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Biophysics in the Classroom

OAPT Conference

Friday, May 3, 2013

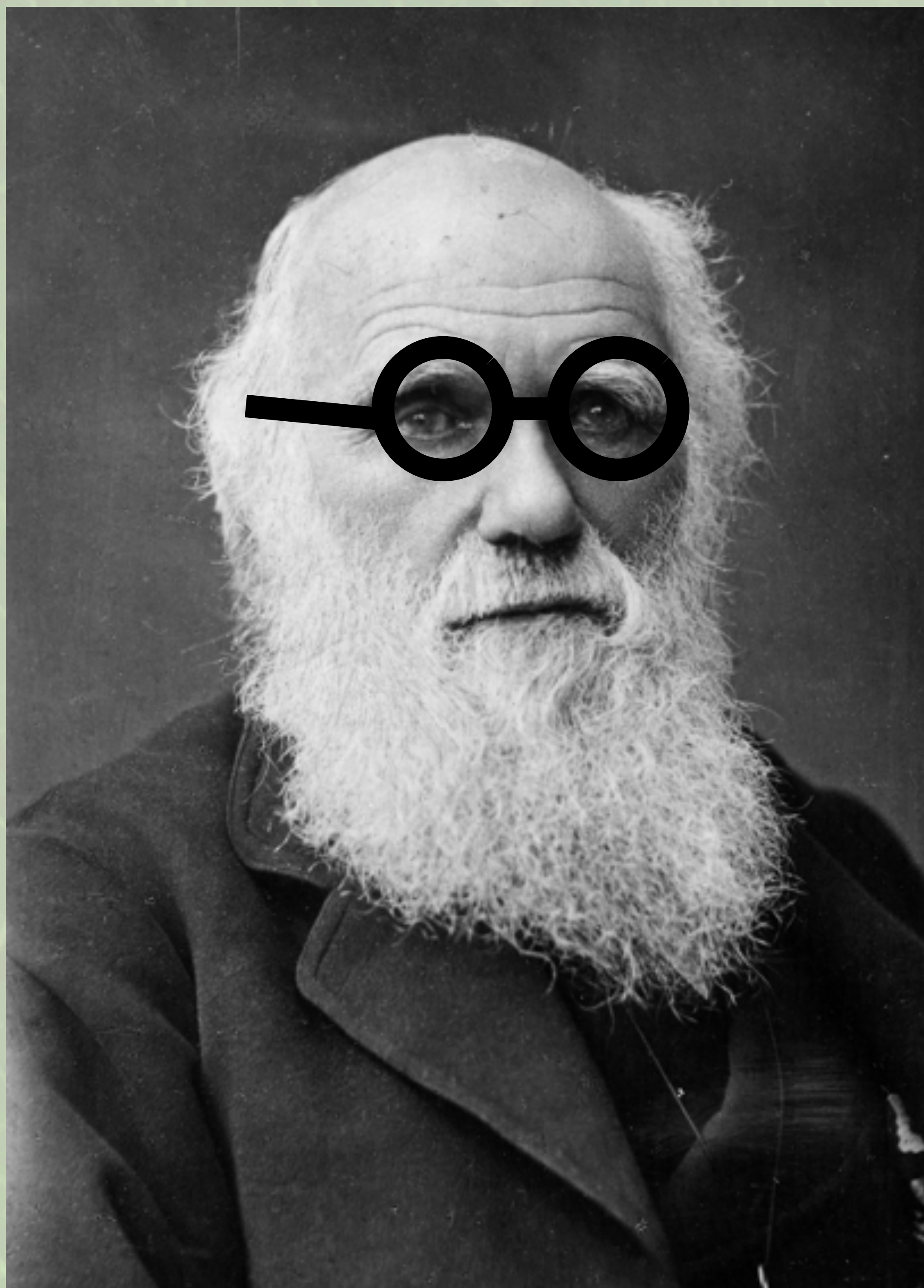
Presented by: Sara Cormier

Outline

- Biophysics - what is it?
- Why bring biology into the physics classroom?
- Simple examples:
    - Grasshoppers
    - Geckos
- Diffusion
    - Qualitative experiment
    - Quantitative experiment

Image Source: 1. http://commons.wikimedia.org, photo taken by Sander van der Molen
2. http://www.grasshoppercontrol.com

Biophysicists



- Biologists with physicists glasses
- Look at biological questions using physics tools and techniques
- Unique perspective often leads to deeper understanding of system
- Prime example of interdisciplinary nature of science

Image Source: www.amnh.org

Examples of Biophysics

- Membrane constituents using neutron scattering
- Protein folding simulations and modeling
- Force measurements on worms and cells
- Magnetotactic bacteria

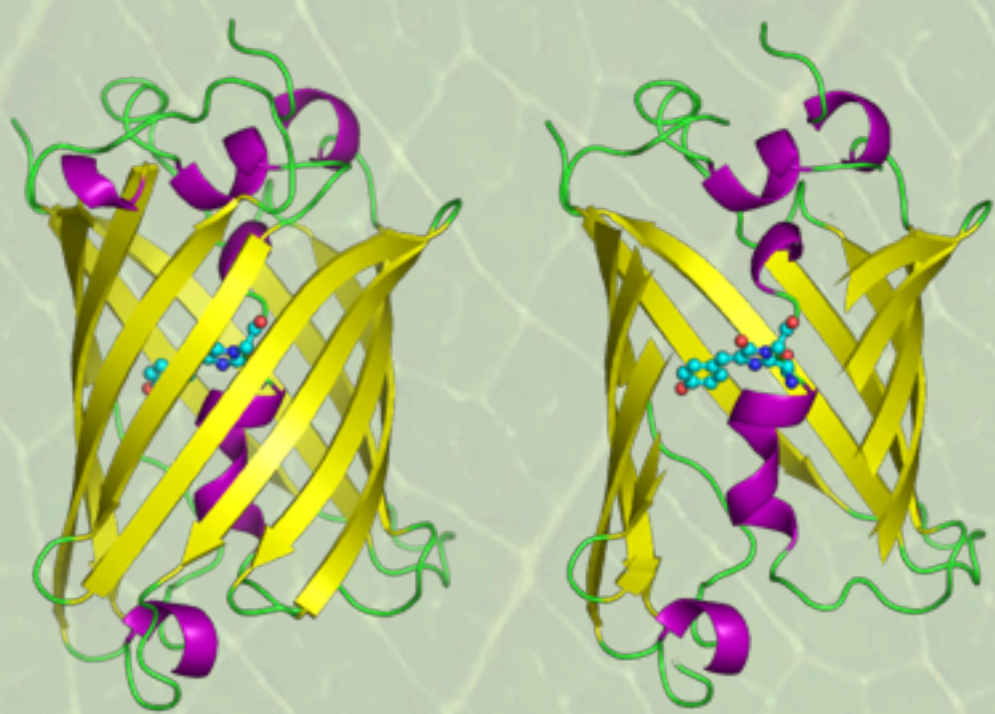
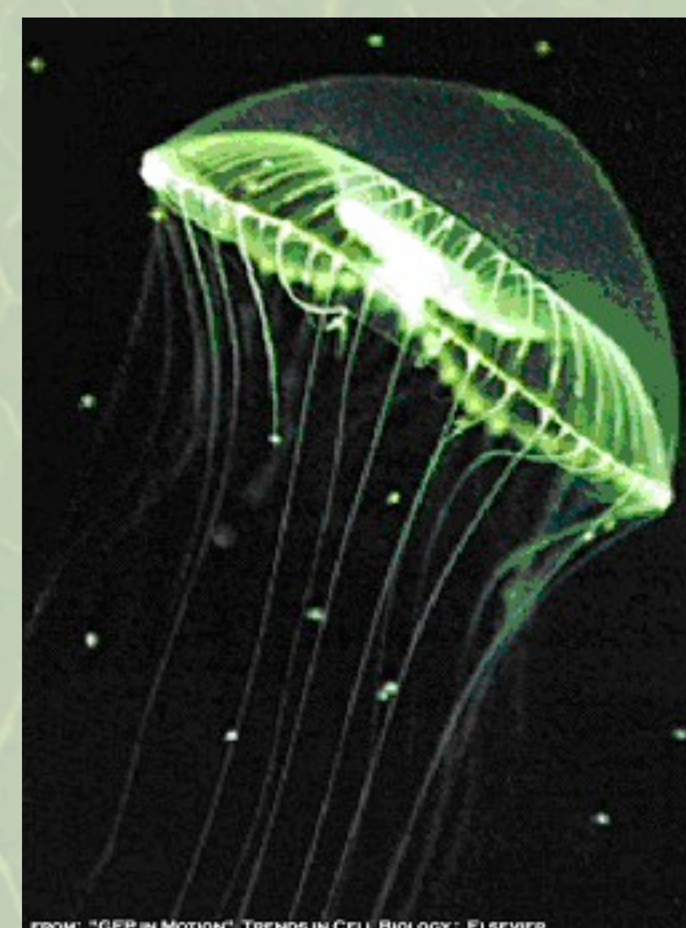


Image Source: 1. www.rcsb.org/pbd
2. McMaster University

Biophysics

- Question: How do you determine precisely the temperature within an individual cell without sticking a thermometer in the cell?
- Answer: We still do not know but one idea is to monitor fluorescent blinking of the Green Fluorescent Protein (GFP)

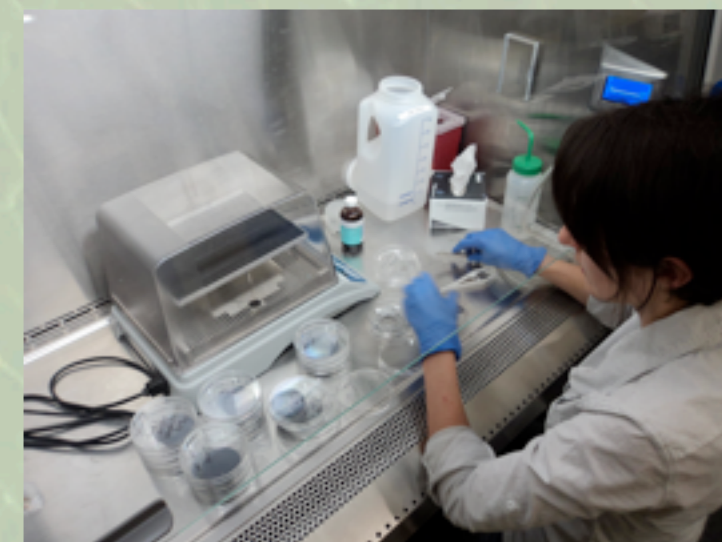
Image Source: news.nationalgeographic.com

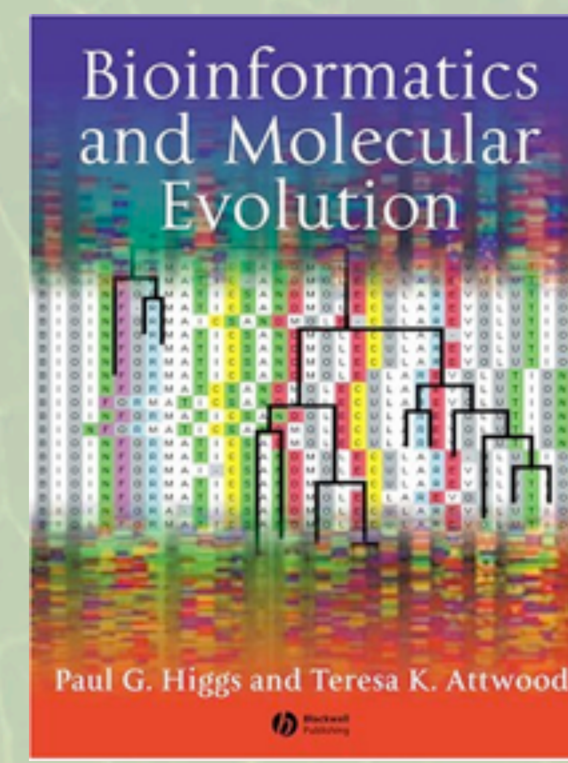


FROM: "GFP IN MOTION" TRENDS IN CELL BIOLOGY; ELSEVIER

Biophysics at McMaster

- Brand new 4 year Honours Biophysics program
- General first year - apply in second year (limited enrollment)
- Combination of core physics courses complemented with biochemistry and biology
- Research experience beginning in second year





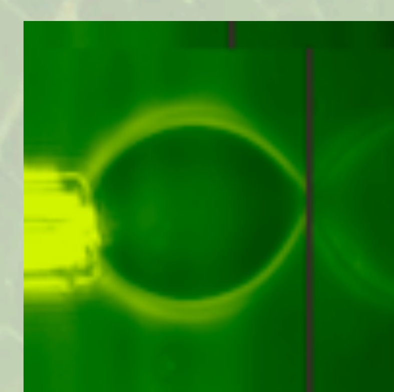


Image Source: www.physics.mcmaster.ca

Biophysics in the Classroom

- Include students who are more interested in biological and life sciences
- Highlight the importance of physics in all branches of science (even medicine)

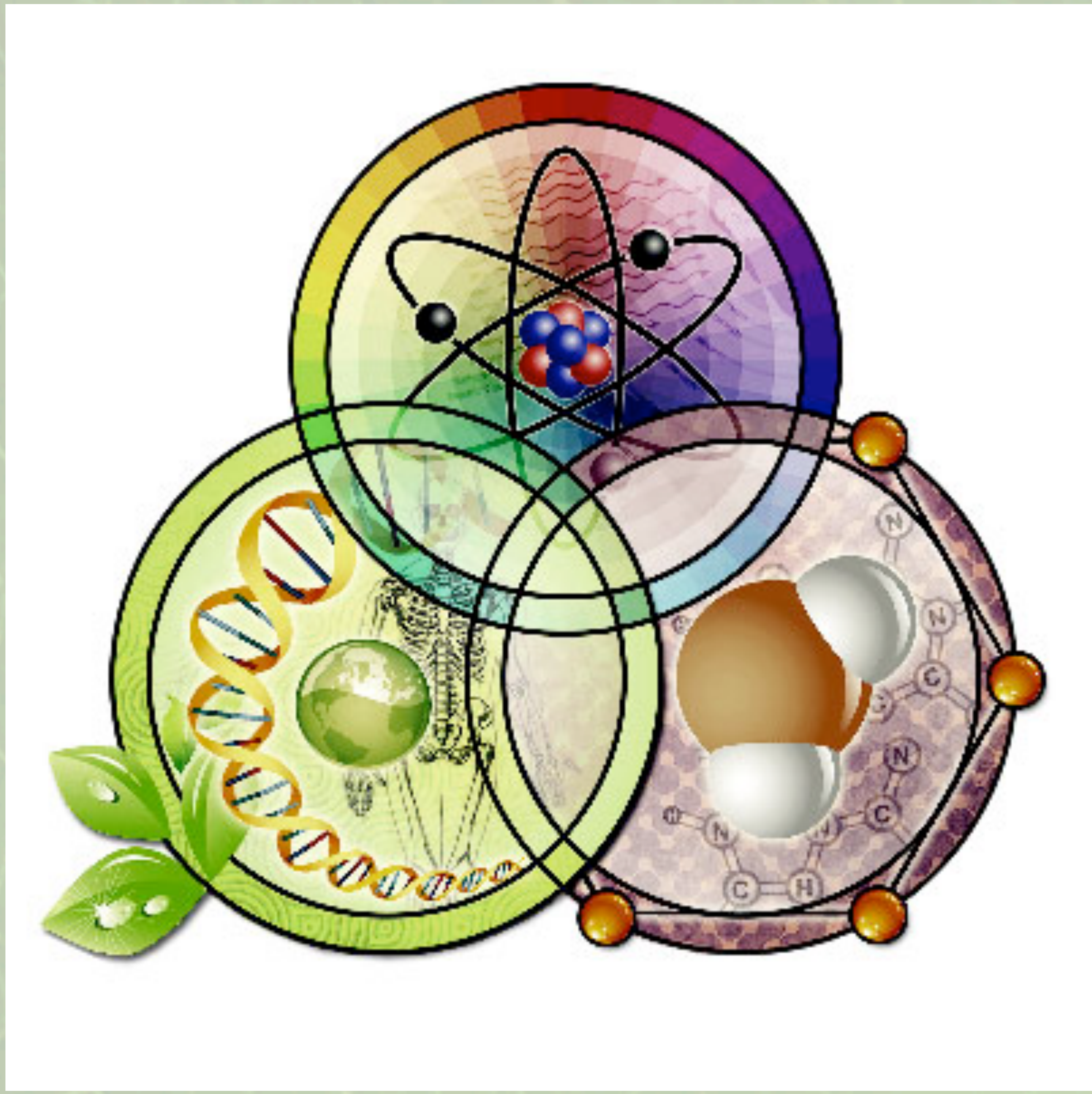


Image Source: http://thepickledhedgehog.com

Grasshopper Power?

- Simple way to add biophysics to the classroom: apply physics concepts to biological systems - use realistic numbers

Example: How much power does a grasshopper output while jumping? (example from first year biophysics course at McMaster)

video link of grasshopper jumping (at 0:37 second mark) : http://www.youtube.com/watch?v=cevL1RWcmqQ

Grasshopper Power?

Question: A grasshopper of mass 0.3g has hind legs that extend 4cm during takeoff at an angle of θ=50° to the horizontal. The grasshopper jumps a total horizontal distance of 75cm. What power does the grasshopper exert during the jump?

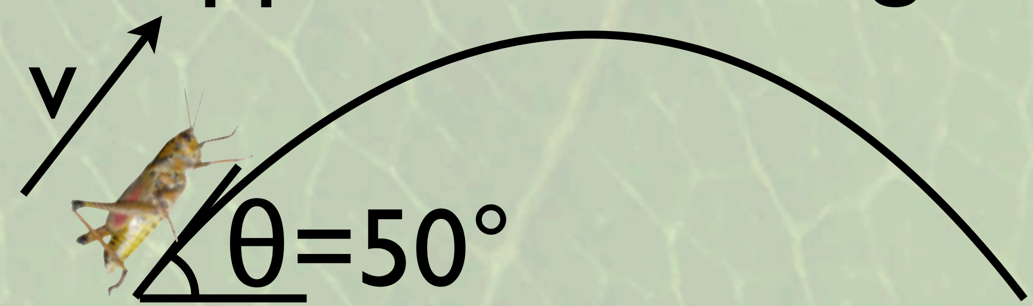
$m_{grasshopper}$=0.3g

Grasshopper Power?

Solution: We must determine the work exerted during the takeoff as well as the time that work is exerted:

$$P = \frac{\Delta W}{\Delta t} \qquad \Delta W = \frac{1}{2}mv^2$$

What velocity does the grasshopper leave the ground with?



x	y
$v_x = v\cos(\theta)$	$v_{yi} = v\sin(\theta)$
$d_x = 75\text{cm}$	v_{yf}
t	t
	$a = g$
	$d_y = 0$

$$d_x = vcos\theta \cdot t \longrightarrow t = \frac{d_x}{vcos(\theta)}$$

$$d_y = -\frac{1}{2}gt^2 + vsin\theta \cdot t \longrightarrow v = \frac{gt}{2sin\theta}$$

$$v = \sqrt{\frac{0.75 \cdot 9.8}{2sin50cos50}} = 7.46\text{m/s}$$

Grasshopper Power?

Work during takeoff:

$$\Delta W = \frac{1}{2}mv^2 \quad = \frac{1}{2}0.0003 \cdot 7.46^2 = 8.35\text{x}10^{-3}\text{J}$$

Time during the takeoff:

$$v_i = 0\text{m/s}$$

$$v_f = 7.4\,\text{m/s}$$

$$d = 0.04\text{m}$$

$$t = \frac{2d}{v_i + v_f} \quad = \frac{2 \cdot 0.04}{7.46} \quad = 0.0107\text{s}$$

Power:

$$P = \frac{\Delta W}{\Delta t} \quad = \frac{8.35\text{x}10^{-3}}{0.0107} \quad = 0.78\text{W}$$

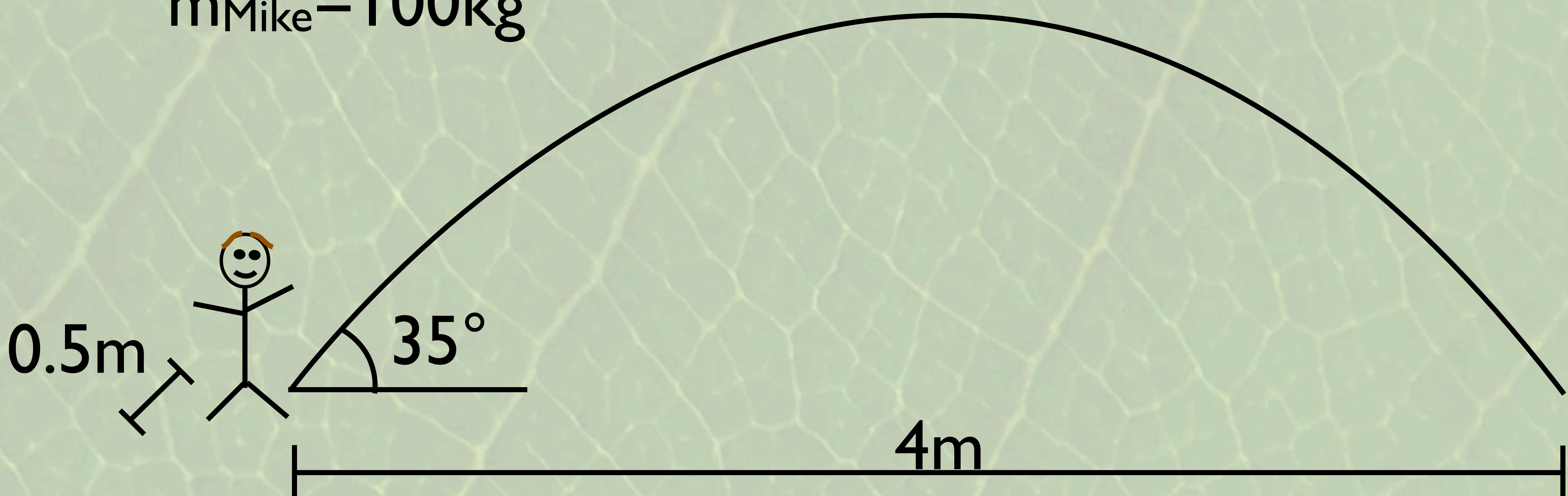
Grasshopper Fun Facts

- Grasshoppers can jump 10x their length in height and 20x their length in distance (equivalent to humans jumping as high as a five storey building or as long as a basketball court)
- Cuticle in grasshopper's knee acts like a spring to catapult grasshopper during jump
- Grasshoppers experience 10-20g during the takeoff of a jump

Grasshopper vs. Human

Question: How much power does Mike, the 100kg human, exert while competing in the long jump competition? Mike's legs extend 0.5m during the jump at an angle of 35° and he is able to jump a horizontal distance of 4m.

m_{Mike}=100kg



Grasshopper vs. Human

Answer (human): $P = 1.3\text{x}10^4\text{W}$

Recall (grasshopper): $P = 0.78\text{W}$

Comparison:

- Energy density is almost the same - human and grasshopper have approximately the same velocity at takeoff
- Power density of grasshopper is ~20x more the power density of a human (faster and shorter takeoff)

Gecko Feet

- Geckos can walk and run quickly upside-down and vertically
- Effective movement on a variety of different surfaces

- Feet are self cleaning - never lose their stickiness
- Nanoscale order - tiny hairs, called setae, "stick" to surfaces with van der Waals forces
- Why? survival

Image Source: 1. http://commons.wikimedia.org, photo taken by Sander van der Molen

Gecko Feet

Ted talk on animal movement, skip to the 13:30 minute mark to hear about geckos and see them run up a vertical wall and peel their feet off surfaces.
http://www.ted.com/talks/robert_full_on_animal_movement.html

Video Source: Ted.com, Robert Full

Gecko Forces?

Question 1: How much force/mm^2 does it take for a 55g gecko to hang upside down if each foot is 115mm^2?

Solution:

$$F_N = mg$$
$$= 0.055 \cdot 9.8$$
$$= 0.539\text{N}$$

Total contact area:

$$= 4 \cdot 115 \quad = 460\text{mm}^2$$

Force per unit area:

$$= 1.2\text{x}10^{-3}\text{N}/\text{mm}^2$$

W. R. Hansen & K. Autumn, PNAS, (2005).

image: © Franco Andreone [www.francoandreone.it]

Gecko Forces?

Question 2: Each gecko foot contains setae (14 400 setae/mm^2). Each setae can withstand up to 200μN. What is the minimum surface contact that a gecko must have to hang upside-down? If all four feet are in full contact how much mass could a gecko theoretically hold?

Solution:

Setae required to hold gecko's weight:

$$F = 0.539\text{N}$$

$$\#\text{setae} = \frac{0.539}{2\text{x}10^{-4}} = 2695$$

Surface area of 2695 setae:

$$= \frac{2695}{14400} = 0.19\text{mm}^2$$

W. R. Hansen & K. Autumn, PNAS, (2005).

Gecko Forces?

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Solution:

Total # Setae:

$$= 460 \cdot 14400$$

$$= 6\,624\,000$$

Force

$$= 6\,624\,000 \cdot 2\text{x}10^{-4} = 1320\text{N}$$

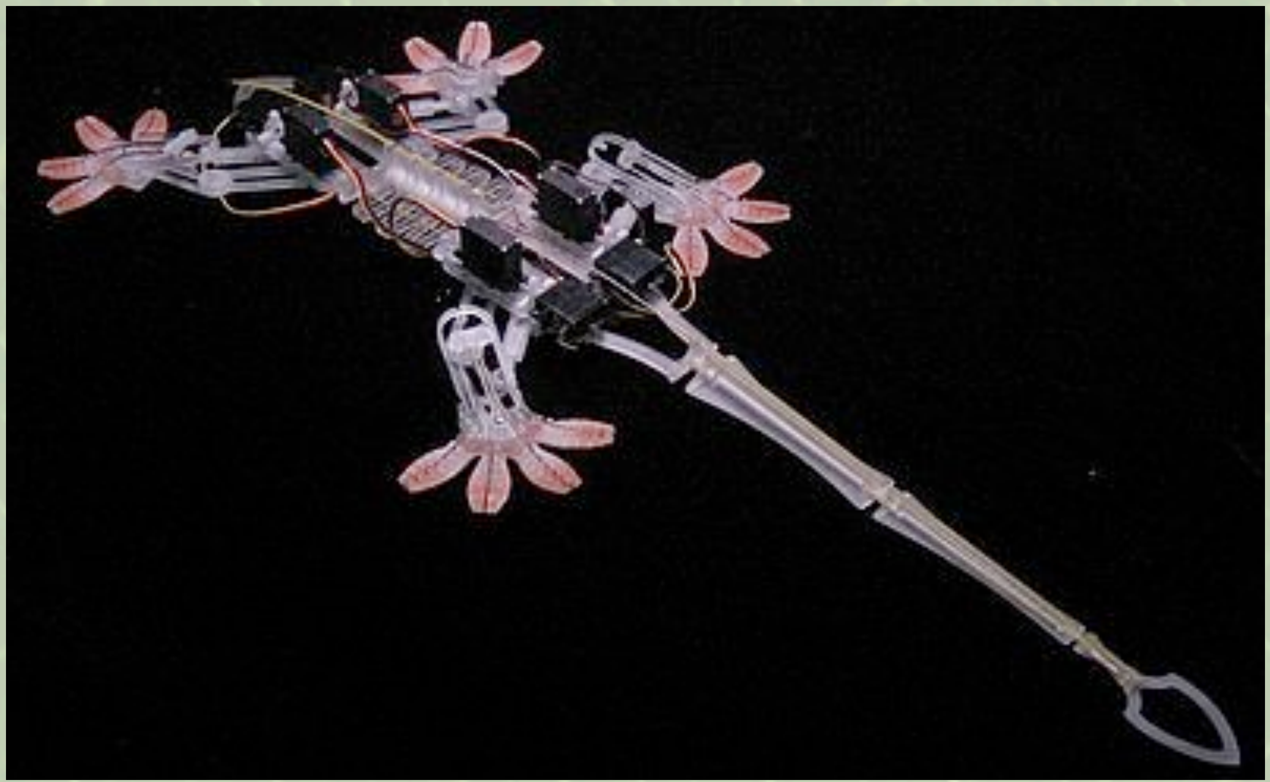
$$m = \frac{1320}{9.8} = 1.3\text{x}10^{2}\,\text{kg}$$

Geckos can support up to 2000x their own weight!

W. R. Hansen & K. Autumn, PNAS, (2005).

Gecko Feet

- Researchers have trouble recreating on the nanoscale - smaller = more energy intensive (no problem for the gecko)
- Applications - better post-it notes, no-pain bandaids, hanging pictures, robots, spiderman suit



Sticky Bot from Stanford. Source: http://bdml.stanford.edu/twiki/bin/view/Rise/StickyBot

Photo Credit: Bjørn Christian Tørrissen

Diffusion

- Diffusion - random motion of particles due to collisions of other molecules - random walk
- Brownian motion - larger molecules (like pollen) move randomly in solution - due to collisions with smaller molecules
- Osmosis - diffusion across a semi-permeable membrane
- Diffusion, osmosis and Brownian motion are typically taught in a biology class

Diffusion in Biophysics

- Diffusion in a cell - crowded environment
- Diffusive processes can lead to patterns (Min proteins and cell division, Bicoid proteins in embryos for nuclear localization)
- All proteins undergo diffusion - transcription factors, signaling, gradients

Bicoid protien: http://physwww.physics.mcmaster.ca/~biophys/molbiophys/diffusion.html

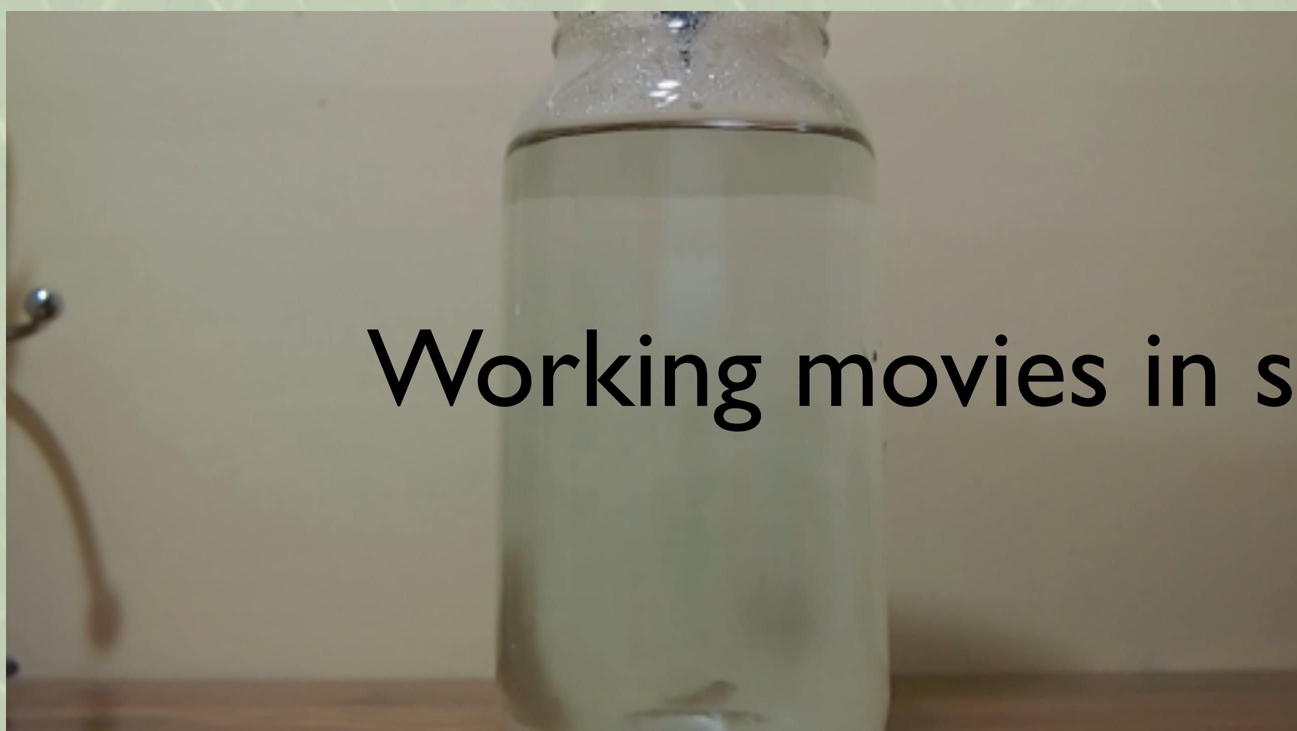
Min protein oscillations: http://jb.asm.org/content/suppl/2010/07/23/192.16.4134.DC1/min2.mov

Brownian Motion

- Larger molecules (like pollen) move randomly in solution - due to collisions with smaller molecules
- Observable under a light microscope
- Robert Brown originally thought pollen was alive

simulation link: http://en.wikipedia.org/wiki/Brownian_motion

Qualitative Diffusion Experiment



Working movies in supplemental materials

T=90°C

T=8°C

Higher T = higher E_k = faster diffusion

Diffusion and Temperature

- Velocity of the dye particles is positively related to Temperature:

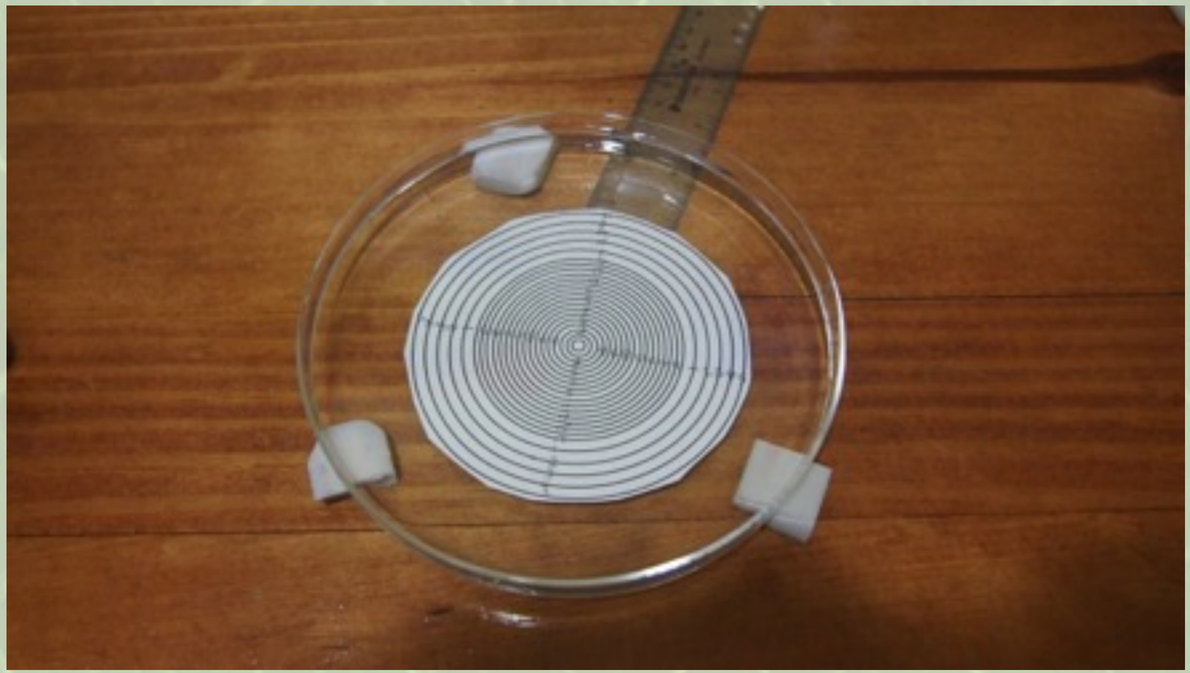
$$E_k \propto kT$$

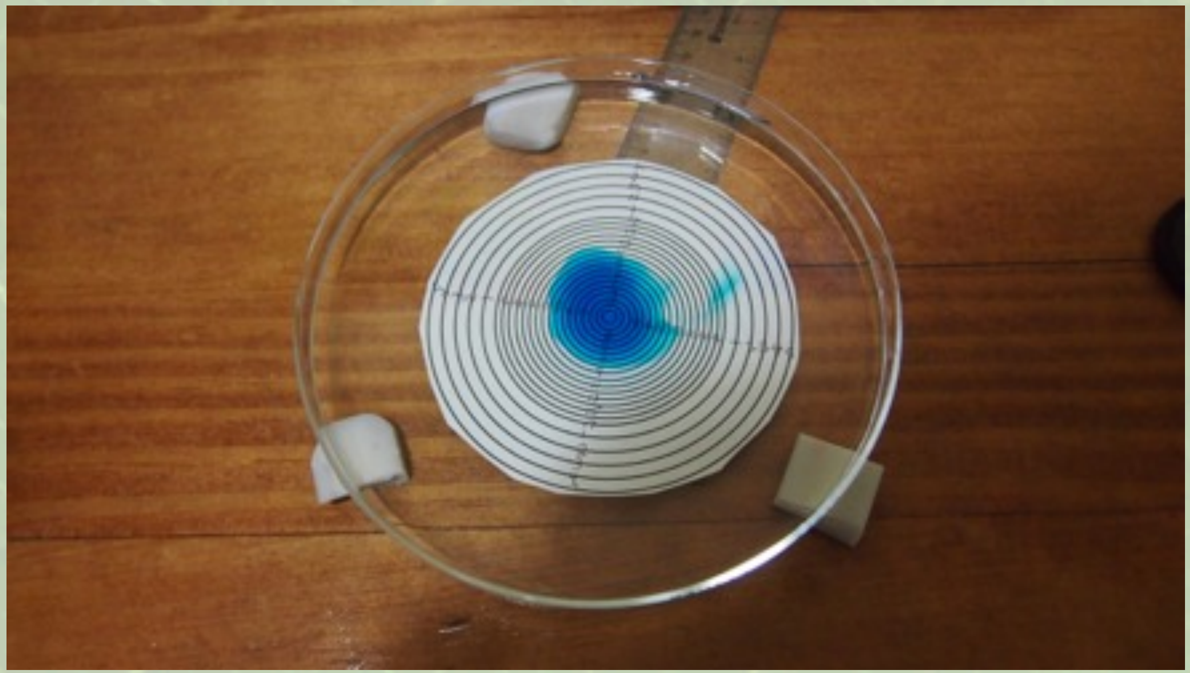
$$E_k = \frac{1}{2}m < v^2 >$$

$$< v^2 > \propto \frac{kT}{m}$$

Quantitative Diffusion Experiment

- Measure the radius of dye (2D) as a function of time
- Equipment: food colouring, clear petrie dish or pyrex, timer, paper to determine radius

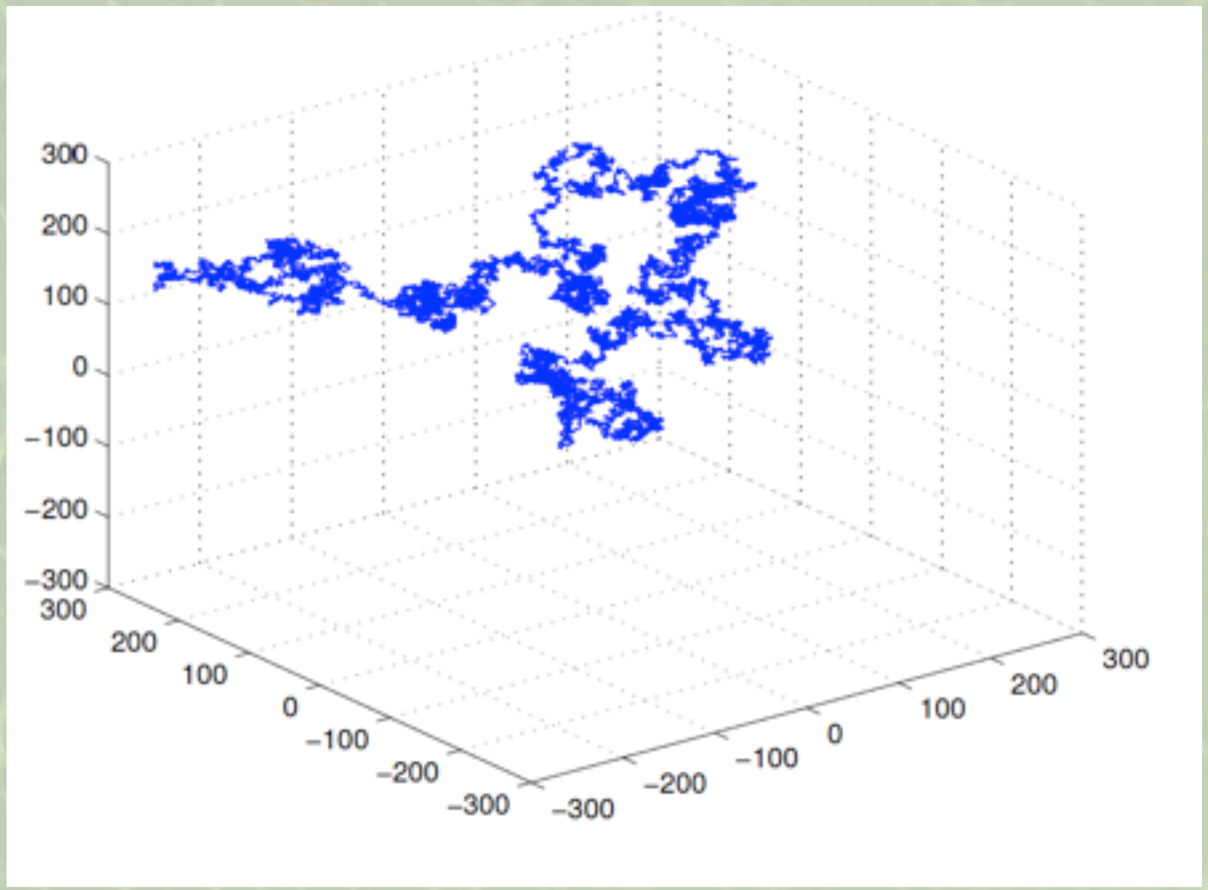




Diffusion is a Random Walk

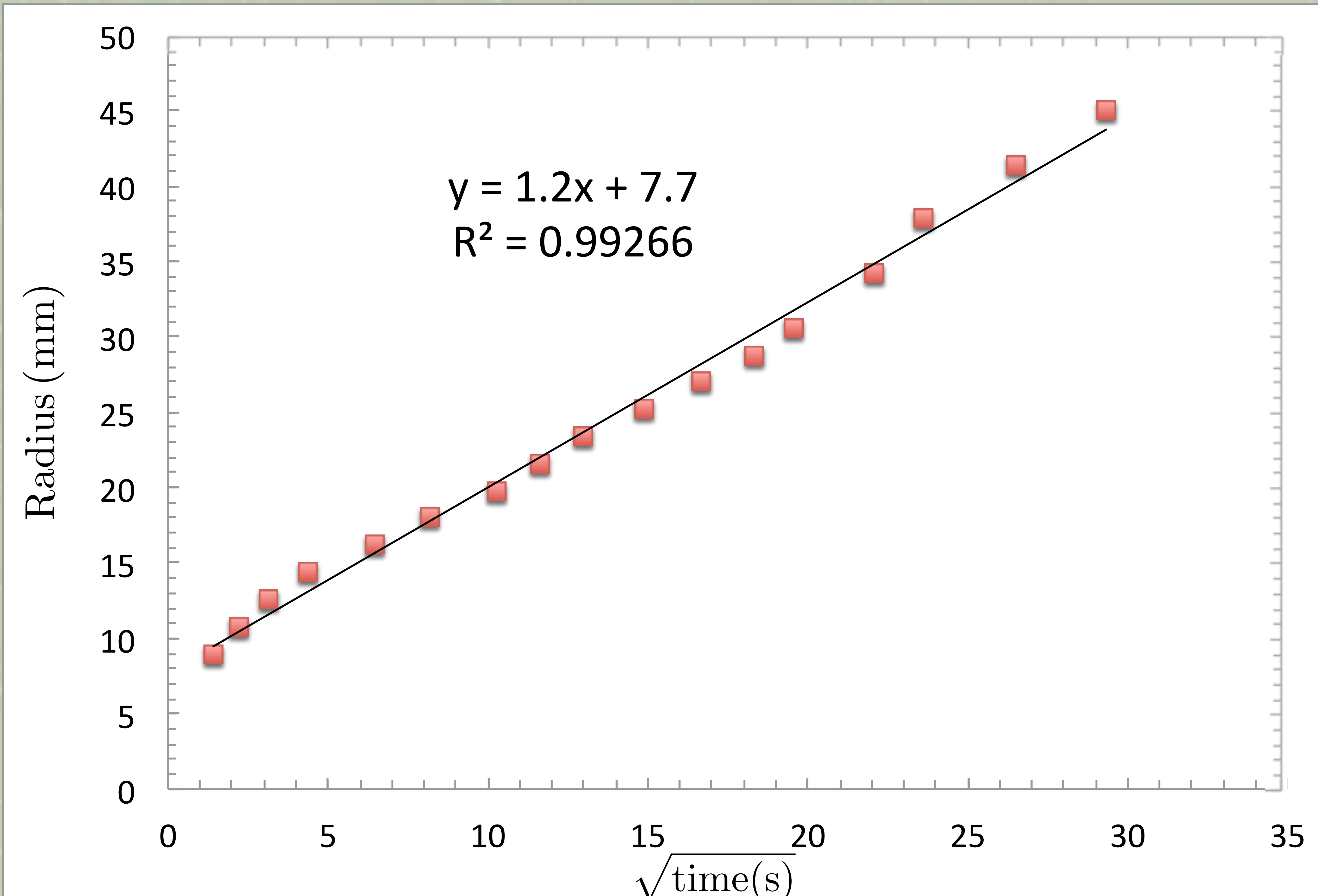
- Random walk - equal probability for dye molecule to diffuse in all directions

$$r \sim \sqrt{t}$$



- Can test scaling with a coin: left = heads, right = tails. After 36 flips will be ~6 steps from the origin.

Results



y = 1.2x + 7.7
R² = 0.99266
Radius (mm)
$\sqrt{\text{time(s)}}$
0
5
10
15
20
25
30
35
40
45
50
0
5
10
15
20
25
30
35

Conclusions

- Integration of biophysics into the classroom can help interest students who lean more towards life sciences
- Examples with realistic values can increase interest (power of grasshoper, force with geckos)
- Diffusion is important in almost all biological processes - can measure quantitatively

Photo Credit: Bjørn Christian Tørrissen

Outreach@Mac

- Video Contest - May 17th
- Online Physics Contest - December
- Physical Sciences@Mac - April and December
- Engineering and Science Olympics - October
- Community of Physics Teachers Meeting - October and March
- Planetarium - $100/hour show
- 3D theatre

Image Source: www.physics.mcmaster.ca

Thorny Devil

- Climate: desert in Australia
- Water sources are scarce
- Capillary action can move water up back to mouth (water and paper towel experiment)
- Thorny Devil has ability to drink from damp sand or fog in the air

video link: http://www.arkive.org/thorny-devil/moloch-horridus/video-10.html