Physics 200
Molecular Biophysics

Jay Newman
N315
X6506
Open office hours

The state of Biophysics

- Biophysical Society annual meeting
  - 1976 700 papers
  - 1986 1500 papers
  - 2013 4200 papers
- Growth is due to
  - New technologies:
    - Computers for data collection, analysis, imaging
    - Lasers and new techniques
    - Accelerator biophysics
    - Improved biochemical purification methods
  - Successes and growing interest:
    - Biophysics/BioTech/NanoBiology is new hot field of science – funding increases
    - Very broad range of discipline
    - Attracts scientists, engineers, medical researchers

Basic Philosophy

Laws of Physics (including Chemistry) can explain all biological phenomena

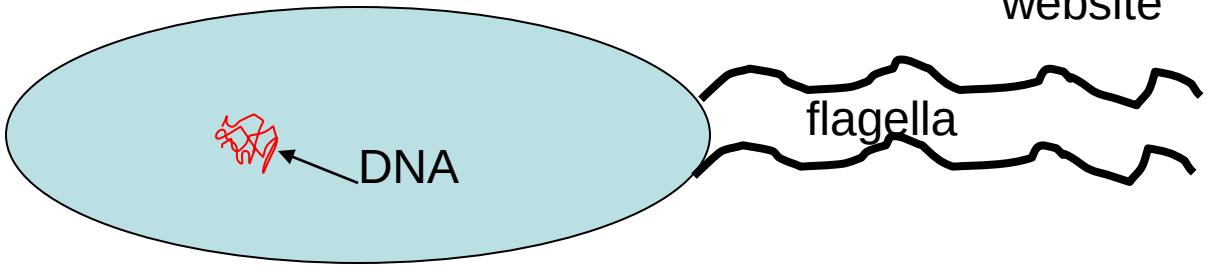
- Problem: The phenomena are very complex

- Two general approaches:
  - "wholistic" – entire organism or organ systems – includes sensory organs = eye, ear, taste; heart, kidney, etc, imaging methods
  - "component/synthesis" – structure/function of purified parts and re-assembly of complex – includes
    macromolecules – protein, DNA, RNA, lipids, viruses
    subcellular – membranes, organelles
    cellular – specialized cells = muscle, nerve; motility; development; communication

- Common Theme: use many different techniques and everything known about your system – all in parallel studies

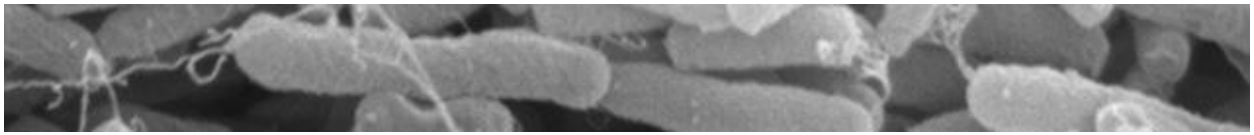
Bacteria

See Howard Berg bio on website



Physical Properties

- Length ~ 1 μm – or 1/1000 mm
- Mass ~ 2 pg (2×10^{-12}g) - or 0.1% of red blood cell
- DNA mass ~ 3% of total
- Length of DNA ~ 1 mm – note human DNA ~ 2 m
- Number of proteins ~ 3000 (but 10,000 copies of some) – about 10 x more in humans
- Life cycle time ~ 20 minutes at 37°C
- Plasmid, or extranuclear DNA, ~ 1 – 20 per bacteria



A physics problem with bacteria

Locomotion - self propelled via flagella.

Life at low Reynolds number

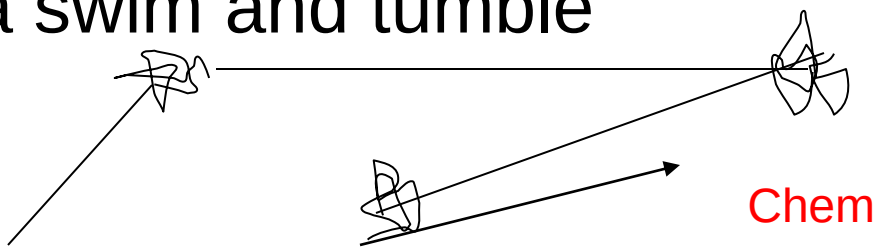
R = inertial forces/viscous forces (= $L\rho v/\eta$)

Swimming whales R ~ 10^{8}

Swimming bacteria R ~ 10^{-6}

So, bacteria do not glide – when flagella stop so do bacteria

Bacteria swim and tumble

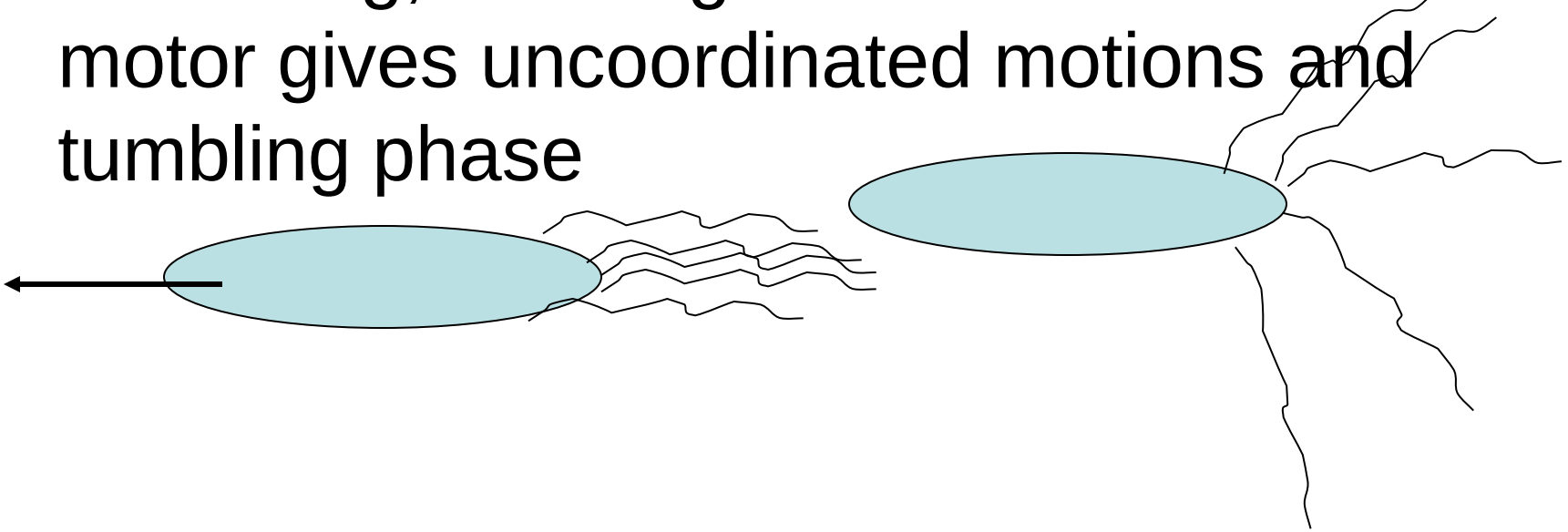


Random swim model

Chemotaxis – attractants, repellants

What is the molecular mechanism?

- Flagella are operated by a **molecular rotary motor** (F1-ATPase) that runs directly on **proton pumping** – flagella are rotated like a corkscrew to provide thrust
- Left-handed rotations give coordinated swimming, while right-handed rotation of motor gives uncoordinated motions and tumbling phase

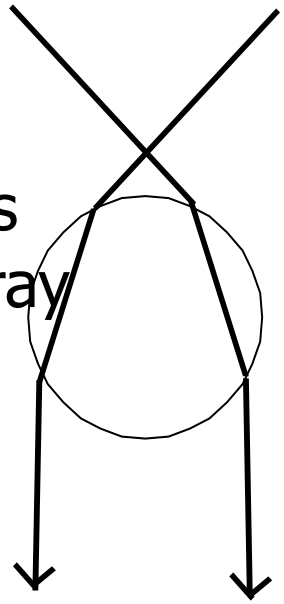


F1-ATPase

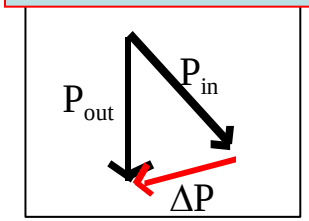
- Normally makes ATP from ADP by proton pumping across the membrane
- Our bodies make and consume roughly our own weight in ATP each day
- In bacteria flagella, ATP splitting is used to drive rotary motor
- Laser tweezers experiments have been used to study the torque generated by the motor - (short digression on laser tweezers)

Trapping of a Transparent Sphere

Two equal intensity rays
Note that a ray picture is ok for the Mie regime



Conservation of momentum shown for one of the two beams

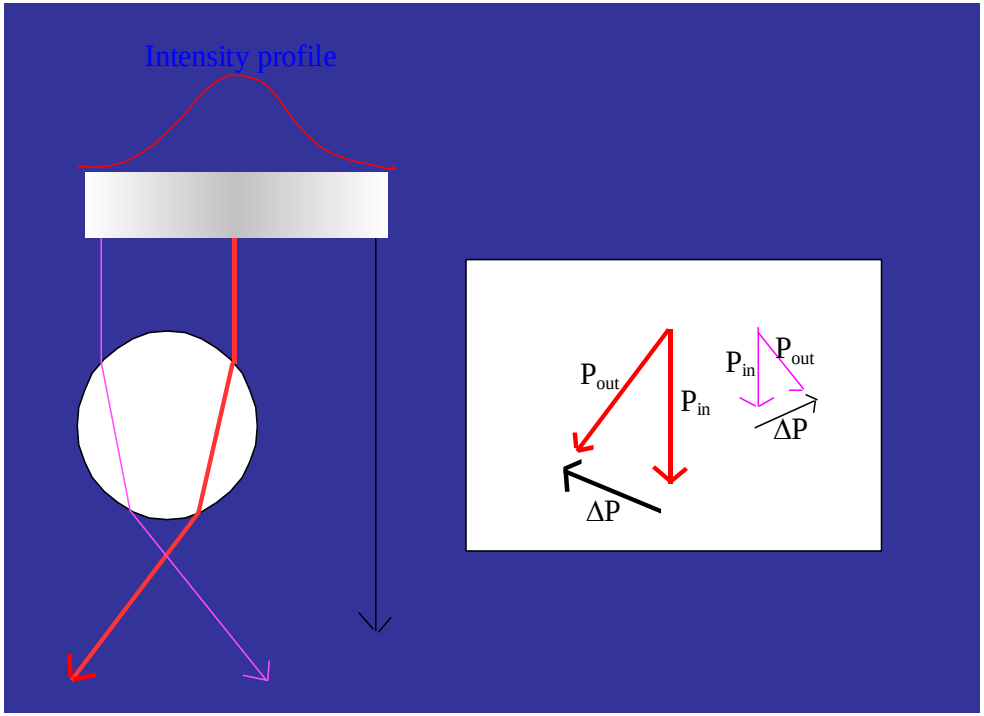


Remember that for a photon
$p = E/c = hf/c = h/\lambda$

- Δp shown is for light beam;
- with the symmetric part, the net Δp for the light is down;
- Δp for particle is opposite

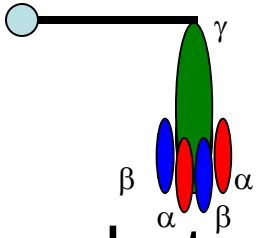
Refraction at the surfaces of a transparent sphere leads to a force directed upwards towards the focal point of the beam - where the intensity is greatest

The Gradient Force



- Dielectric sphere shown off center for a Gaussian profile beam
- Resulting force on particle is larger transverse toward center and net downward toward focus- both acting towards more intense region

Laser tweezers on F1-ATPase



- Actin rod attached to end of shaft with a plastic bead on end
- Laser tweezers used to grab the bead and at very low ATP concentrations, measure the torque produced by the splitting of a single ATP – about 44 pN-nm
- 3 ATP's are needed per full turn – so that the work done per ATP ($\Delta\theta = 2\pi/3$) is $W = \tau\Delta\theta = 92$ pN-nm or 92 x 10^{-21} J, just about the energy liberated by the hydrolysis of one ATP to ADP
- So this reversible molecular rotary motor is nearly 100% efficient
- These studies are leading to the development of artificial rotary motors in nanotechnology