

Physical Principles in Biology
Biology 3550
Fall 2017

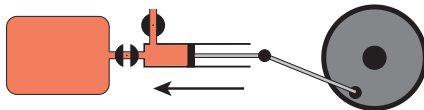
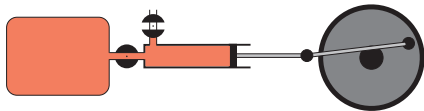
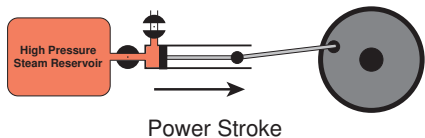
Lecture 36

Introduction to Molecular Motors

Monday, 27 November

©David P. Goldenberg
University of Utah
goldenberg@biology.utah.edu

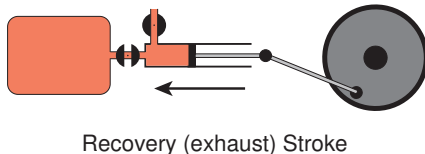
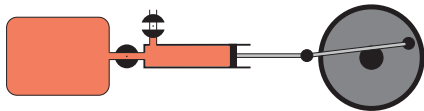
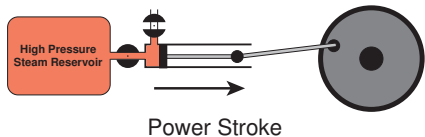
A Simple Steam Engine



Recovery (exhaust) Stroke

- Energy source is a pressure difference, created by a temperature difference.
- Free energy of steam is lost as it expands.
- Expansion of steam is coupled to movement of piston and flywheel, capturing some of the energy.
- Momentum of the flywheel returns engine to starting state.
- Valves control flow of steam and must be synchronized to piston movement.
- If flow of steam is unlinked from motion of piston or wheel, free energy is lost.

A Simple Steam Engine



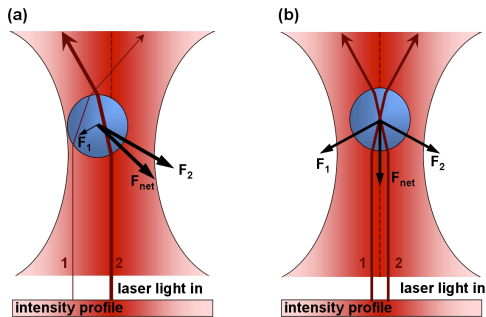
■ Similar requirements for a molecular motor:

- Loss of free energy (*e.g.*, ATP hydrolysis) must be coupled to mechanical work.
- Motor must operate cyclically.
- Individual steps in cycle must be regulated.

■ Important differences for a molecular motor:

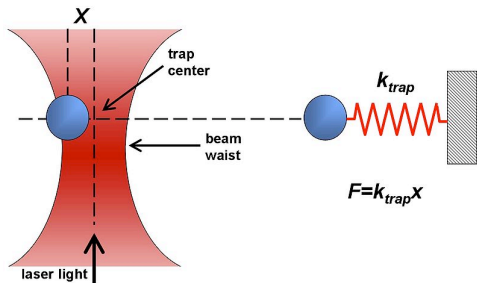
- No temperature differences at the molecular scale.
- No momentum at the molecular scale.

A Tool for Studying Molecular Forces: Optical Tweezers



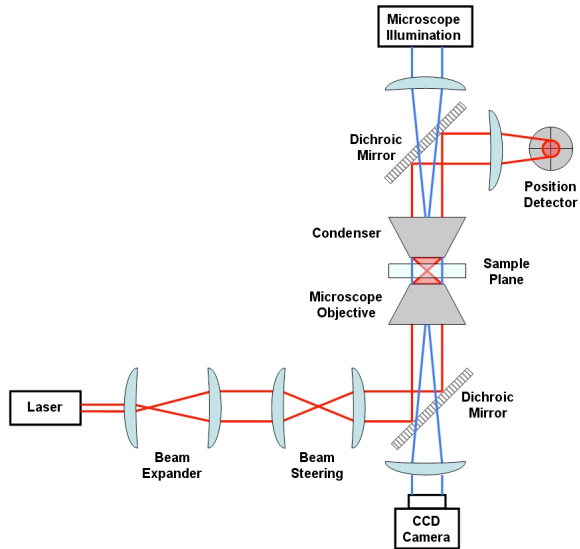
- Glass or silica beads ($\sim 1 \mu\text{m}$ diameter) placed in a narrowly focused beam of light.
- Light is refracted (bent) by the bead, resulting in a force on the bead.
- if bead is outside of the beam center, there is a net force that pulls it to the center.
- At the center of the beam, forces on bead are balanced.

A Tool for Studying Molecular Forces: Optical Tweezers



- Force of optical trap acts like a spring: Force is proportional to distance of bead from beam center.
- If another force is acting on the bead, that force can be measured from displacement of bead.

Optical Tweezers Apparatus

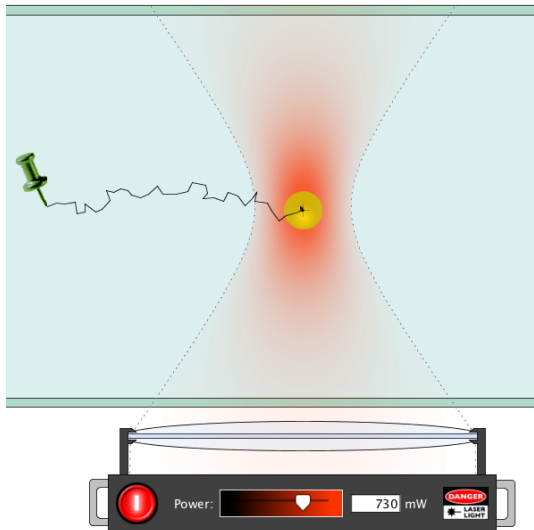


- Apparatus based on an optical microscope.
- Laser provides light for trap.
- Beam position can be “steered”
- Microscope allows the bead to be observed.
- Bead position is tracked with position detector.

Figure from:

https://en.wikipedia.org/wiki/Optical_tweezers

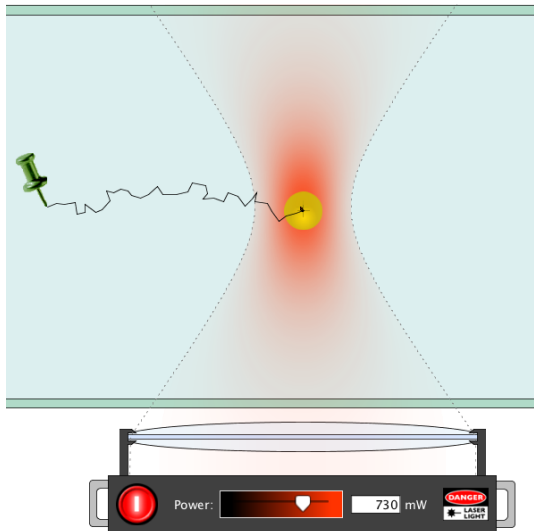
Stretching DNA with Optical Tweezers



- One end of DNA is held in fixed position.
- Other end of DNA is attached to a bead.
- Bead is trapped in focused laser light.
- Optical trap can be used to move bead.
- What happens if the laser is turned off?

DNA stretching demo: <https://phet.colorado.edu/en/simulation/legacy/stretching-dna>

Clicker Question #1



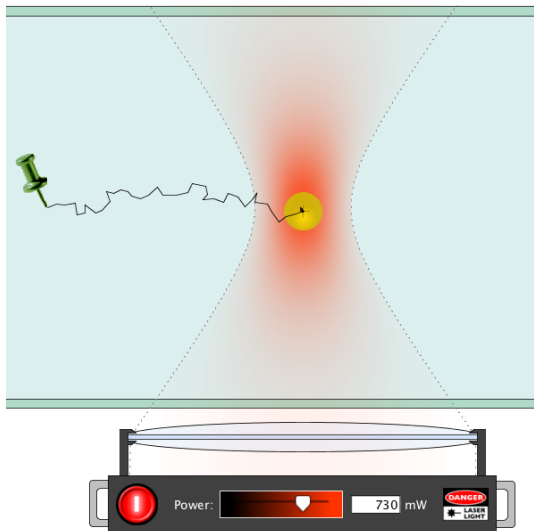
What happens if the laser is turned off?

- 1 The bead stays put.
- 2 The bead moves randomly by Brownian motion.
- 3 The bead moves towards the fixed DNA end.
- 4 The bead moves away from the fixed DNA end.

All answers count for now.

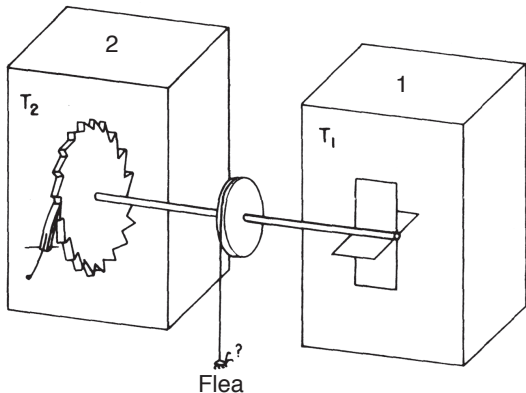
DNA stretching demo: <https://phet.colorado.edu/en/simulation/legacy/stretching-dna>

Stretching DNA with Optical Tweezers



- Thermal motion of solvent molecules generates a force.
- Force increases as DNA ends are moved further apart.
- Force is entropic in nature: There are more possible conformations with the ends closer together.
- Force does not depend on a temperature difference.
- Could a motor be built using this kind of force?

A “Brownian Ratchet”



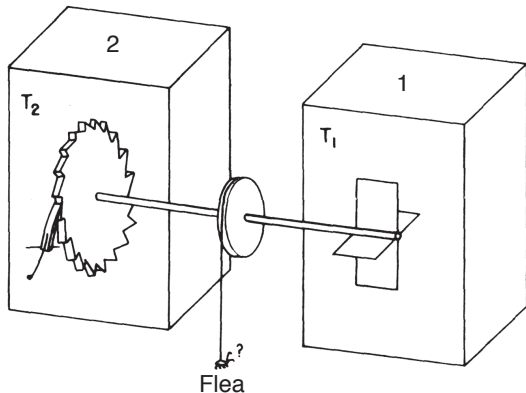
- Thermal motions of gas molecules in compartment 1 make paddle wheel jiggle back and forth.
- Ratchet mechanism in compartment 2 allows motion in only one direction.
- String is wound onto the pulley and the flea is slowly lifted.
- Will this work?

Feynman, R. P., Leighton, R. B. & Sands, M. (2013).
The Feynman Lectures on Physics, volume I,
chapter 46. Basic Books

http:
[//www.feynmanlectures.caltech.edu/I_46.html](http://www.feynmanlectures.caltech.edu/I_46.html)

Clicker Question #2

Will the Brownian ratchet lift the flea?



- 1 Yes
- 2 Only if the temperature of compartment 1 is greater than that of 2.
- 3 Only if the temperature of compartment 2 is greater than that of 1.
- 4 No

All answers count for now.

In the absence of a temperature difference, thermal motion can generate a force and directional motion, but cannot drive a cyclic motor.