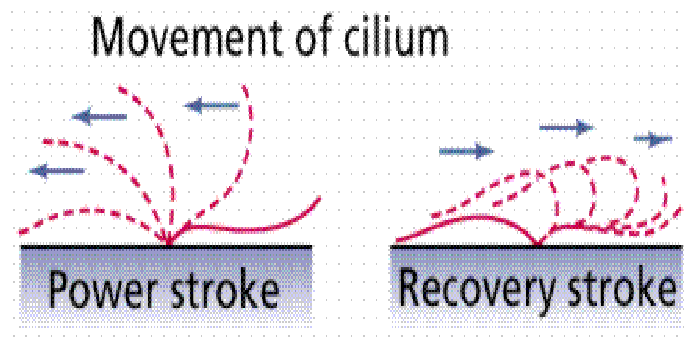


# Biological Applications

- Motion can be canceled by applying the reverse force
- So a kind of „paddle move“ won't work

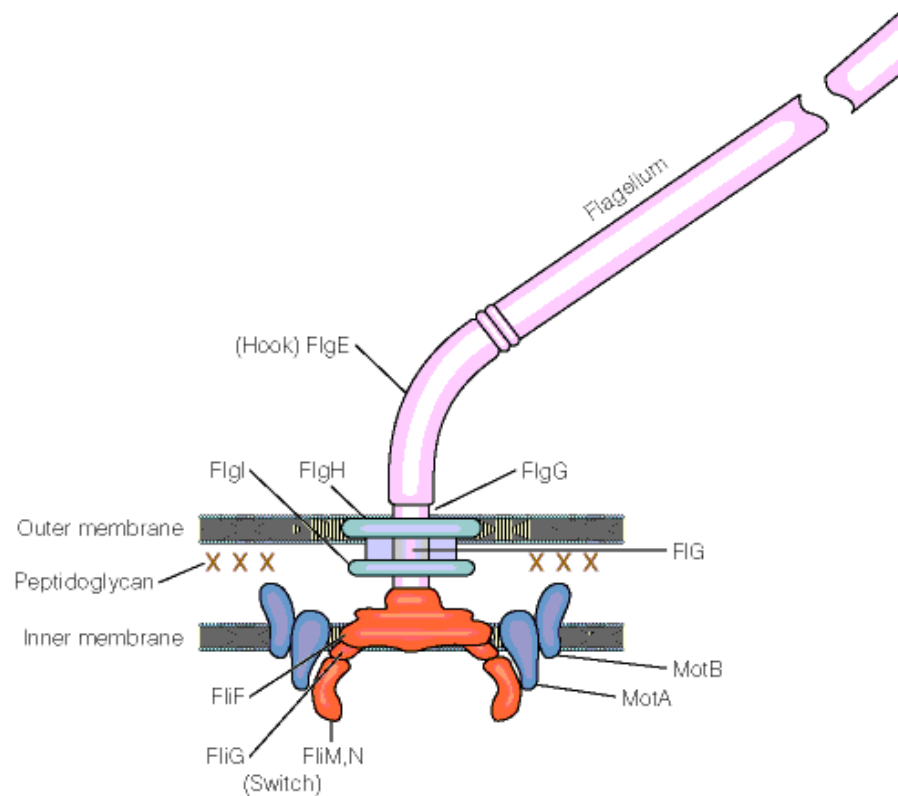


# Ciliary Propulsion



- Whiplike appendages  
5-10 $\mu\text{m}$  long and  
200nm diameter
- Moves either parallel  
or perpendicular to its  
axis

# Bacterial flagellar motor



- Flagella not flexible
- Rotary motion
- 45 nm wide

# Bacterial Motion

- Why do bacteria swim anyway?
- Get food
- Attack and escape
- Unprofitable environment

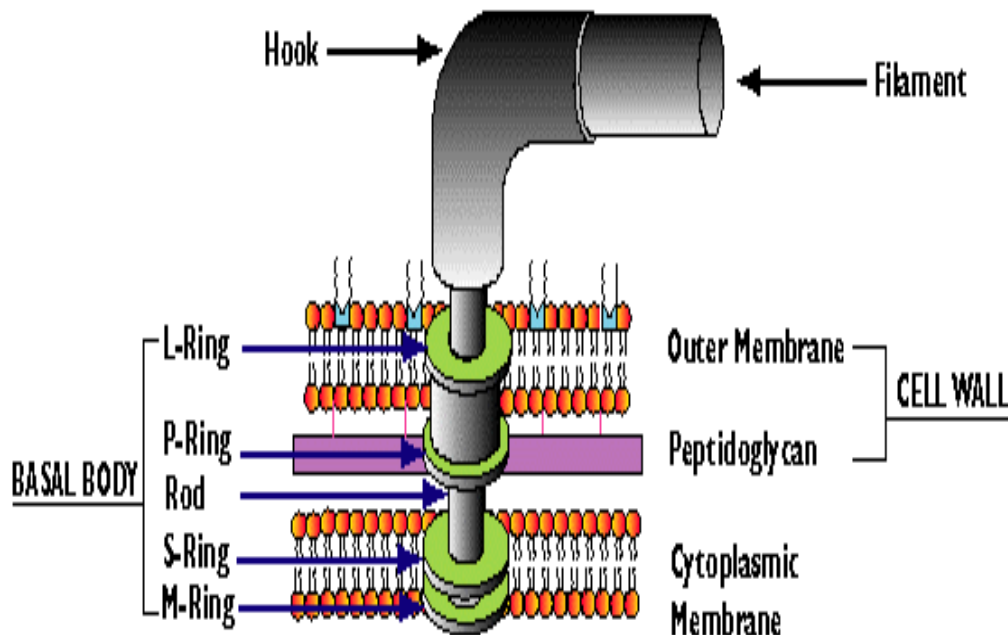
# Motile Behavior of Bacteria

## Using *E. coli* as a model

- *E. coli* is equipped with a set of rotatory motors about 45nm in diameter, each driving a long helical filament. The motor and the filament are termed, flagella.
- The flagellum consists of three parts;
  - basal body
  - Proximal hook
  - Propeller

# Protein components of flagellum

## FLAGELLA STRUCTURE IN GRAM NEGATIVE ORGANISM



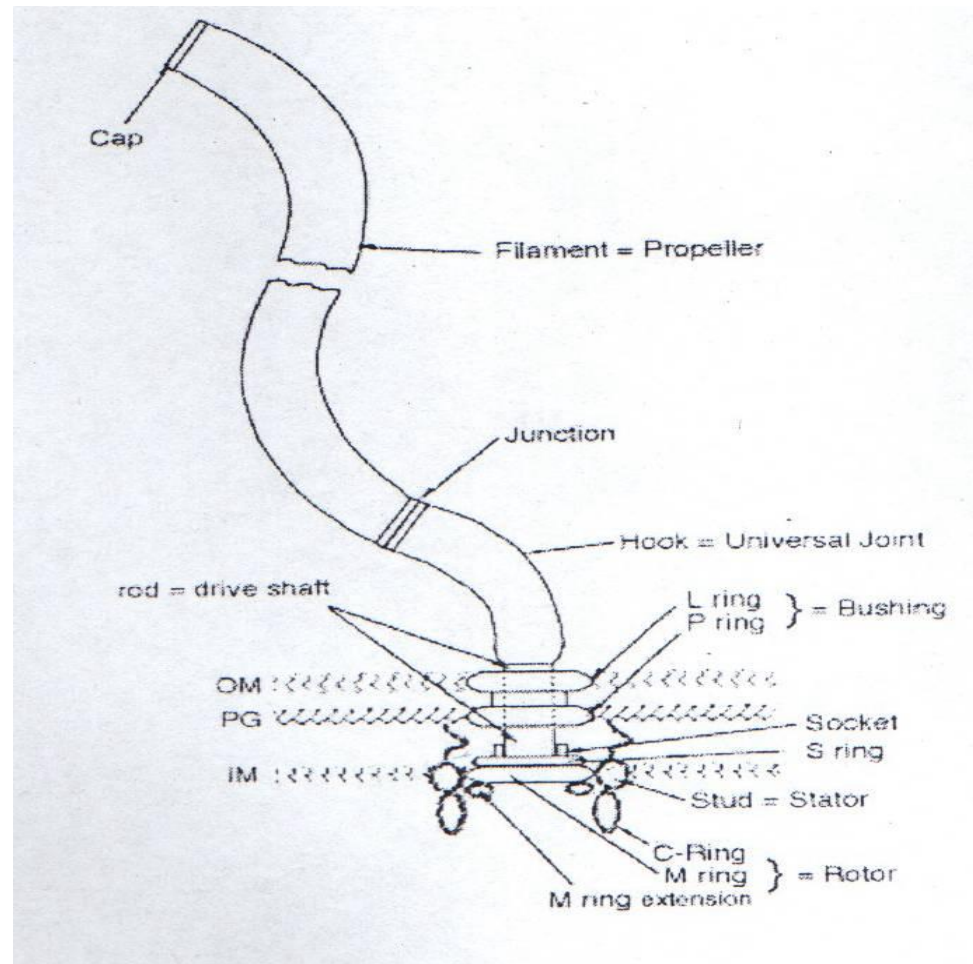
- Stator proteins: Mot A and B
- Rotor proteins: FliF, G, M and N (M and S ring)
- Propeller proteins: FlgB, C and G, FlgH and I (L and P rings)

# The Bacterial Flagellar Motor

- Peritrichously flagellated bacteria:  
e.g.: -*Salmonella typhimurium*  
-*Escherichia coli*
- Bacterial flagellum has a rotary motor turning a rigid helical propeller
- Energy source: electromotive gradient for protons or sodium ions across cell membrane
- A working bacterial flagellum contains about 20 proteins
- Flagellar motors can run in both directions, i.e., clockwise (CW) and counterclockwise (CCW)

# The Bacterial Flagellar Motor

## Flagellar Architecture



# The Bacterial Flagellar Motor

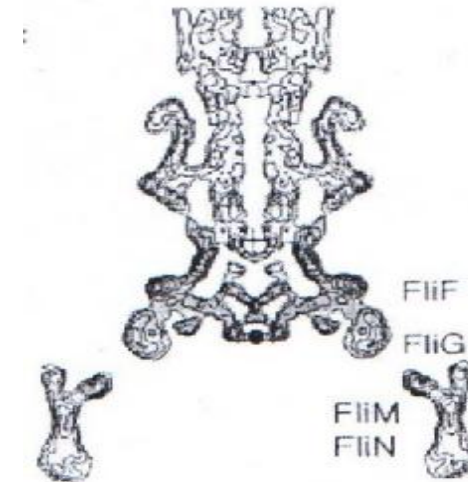
## The Components of the Motor

- Genes of a flagellum are named:
  - fla è flagellar
  - mot è motility
  - che è chemotaxis
- About 40 fla genes: structural proteins, regulatory proteins, and proteins involved in assembly
- 2 mot genes: motA and motB
- 6 che genes

# The Bacterial Flagellar Motor

## FliG, FliM, and FliN

- FliG, FliM, and FliN are cytoplasmic proteins
  - è form switch complex
- Switch complex:-torque generation
  - reversal of rotation direction
- Switch is bistable
- The motor switches between CCW- and CW rotation
- Phosphorylated CheY alters probability of switching by binding to the switch complex
- FliM and FliN è part of the rotor



# The Bacterial Flagellar Motor

## FliG, FliM, and FliN

- FliN:-may stabilize the structure
  - no direct involvement in torque generation
- FliM:-directly involved in switching
  - no direct involvement in torque generation
- FliG:-directly involved in torque generation
  - with FliM also involved in switching

# The Bacterial Flagellar Motor

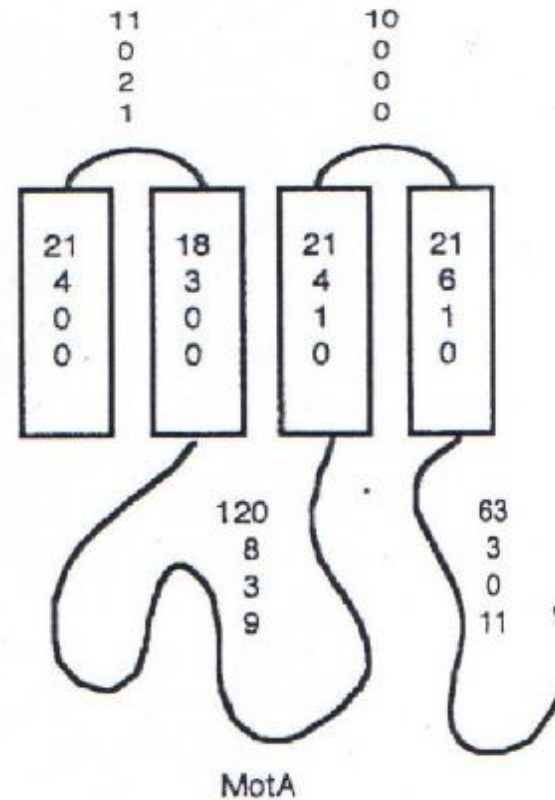
## Mot Genes

- Mot genes: -anchor the motor
  - transport and transfer proteins
  - position the torque generator
- Mot proteins comprise or activate eight independent torque generators
- MotA and MotB è part of the stator

# The Bacterial Flagellar Motor

## MotA

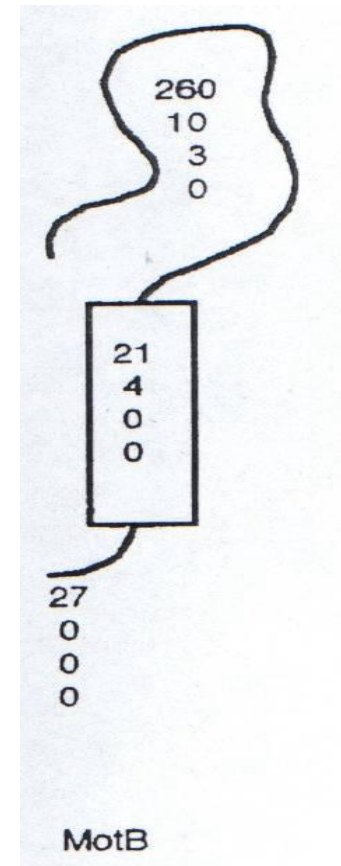
- MotA:
- transmembrane proton channel
- four membrane crossings
- functions:
  - delivery of protons across the membrane
  - utilization of protons to generate torque



# The Bacterial Flagellar Motor

## MotB

- MotB:
- part of transmembrane proton channel
- one membrane crossing
- functions:
  - anchoring of the motor to the cell
  - positioning of the motor's parts
  - formation of the proton channel with MotA



# Bacterial movement.

- The motor is driven by protons flowing from the outside to the inside of the cell.
- Proton translocation causes the cytoplasmic part of MotA to move and exerts a force on FliG, driving the rotor(rotation).

# Bacterial movement.

- The movement of the cell depends on the movement of the motor.

CW movement bacteria tumbles.

CCW movement bacteria moves steadily forward

- All motors must rotate CCW before the cell can move forward.

# Bacterial movement.



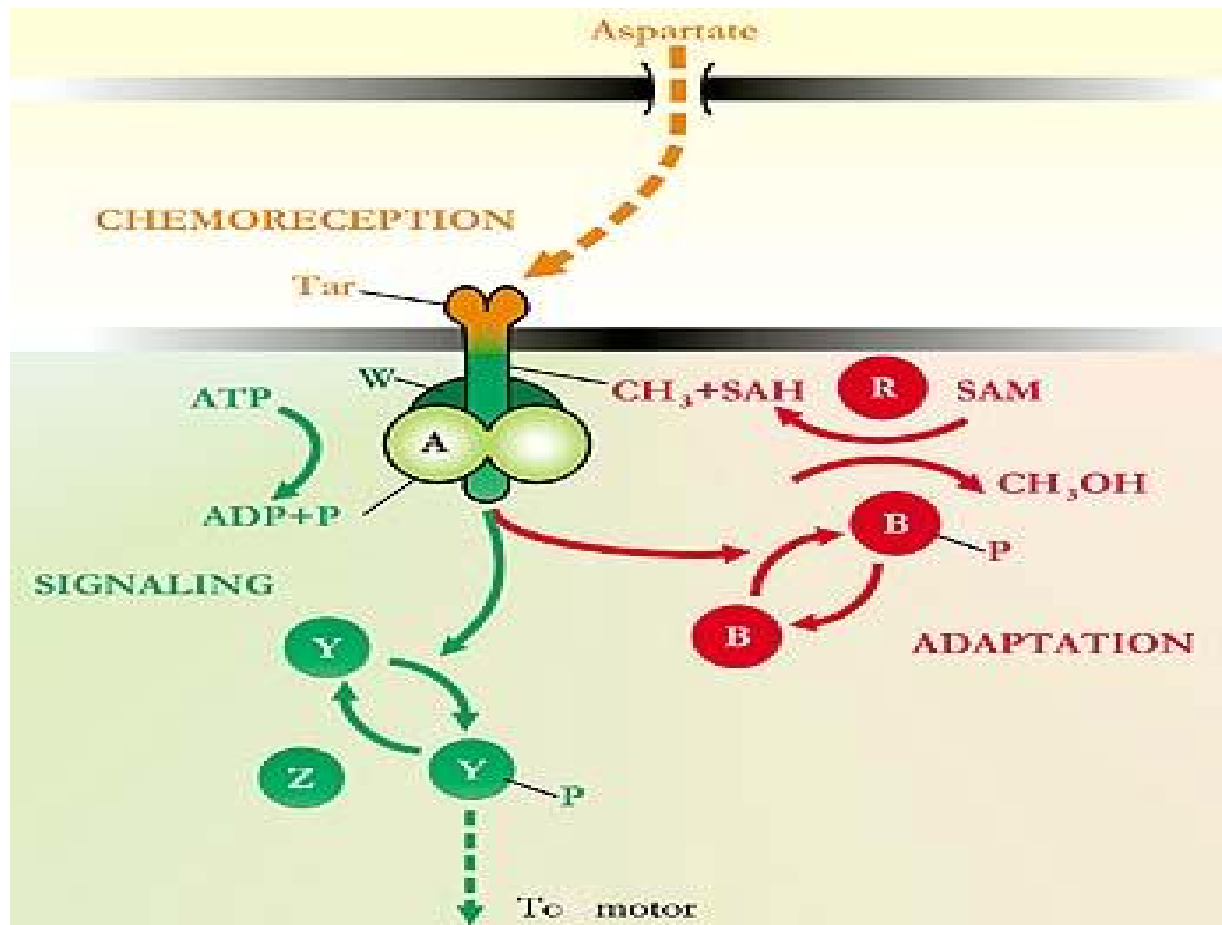
# Processing chemical signals.

- To change direction, three steps are involved;
- Chemoreception: Aspartate diffuses to Tar and binds.
- Signalling: Binding of CheY-P to motor, stabilizes CW movement. If less CheY-P is produced, the probability that the motor spins CCW increases.

# Processing chemical signals.

- Adaption: The decreased catalytic activity of CheA renders CheA less susceptible to the action of CheB-P and also reduces the concentration of CheB-P, which dephosphorylates spontaneously. Methyl groups are added to Tar by CheR and removed by CheB-P. Hence the methylation level goes up. This tends to restore the catalytic activity of CheA. Bacterial goes back to previous movement.

# Processing chemical signals.



# Why don't Bacteria swim like Fish?

- For animals water is very liquid
  - For bacteria a low Reynolds Number is calculated: Water it is very viscous
- Ø Movement is slow and needs special adaptation

# Why don't Bacteria swim like Fish?

- Movement is beneficial for finding nutrients and escape from unfavourable environment
- Direction of swimming is influenced by chemotaxis: „If environment is becoming better, don't stop so soon.“

# Why don't Bacteria swim like Fish?

- „Flip-Flop“-Motion does not work in a viscous environment
- Flagella Motors rotate the flagellum like a propeller, turning it like a screw

# Why don't Bacteria swim like Fish?

- By rotating CW bacteria can change their direction of movement
- By rotating CCW they can move steady in one direction

# Why don't Bacteria swim like Fish?

So, if you should ever fall into a  
swimming-pool full of honey...

# Why don't Bacteria swim like Fish?

...use your flagellum!



# References

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- For early work: G I Taylor: *Analysis of the swimming of microscopic organisms*, Proc R Soc London Ser A **209**, 447 (1952)  
(This and other pertinent papers can be found for download at <http://www.tam.uiuc.edu/courses/TAM307/2003.2/articles/> )