



ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Professor Paul Selvin
Physics 498

Announcements

Homework #10 due April 14th

Derive $x^2 = \#Dt$,
where $\# = 2n$, where $n =$ dimension
...other



(Last Diffusion Lecture) Diffusion & Bacteria Moving

Equipartition Theorem—

$\frac{1}{2}$ kT per degree of freedom that depends on squared in energy

($\frac{1}{2} kx^2$, $\frac{1}{2} mv^2$)

Most commonly $E = \frac{3}{2} kT$

Bacteria:

Amazing Swimmer: Goes 10 body lengths/sec, compared to 1 body length/sec for you.

Despite it's swimming through the equivalent of concrete.

Drag force = 10x its own weight.

Goes no where (< 1 A) once motor turned off.

Inertia does not matter for bacteria or anything that is small / microscopic.



Power Consumed by Bacteria

What is size of force needed
to keep bacteria moving?

Ans: when $F_{\text{prop}} = F_{\text{drag}}$, steady motion $= \gamma v$

$$\underline{F_{\text{prop}} = 0.5 \text{ pN}}$$

(25 $\mu\text{m}/\text{sec}$)

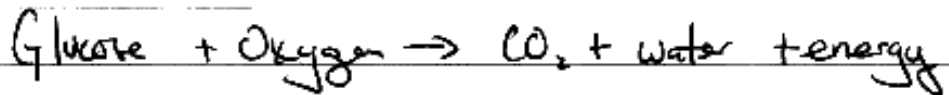
$$\gamma = 6\pi\eta r$$

What is power produced by bacteria?



How much food does Bacteria
need to burn for locomotion?

Burn food: (Glucose/sec) Put in Life is a
slow burn!





Introduction to Reynold's

When does inertia matter?

Inertia = mass

How big do you have to be
(or how low viscosity)

If you want to accelerate (or decelerate)
something, is main thing you need to
overcome the mass/inertia, or the friction?



a) in outer space
resistance to acceleration is only mass

b) on ice
res. mostly mass

c) stuck in mud
resistance mostly friction

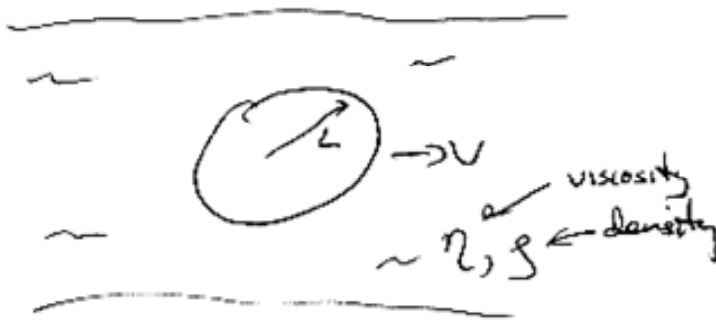
"ma" sometimes called inertial "force" (yuck!)

For bacteria, friction (viscous drag) dominates
For you? For ocean liner?



Reynold's # is ratio of "inertial to viscous" forces

Viscous forces = drag - depend on properties of fluid & pattern of fluid flow around object



$$R = \frac{L v \rho}{\eta} \quad (\text{derived from } \frac{\text{inertial forces}}{\text{viscous forces}})$$

$R \ll 1$ friction dominates

Stir honey (big η) not too fast (reasonable v)
& motion stops immediately after stop

stirring
i.e. inertia doesn't matter

$R > 1$ inertia matters
Stir coffee, motion continues -

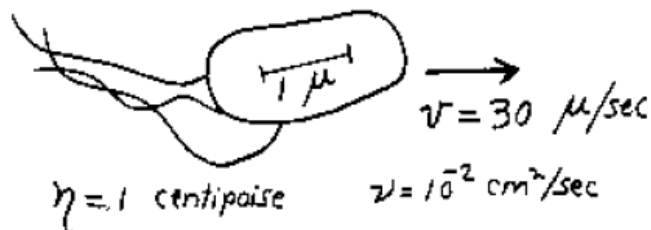
$R \geq 100$ Stir really fast \rightarrow big disturbance
Turbulent flow



If $R_e \gg 1$ mass opposes Δ in motion
If $R_e \ll 1$ viscous forces opposes Δ in motion

What is Reynold's # for bacteria? (Make estimates for L , v , η , ρ)

$$R_e = Lv\rho/\eta$$



Bacteria: $L = 10^{-4}$ cm $\rho = 1$ g/cm³ $\eta = 0.01$ g/cm-sec
 $v = 10^{-3}$ cm/sec

$$R_e = \frac{Lv\rho}{\eta} \sim \frac{(10^{-4} \text{ cm})(10^{-3} \frac{\text{cm}}{\text{sec}})(1 \frac{\text{g}}{\text{cm}^3})}{0.01 \text{ g/cm-sec}} \sim 10^{-5} \ll 1$$

Bacteria knows nothing about inertia

(agrees with previous result that stops in $< 1 \text{ \AA}$)



R_e for Fish? (Make estimates)

$$\text{Fish: } L = 10 \text{ cm} \quad v = 100 \text{ cm/sec}$$

$$R_e = \frac{(10)(100)(1)}{0.01} \sim 10^6 \gg 1$$

Fish knows a lot about inertia

Stop swimming: will coast



Where bacteria live

A single teaspoon of topsoil contains about a billion bacterial cells (and about 120,000 fungal cells and some 25,000 algal cells). The human mouth is home to more than 500 species of bacteria. Each square centimeter of your skin averages about 100,000 bacteria. Bacteria live on or in just about every material and environment on Earth from soil to water to air, and from your house to arctic ice to volcanic vents.

Some bacteria (along with archaea) thrive in the most forbidding, uninviting places on Earth, from nearly-boiling hot springs to super-chilled Antarctic lakes buried under sheets of ice. Microbes that dwell in these extreme habitats are aptly called [extremophiles](#).



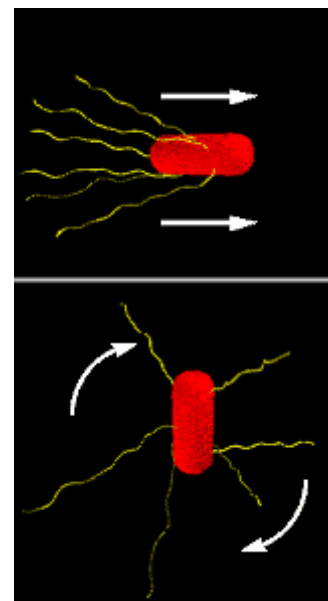
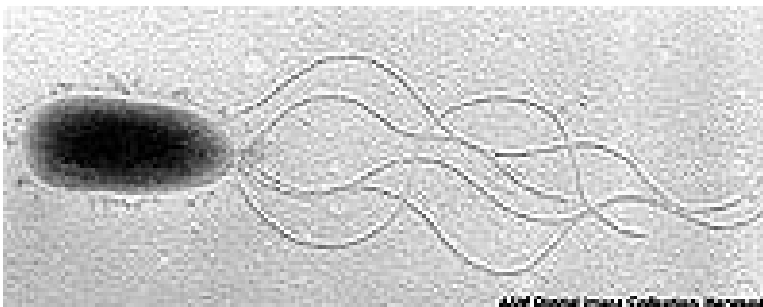
How E.Coli move

(Not universal: Other bacteria secrete a slime layer and ooze over surfaces like slugs.)

Head off in one direction, by rotating a propeller counterclockwise. In bacteria propeller called flagellum.

Then at seemingly random times, the propeller rotates clockwise, causing the bacteria to tumble, goes in a random direction, re-starts the propeller going counterclockwise, and goes again.

If go in direction where gradient of food is increasing, tend to go longer; if gradient is decreasing (less food around), will tend to switch more frequently.





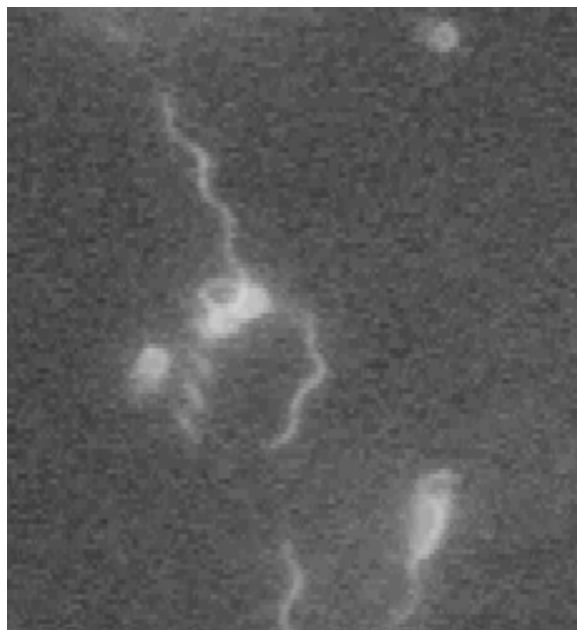
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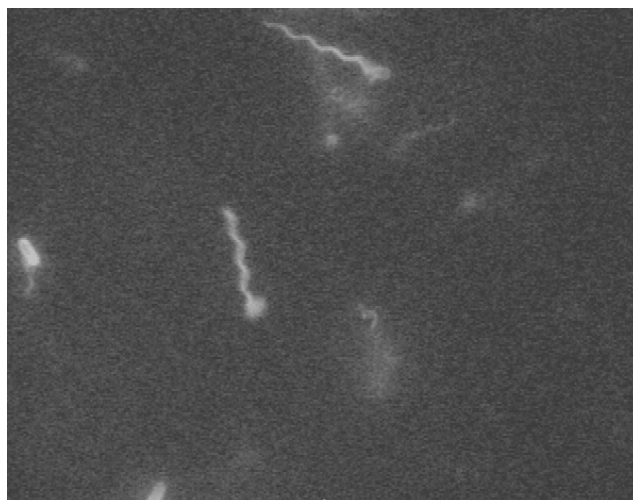
E.Coli Swimming

(From Howard Berg, Harvard)
Fluorescently labeled, at 60 Hz

Stuck on
glass



Freely
swimming



http://www.rowland.harvard.edu/labs/bacteria/movies_ecoli.html



Class evaluation

1. What was the most interesting thing you learned in class today?
2. What are you confused about?
3. Related to today's subject, what would you like to know more about?
4. Any helpful comments.

Answer, and turn in at the end of class.