207 News

1) CourseEvalUM is open for student reviews of all courses, including 207, at:
http://www.CourseEvalUM.umd.edu

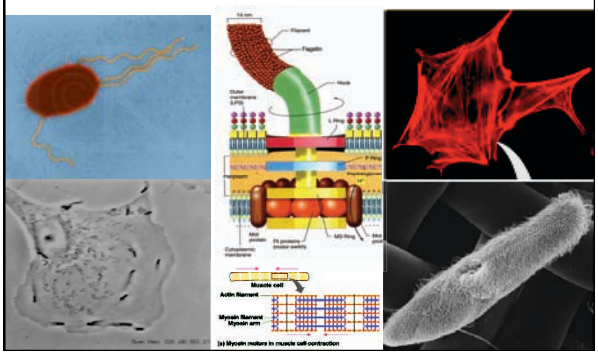
2) Please take 207 attitude survey (for 10 pts) at:
http://perg-surveys.physics.umd.edu/MBEXpost.php
(this url should be available by Monday morning)

3) Mid-term exam 3 handed back at the end of lecture

4) Mid-term exam 3 regrade requests due – next Mon 5/9

5) Final exam (130 pts) – 75 pts on electrical signaling, nervous systems, motility, muscles, and biomechanics, plus 55 pts on comprehensive Q's. Mon 5/16 in BPS 1243/1250 at 8-10 AM!!

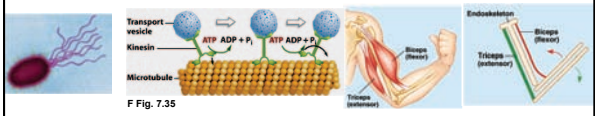
Onwards and Upwards: Motility I - Evolutionary Survey of Molecular and Cellular Mechanisms



Key concept from biomechanics:

Motility depends on forces being applied against stationary "skeletons" composed of:

1) long fibers inside the cell (= cytoskeletons),
2) hard structures (= exo- and endoskeletons),
3) internal fluids (= hydroskeletons), and/or
4) external media (soil, water, air)



F Fig. 7.35

Flagella swimming against medium | Motor protein moving against cytoskeleton | Vertebrate muscle contracting against endoskeleton

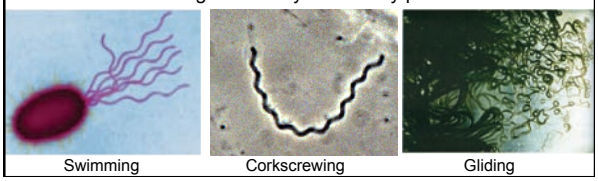
Prokaryotic motility - great diversity of unrelated mechanisms

Most prokaryotic mechanisms apply force outside cell membrane:

1. Swimming - prokaryotic flagella
2. Corkscrewing - endoflagella in spirochetes
3. Gliding - nonswimming movement across solid surfaces

Few prokaryotic mechanisms apply force inside the cell:

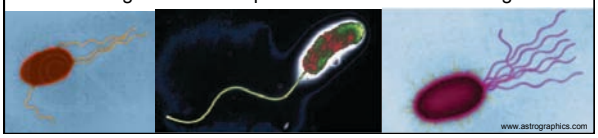
1. Actin rockets - intracellular pathogens recruit host actin
2. Bacterial homologs of eukaryotic motility proteins



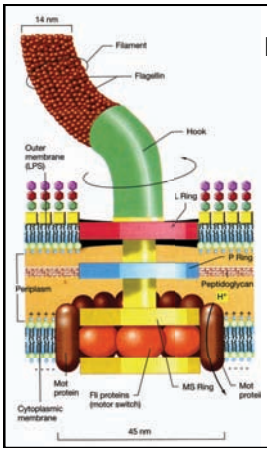
Swimming | Corkscrewing | Gliding

Prokaryotic flagella - swimming behavior

- Long whip-like appendages (20 μm in length) attached to the cell at one end and free at the other
- Composed of >30 different proteins
- Different numbers and different arrangements
- Motile cells accomplish taxis - directional movement
  e.g., chemotaxis, aerotaxis, phototaxis, magnetotaxis
- Astonishing maximum rates (on a prokaryotic scale!)
  sprinting cheetah - up to 110 km/hour = 25 body lengths/sec
  swimming bacterium - up to 17 cm/hour = 60 cell lengths/sec



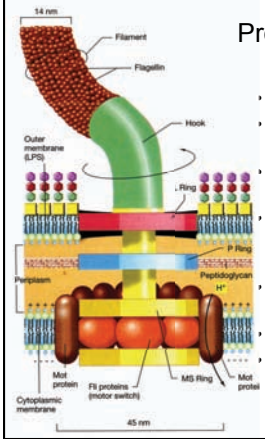
Flagellum in gram-negative bacterium like *E. coli*



- Modified pilus capable of motion
- Extends through cell membrane
- Filament protein - flagellin
- Hollow structure - new flagellin deposition near the tip
- Base composed of >30 proteins
- Ring proteins positioned in membranes and cell wall
- Central shaft can rotate either clockwise or counterclockwise
- A true wheel - very rare in biology

Madigan et al. Fig. 4.41

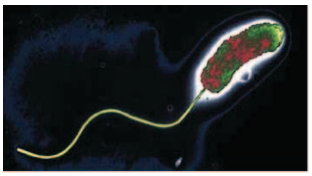
Prokaryotic flagella - amazing molecular machines



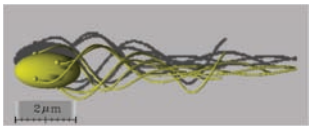
- Proton-powered rotary motor
- Mot (motor) proteins convey H^+ down electrochemical gradient
- Mot proteins generate a torque that rotates the filament
- Fli proteins function as molecular switch to control rotation direction in response to cellular signals
- Energy consumption - 1000 protons per single rotation
- Maximum - 1000 rotations/second
- Yet eukaryotes evolved a different flagellum from other ancient proteins also found in prokaryotes!

Madigan et al. Fig. 4.41

Different types of flagellar arrangements

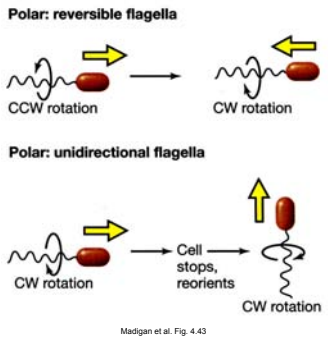


Vibrio cholerae - single polar flagellum (monotrichous)



Escherichia coli - multiple flagella distributed over cell (peritrichous)

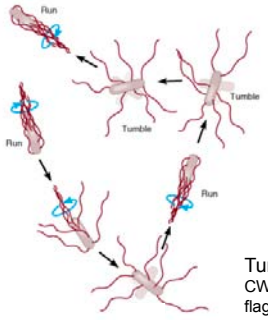
Swimming behavior - monotrichous bacterium



Madigan et al. Fig. 4.43

Swimming behavior - peritrichous bacterium

Swimming - CCW rotation of bundled flagella



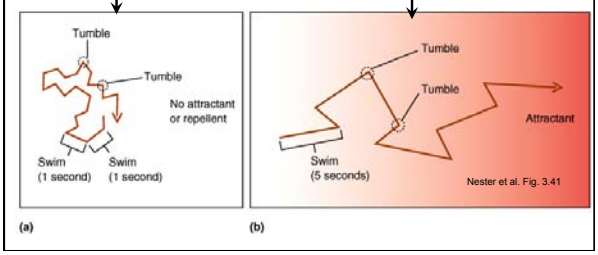
Tumbling - CW rotation pushes flagella apart

(a)

Swimming behavior

Bacterium swimming in absence of gradient- "random walk"

Bacterium swimming in the presence of gradient- "biased random walk"



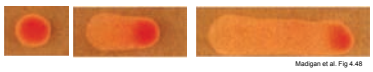
Taxis - directed movement in response to chemical and physical gradients

Chemotaxis - typical assay

Madigan et al. Fig. 4.47

0 hour | Attractant | Control | Repellant

Phototaxis - typical assay



Light

Madigan et al. Fig 4.48

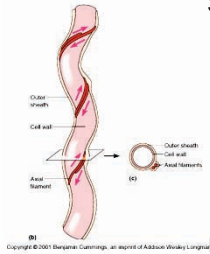
0 hour | 1 hour | 2 hours

Aerotaxis - lower or higher oxygen concentrations

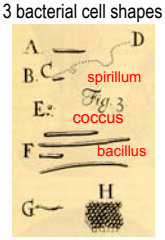
Magnetotaxis - Fe_3O_4 particles (magnetosomes) align some bacteria in magnetic field (uncertain functions)

Madigan et al. Fig 12.32

Corkscrewing - endoflagella in spirochetes



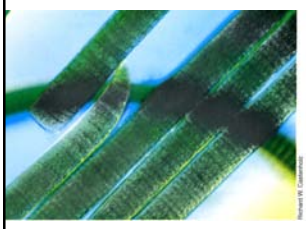
3 bacterial cell shapes

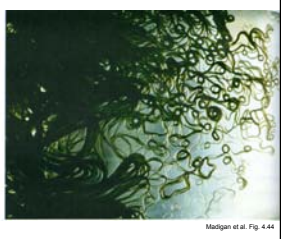


Leewuwenhoek (1684)

Endoflagella - similar to other flagella outside cell wall but embedded in outer sheath
- flagellar rotation causes the twisting of bacterium
- spirillum – one of Leeuwenhoek's 3 types of "wee animalcules"

Gliding - nonswimming movement across solid surfaces





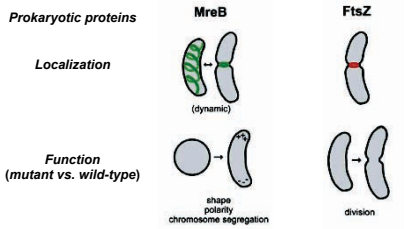
Madigan et al. Fig. 4.44

For example, *Oscillatoria* (filamentous cyanobacterium) moves on tracks of secreted slime that adheres to solid surfaces or other filaments.

Deep molecular homology means that we can find homologs of that gene family in all major lineages. Homologous genes encode for proteins with:

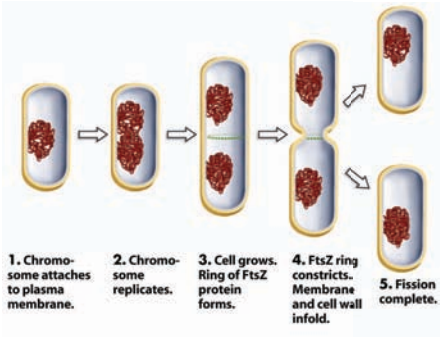
1. identical functions
2. identical, related, or sometimes even different functions
3. different functions

Recent discoveries - several "obscure" prokaryotic proteins



Big surprises: FtsZ - universal prokaryotic division protein in archaea, bacteria, and eukaryotic organelles
MreB - genetic basis of Leeuwenhoek's other 2 shapes (coccus vs. bacillus)
Homologs of eukaryotic motility proteins - FtsZ ~ tubulin and MreB ~ actin

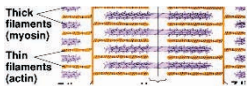
Binary fission in bacteria – FtsZ ring



F. Fig 11.8

Eukaryotic motility - diverse mechanisms, largely depending on two proteins

1. One set of motility mechanisms involves the protein **actin**, its polymer (**microfilaments**), and its motor protein (**myosin**).
2. Another set involves the protein **tubulin**, its polymer (**microtubules**), and its motor proteins (**dynein** and **kinesin**).
3. Energetics - ATP or GTP hydrolysis powers the formation of the polymers and the movement of the motor proteins
4. Cytoplasmic localization, as opposed to the extracellular localization of most prokaryotic mechanisms
5. Osmotic mechanisms - e.g., carnivorous plants, sensitive plants

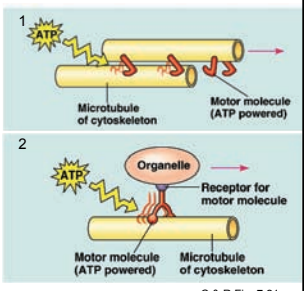


Basic unit of skeletal muscle - sacromere

Mimosa pudica - sensitive plant

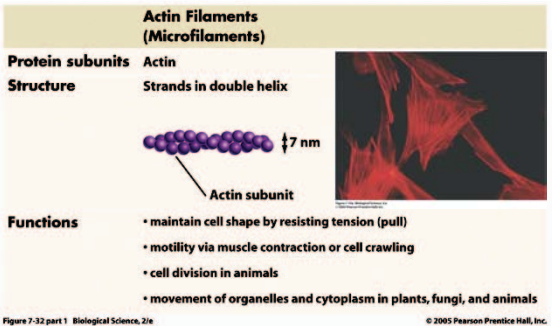
General mechanisms - eukaryotic motility

1. Motor proteins pull cytoskeletal elements past each other, e.g., microtubules in cilia and flagella, thin (micro)filaments in muscles
2. Motor proteins move proteins, vesicles, and organelles on cytoskeletal elements to different intracellular regions
3. Polymerization and depolymerization of cytoskeletal elements is also involved in cellular motility.



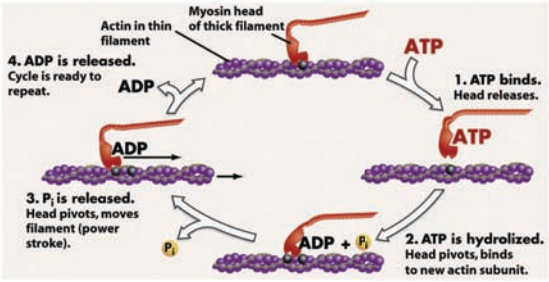
C & R Fig. 7.21

Actin and Microfilaments - F. Table 7.3



- Microfilaments form a 3-D network often localized just inside the cell membrane and around the nucleus
- Eukaryotic homolog of prokaryotic protein **MreB,** which is also involved in cell shape

Microfilaments, myosin, and motility



- ATP hydrolysis cause myosin to undergo a conformational change.
- Myosin converts chemical energy of ATP into mechanical energy.
- Rigor mortis in dead bodies - myosin locks on actin due to no more ATP

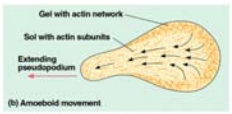
F. Fig. 46.22

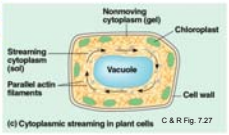
Microfilaments, myosin, and motility

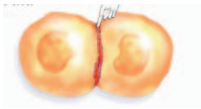
Amoeboid movement/cell crawling - myosin moving on microfilaments squeezes the cytoplasm to cause forward movement of pseudopodium whose shape is fixed by the position of new microfilaments

Cytoplasmic streaming in walled cells - myosin is cross-linked between parallel arrays of microfilaments and cytoplasmic organelles, and the movement of myosin along the microfilaments causes cytoplasmic movement

Cell division in most eukaryotes - a ring of actin and myosin filaments attach to the membrane. Actin and myosin filaments slide past each other, causing the ring to shorten. The attached membrane is pinched inward, creating the cleavage furrow.

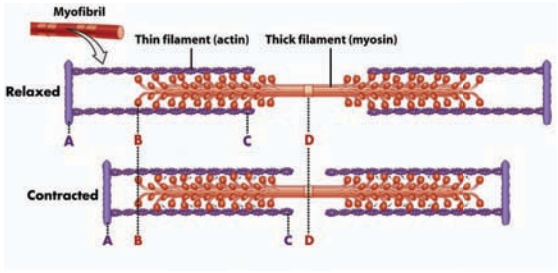






F. Fig. 7.32

Microfilaments, myosin, and motility



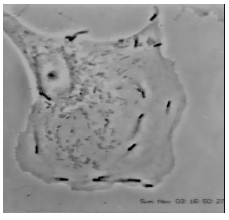
Muscle contraction - myosin forming thick filaments hydrolyzes ATP to move along thin filaments composed of actin, thereby shortening the muscle F. Fig. 46.20

Certain pathogenic bacteria - intracellular movement by recruiting host actin

For example, *Shigella dysenteriae* and *Listeria monocytogenes* survive, replicate and move around inside of mammalian cells.

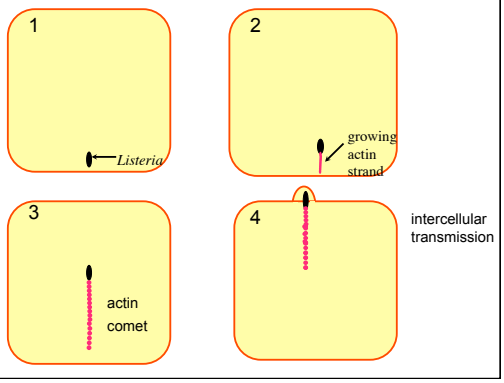
Listeria attached to "actin comets" in host (intestinal) cell – 60X speed

David Mosser (CBMG)

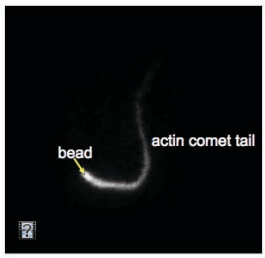


http://www.youtube.com/watch?v=sF4BeU60yT8

Actin comet formation in intestinal cell



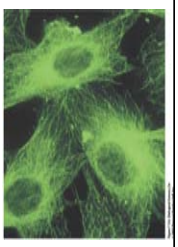
ActA protein from bacteria on latex bead stimulates the polymerization of host actin



ActA-coated latex bead moving in cytoplasmic extract from frog cells

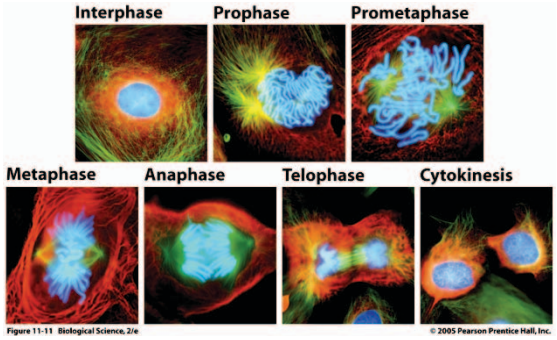
Tubulin and microtubules - F. Table 7.3

	Microtubules
Protein subunits	α-tubulin and β-tubulin dimers
Structure	Hollow tube
	25 nm
	Tubulin dimer
Functions	• maintain cell shape by resisting compression (push)
	• motility via flagella or cilia
	• move chromosomes during cell division
	• formation of cell plate during plant cell division
	• move organelles
	• growth of plant cell walls



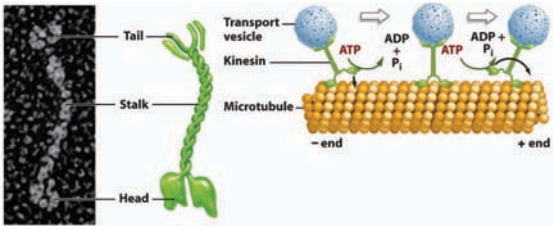
- Microtubules form a 3-D network often reaching across the cytoplasm
- Eukaryotic homolog of prokaryotic protein FtsZ, which is also involved in cell division

Microtubules and mitotic spindle in an animal cell



DNA appears blue / microfilaments red / microtubules green
F. Fig. 11.10

Microtubules and intracellular transport F Fig. 7.35

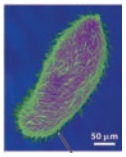


- Kinesin - a motor protein associated with microtubules
- ATP hydrolyses causes each segment of kinesin head to undergo a shape change, such that kinesin with attached vesicle moves down the microtubule track.

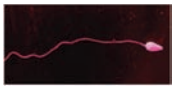
Microtubules and cilia/flagella

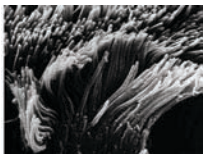
Cilia - many whip-like structures 2-20 μm in length
Flagella - one or a few whip-like structures 10-200 μm in length
Same "9 + 2" internal arrangement of microtubules

Functions - External surfaces of unicellular and small multicellular organisms for motility
Internal surfaces of large multicellular organisms for fluid movement

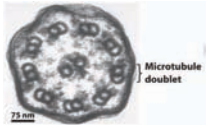


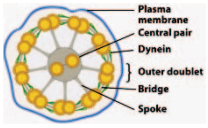
F Fig. 7.38
Ciliated paramecium

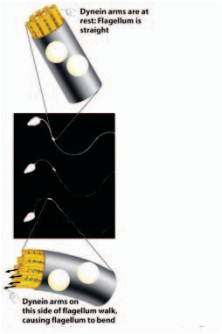

C & R Fig. 7.2
Flagellated sperm


C & R Fig. 7.23
Surface view of rabbit trachea

Cilium/flagellum action - F. Fig. 7.37/38







- "9 + 2" arrangement of microtubules inside cell membrane.
- Motor protein dynein hydrolyzes ATP to generate walking motion.
- Entire structure undulates via dynein arms pulling, and then releasing adjacent outer MT doublet on one side

Evolutionary perspectives

1. Eukaryotic motility mechanisms use certain homologous proteins also found in prokaryotes.

   Prokaryotic FtsZ is homologous to eukaryotic tubulin
   Prokaryotic MreB is homologous to eukaryotic actin

2. But eukaryotic mechanisms use cytoskeletal structures that are not homologous to prokaryotic structures.

Flagellum type	Subunit	Action	Axis location
Prokaryotic	Flagellin	Rotation in membrane	Outside cell membrane
Eukaryotic	Tubulin	Undulation along axis	Inside cell membrane

Prokaryotic binary fission uses a FtsZ ring
Eukaryotic cleavage furrow uses actin and myosin filaments

Study questions = Learning objectives

Describe different types of prokaryotic motility.

Compare and contrast the structure, energy source, and mechanism of action of bacterial flagella vs. eukaryotic flagella.

Name and describe the roles of the homologs of actin and tubulin in bacteria.

Describe the general features of how cytoskeletal elements and motor proteins interact to generate motility in eukaryotes.

Describe the structure of actin filaments and their roles in the cytoplasmic movements of various organisms.

Describe the structure of microtubules and their roles in eukaryotic motility.

Describe the evolutionary relationships in the motility mechanisms of prokaryotes vs. eukaryotes.