Lecture 9: Directed motion in the cell

Goal: Introduce directed motion, driven by non-equilibrium, energy consuming processes.

- Overview of classes of motors
- Ratchet estimates

PBOC Chapter 16.1, 16.3.3

Motion in the cell

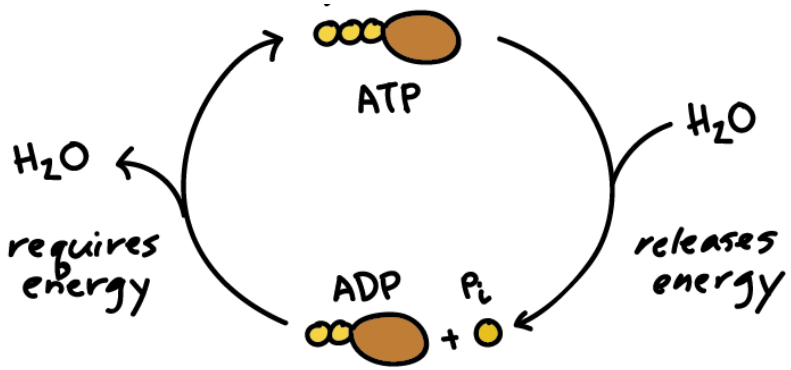
Active vs. passive transport

Directed motion in the cell

What forms of energy are used?

Directed motion in the cell

What forms of energy are used?



Directed motion in the cell

Directed motion in the cell

Mechanisms

i) Translational motors
ii) Rotary motors
iii) Polymerization ratchets
iv) Translocation ratchets

Directed motion in the cell

Translational motors

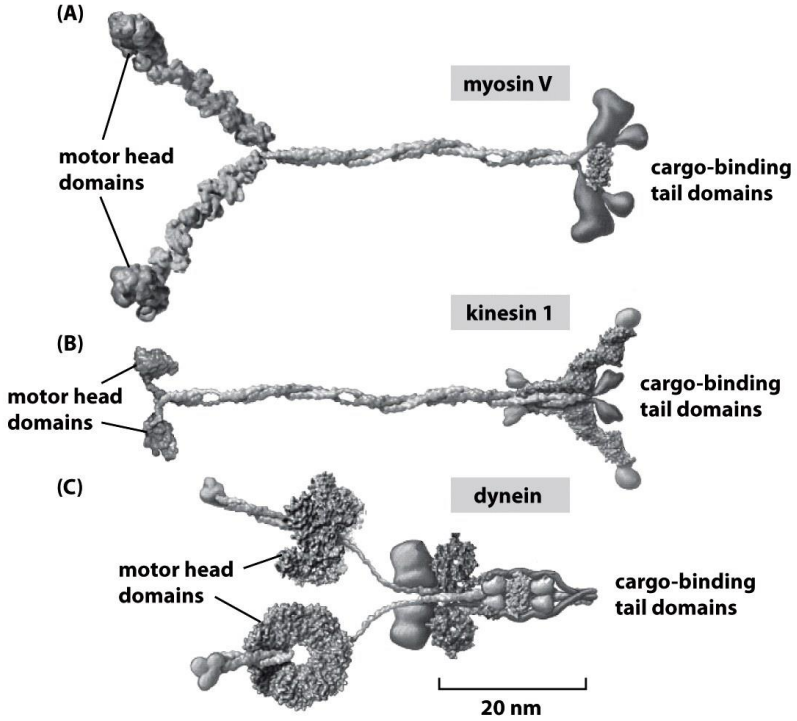
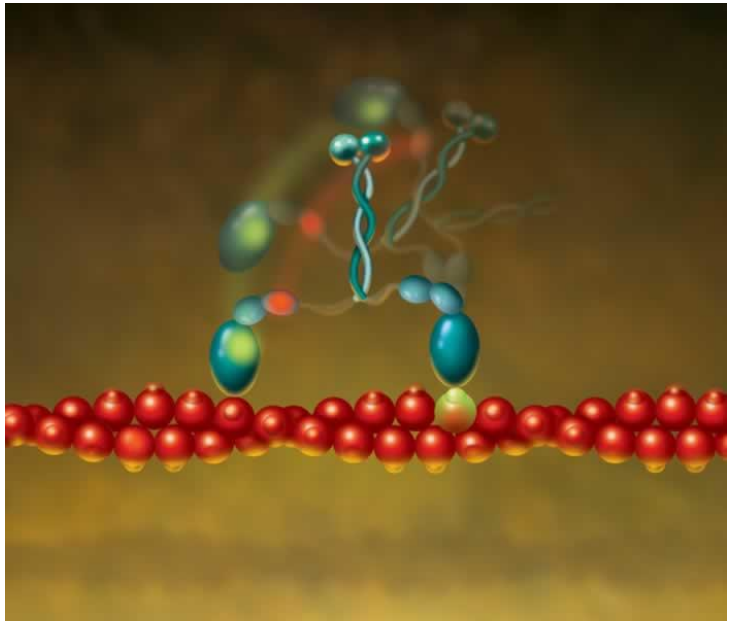


Figure 16.2 Physical Biology of the Cell (© Garland Science 2009)

Directed motion in the cell

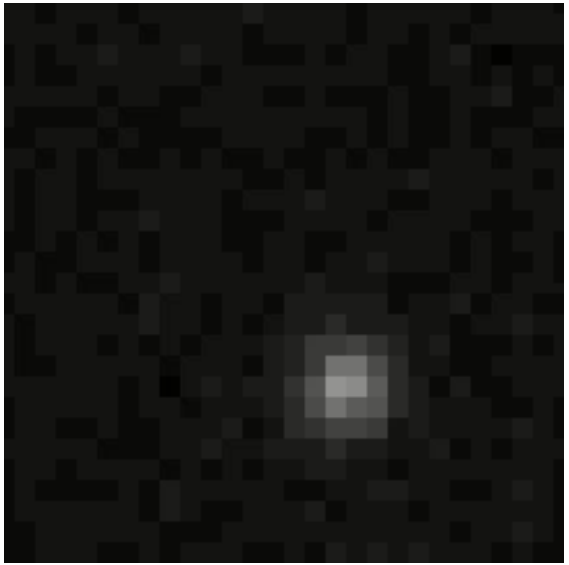
Translational motors

Experiment:



Directed motion in the cell

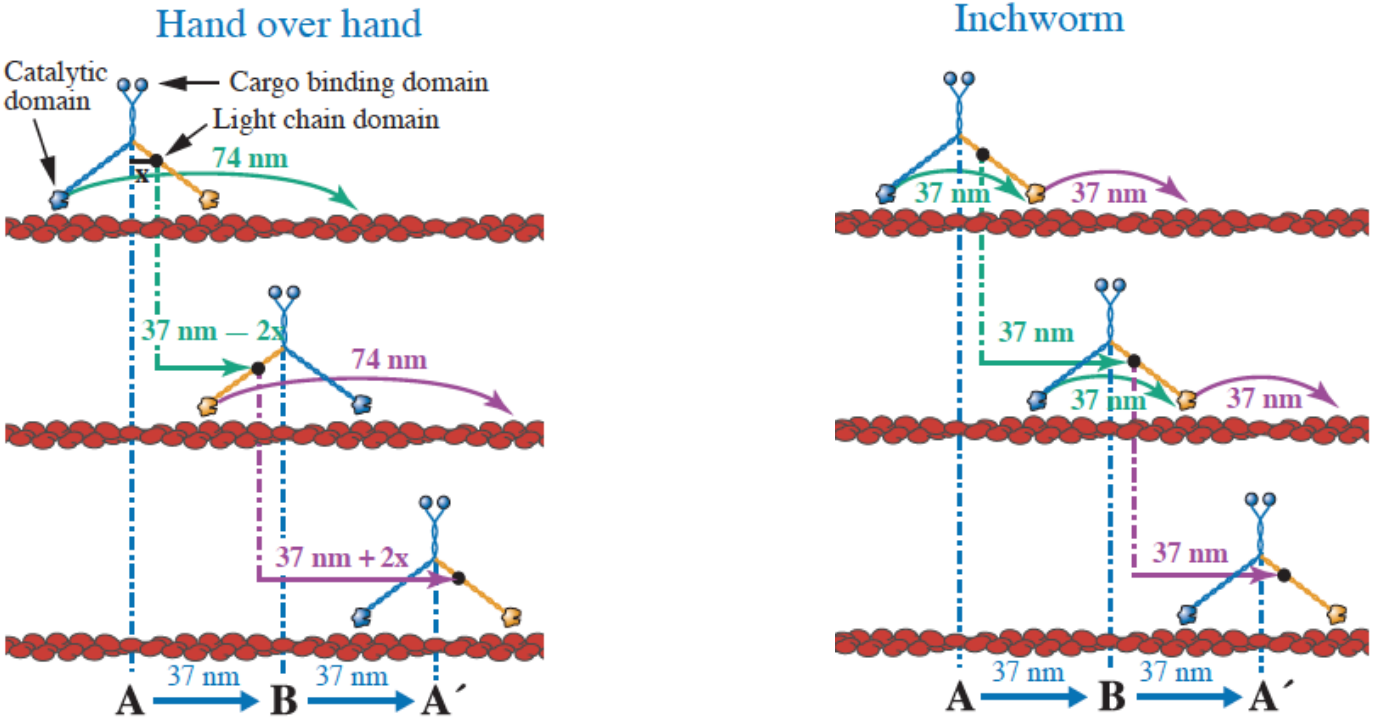
Translational motors



Movement of a single fluorescent dye attached to myosin V for the lower right trace shown in Fig. 3. Each pixel is 86 nm. Discrete steps are clearly visible. The intensity is in gray-scale.

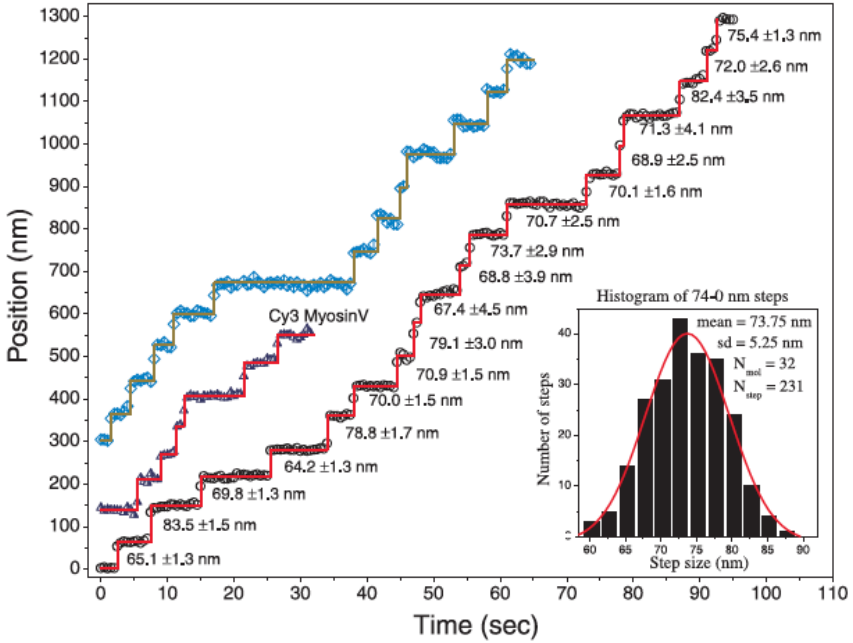
Directed motion in the cell

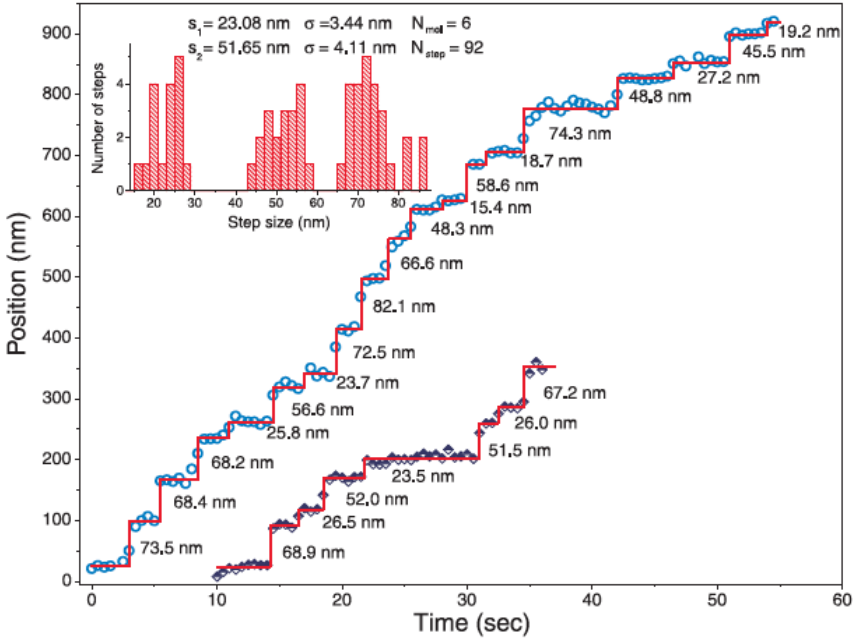
Translational motors



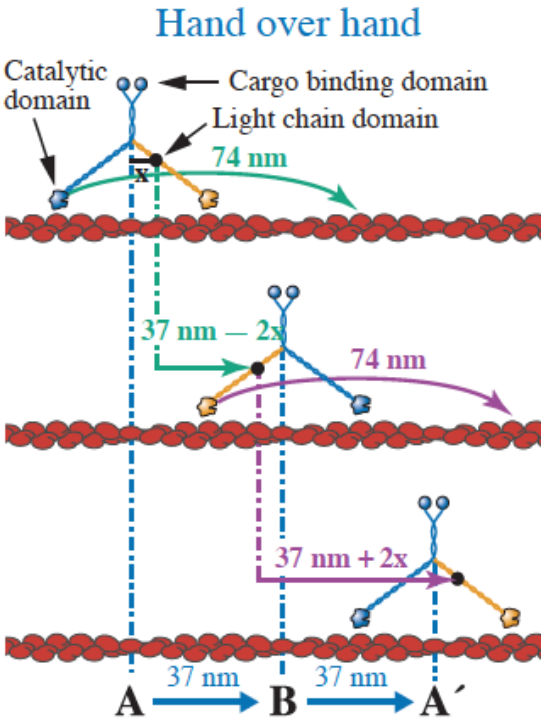
Directed motion in the cell

Translational motors





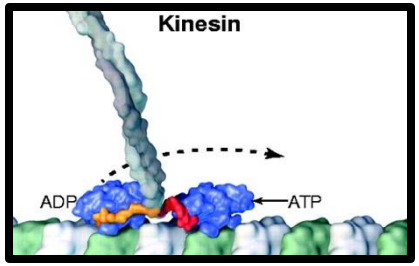
Directed motion in the cell



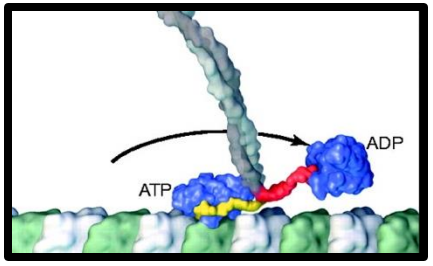
Myosin V Walks Hand-Over-Hand: Single Fluorophore Imaging with 1.5-nm Localization

Ahmet Yildiz,[1] Joseph N. Forkey,[3] Sean A. McKinney,[1,2] Taekjip Ha,[1,2] Yale E. Goldman,[3] Paul R. Selvin[1,2*]

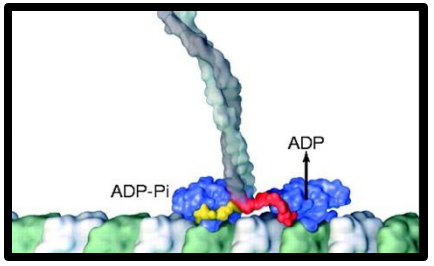
Directed motion in the cell



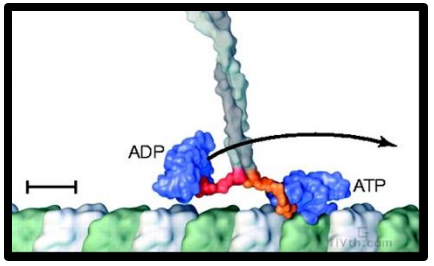
1. Both catalytic cores, “heads” (blue) are bound to tubulin (green/white). Mechanical element is the neck linker (red/orange)



2. ATP binding to the leading head allows the neck linker to dock (yellow). This throws the trailing head forward.



3. After a random diffusional search, the new leading head docks onto the tubulin binding site. This completes the 80 Å displacement step.



4. ADP dissociates, then ATP binds to the leading head and the neck linker begins to zipper onto the core (orange). The trailing head, which has released its Pi and detached its neck linker (red) from the core, is in the process of being thrown forward.

Directed motion in the cell

Rotational motors

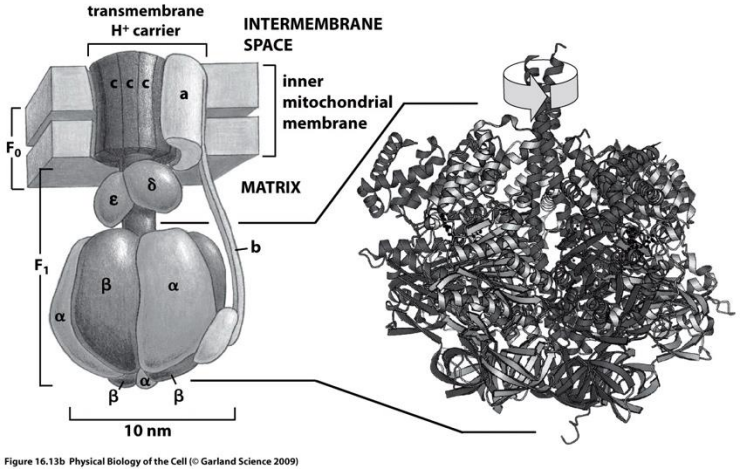


Figure 16.13b Physical Biology of the Cell (© Garland Science 2009)

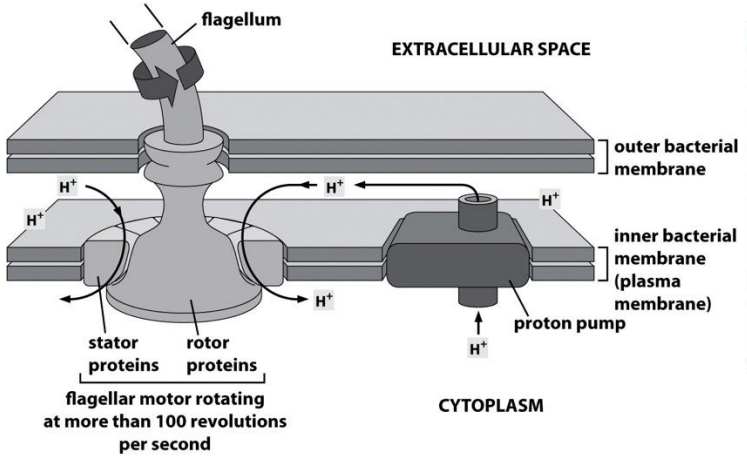
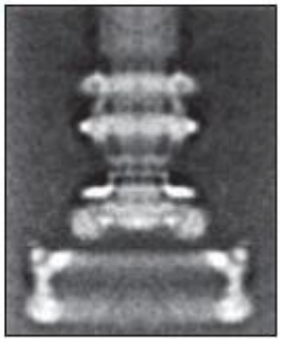


Figure 16.13a Physical Biology of the Cell (© Garland Science 2009)



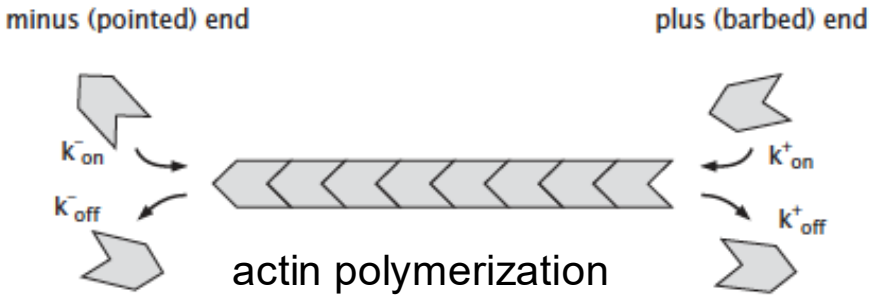
ATP synthase

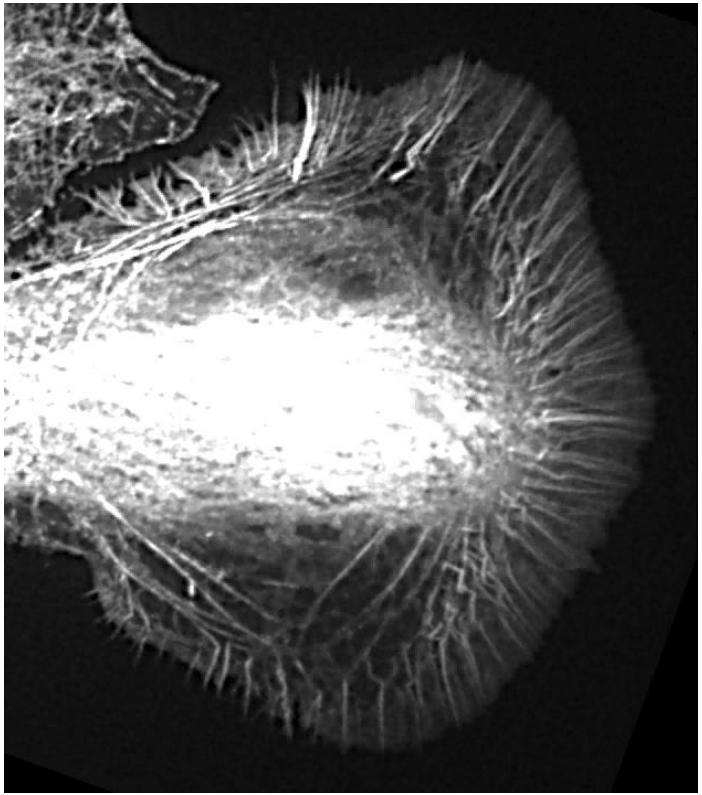
bacterial flagellum

https://www.youtube.com/watch?v=cwDRZGj2nnY

Directed motion in the cell

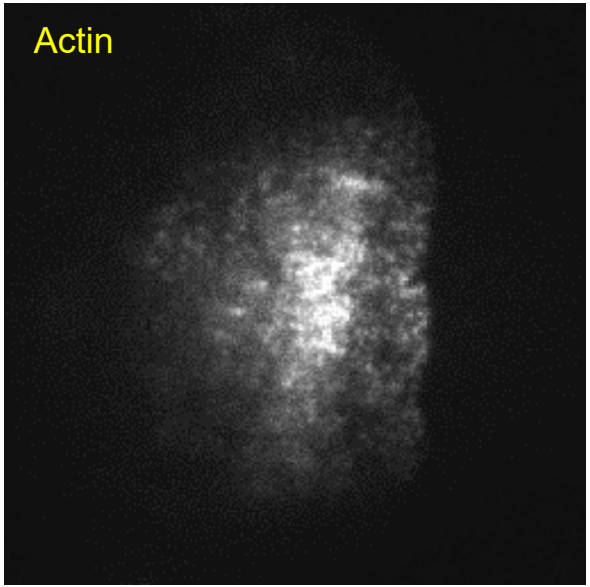
Polymerization motors

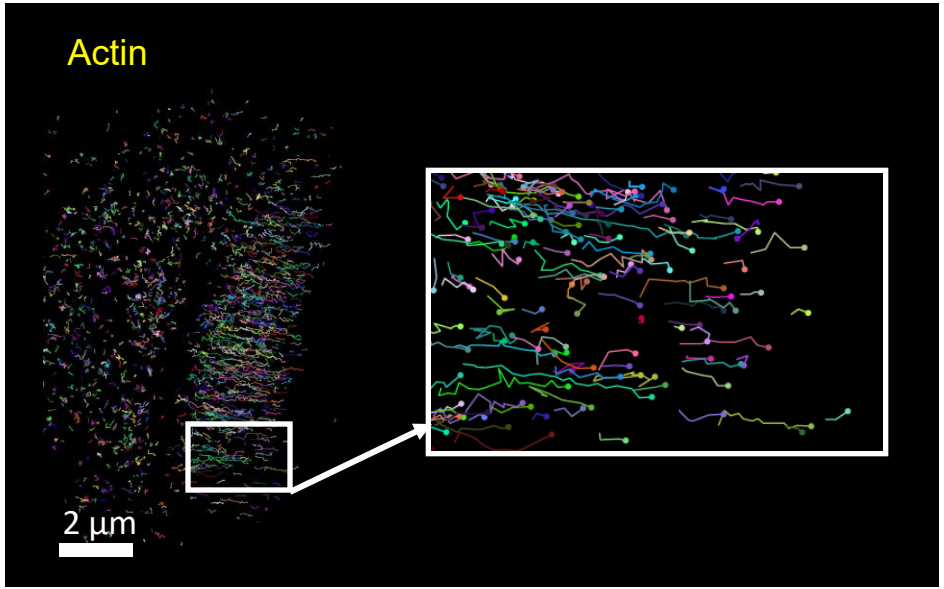




Directed motion in the cell

Polymerization motors

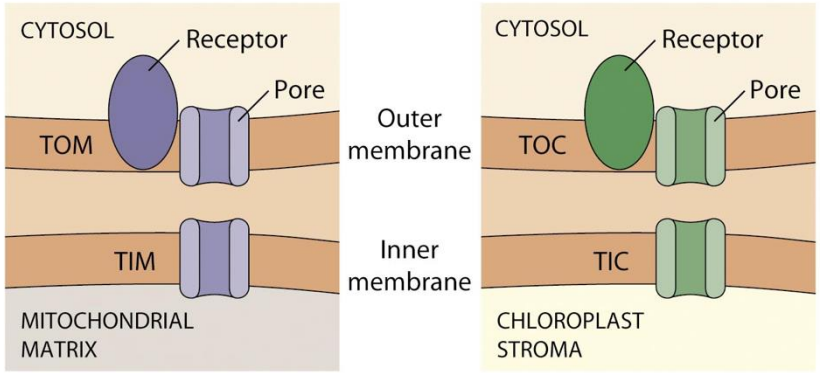




Directed motion in the cell

Translocation motors

Move macromolecules across membranes
(nucleic acids, proteins)



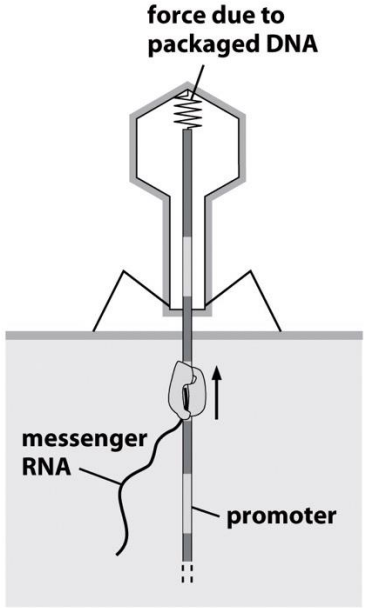
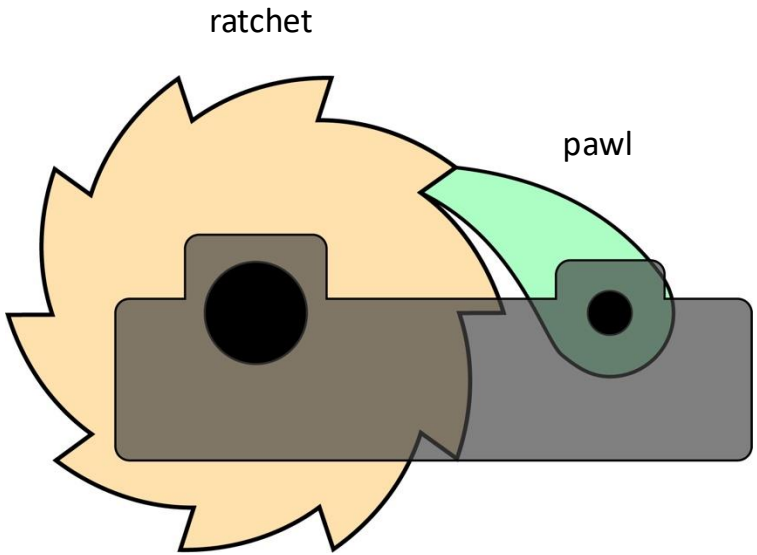


Figure 16.17b Physical Biology of the Cell (© Garland Science 2009)

Transport in cellular systems

Ratchets enforce unidirectionality



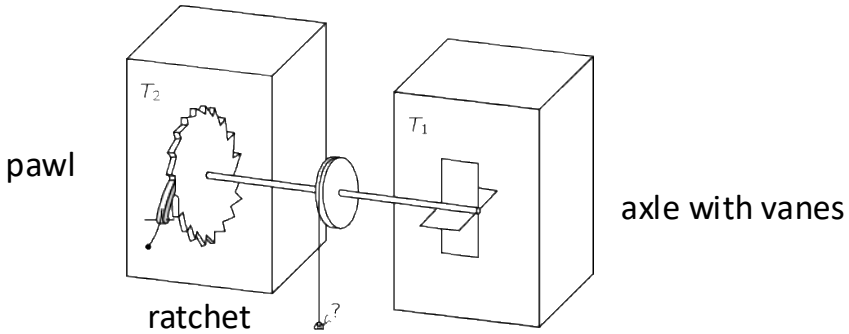
a device in which a toothed rack or wheel is engaged by a pawl to permit motion in one direction only

Transport in cellular systems

Brownian ratchet: Perpetual motion

Recall: Carnot, work cannot be extracted from a system in the absence of a temperature gradient.

Feynman proposed a thought experiment.



- molecular collisions turn paddle
- pawl allows ratchet to turn only in one direction

What is missing?

Transport in cellular systems

Directed motion: Translocation

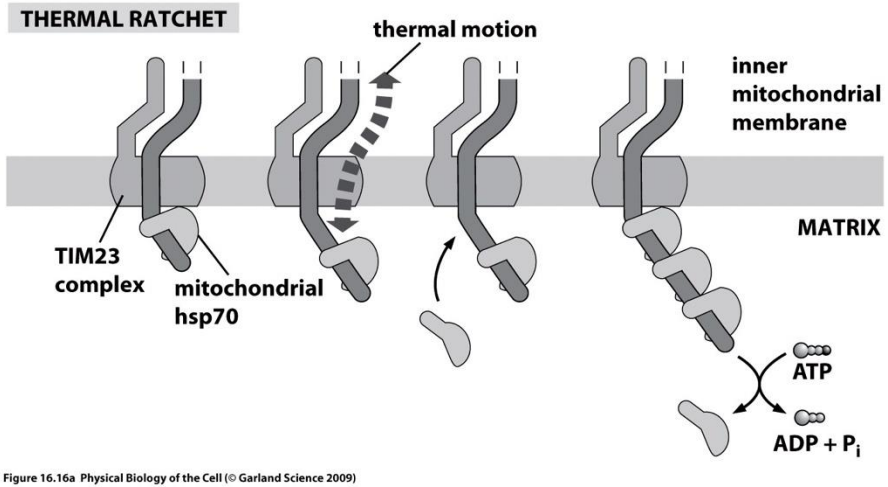


Figure 16.16a Physical Biology of the Cell (© Garland Science 2009)

- thermal motion
- binding enforces direction
- non-equilibrium aspect

Transport in cellular systems

Directed motion: Translocation

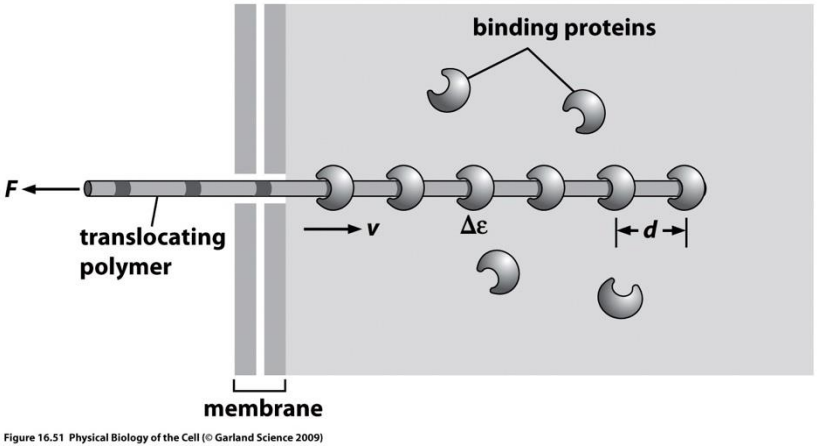


Figure 16.51 Physical Biology of the Cell (© Garland Science 2009)

Estimate two timescales:

1. Time for polymer to diffuse by its length L

2. Time for polymer to diffuse by its length L when assisted by binding (translocation ratchet)

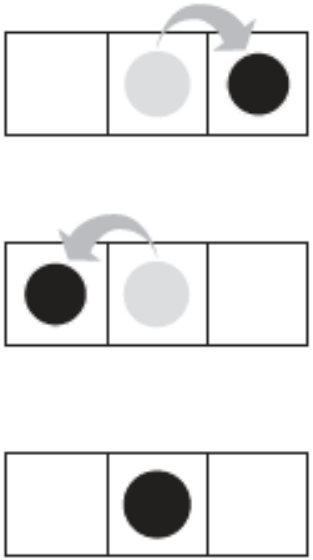
Transport in cellular systems

Directed motion: Translocation

TRAJECTORY

DISPLACEMENT *x*

WEIGHT



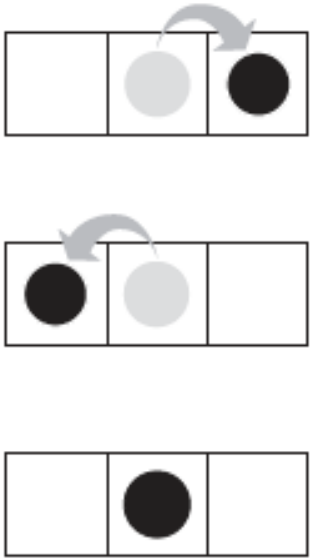
Transport in cellular systems

Directed motion: Translocation

TRAJECTORY

DISPLACEMENT *x*

WEIGHT



Lecture 9: Directed motion in the cell

Summary: