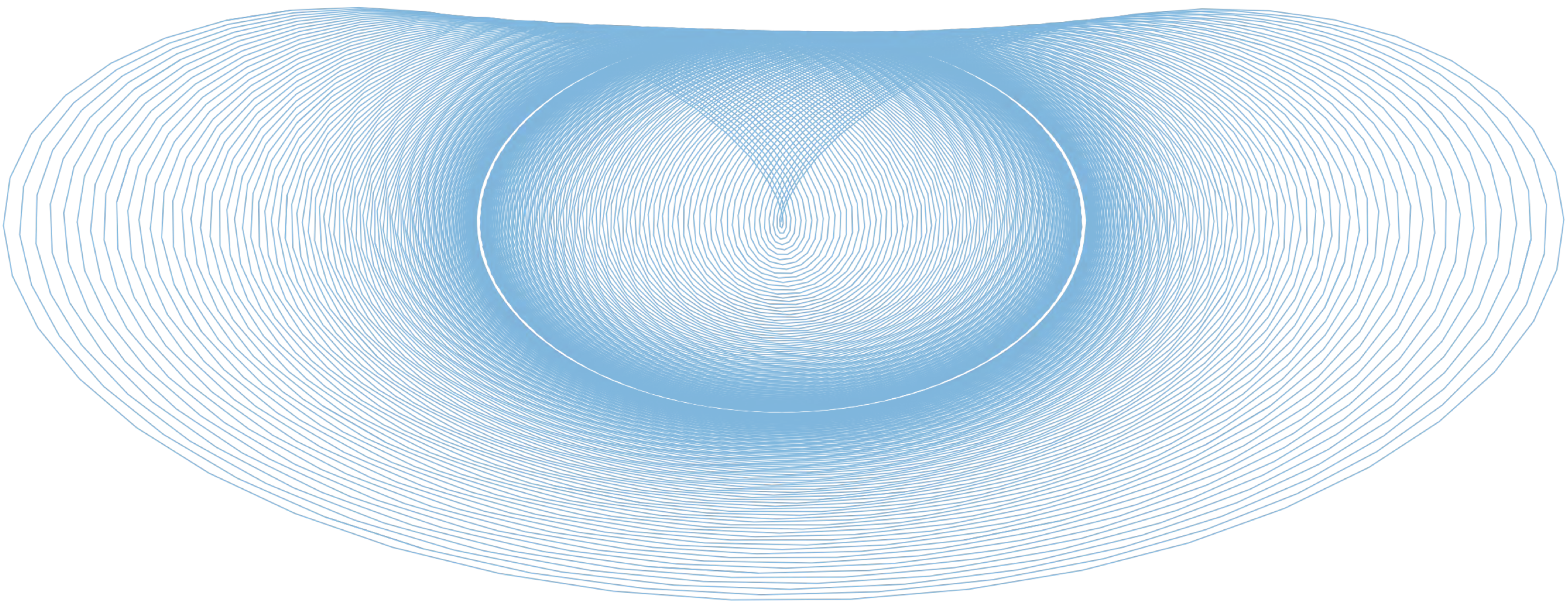
PHYS 1420 (F19)
Physics with Applications to Life Sciences



2019.10.04

Relevant reading:
Kesten & Tauck ch.6.1-6.2

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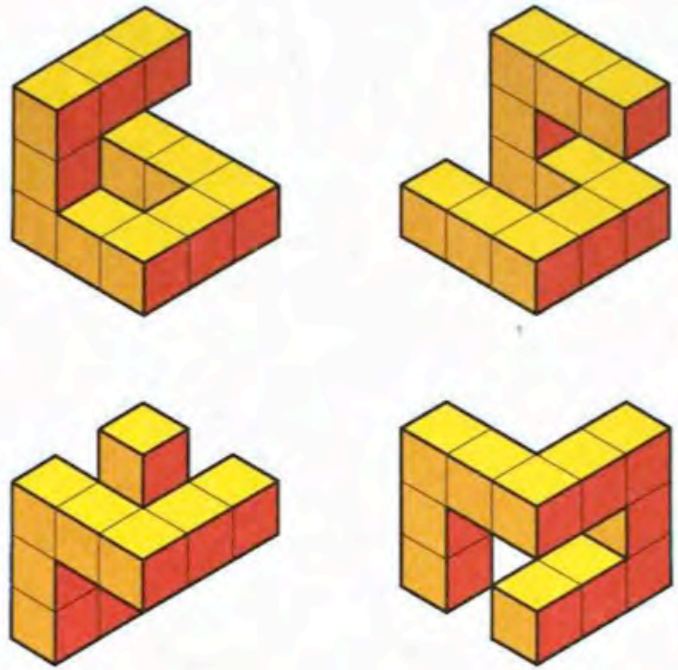
Ref. (re images):
Wolfson (2007), Knight (2017)

201. Cubical Snake



A B C D

Which view of 11 cubes in a snaking chain does not match the other three?

A B C D

<u>Announcements & Key Concepts</u> (re Today)

→ Online HW #5 posted and DUE XX

→ Midterm exam on Oct. 21 (course webpage will have some prep. guidelines)

Some relevant underlying concepts of the day…

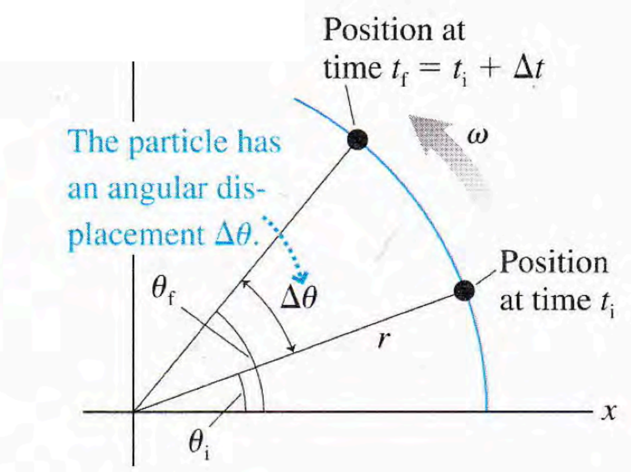
- Circular motion (REVISTED)

- HO motivations…

- Intro to the concept of energy & work

Review: Uniform circular motion

FIGURE 4.27 A particle moves with angular velocity ω.



Wolfson

$$\theta(\text{radians}) \equiv \frac{s}{r} \qquad v_t = \frac{ds}{dt} = r\frac{d\theta}{dt}$$

$$a = \frac{v^2}{r} \qquad \text{(uniform circular motion)}$$

Polar coordinates

$$r = \sqrt{x^2 + y^2} \quad \text{and} \quad \theta = \tan^{-1} y/x$$

$$x = r\cos\theta \quad \text{and} \quad y = r\sin\theta$$

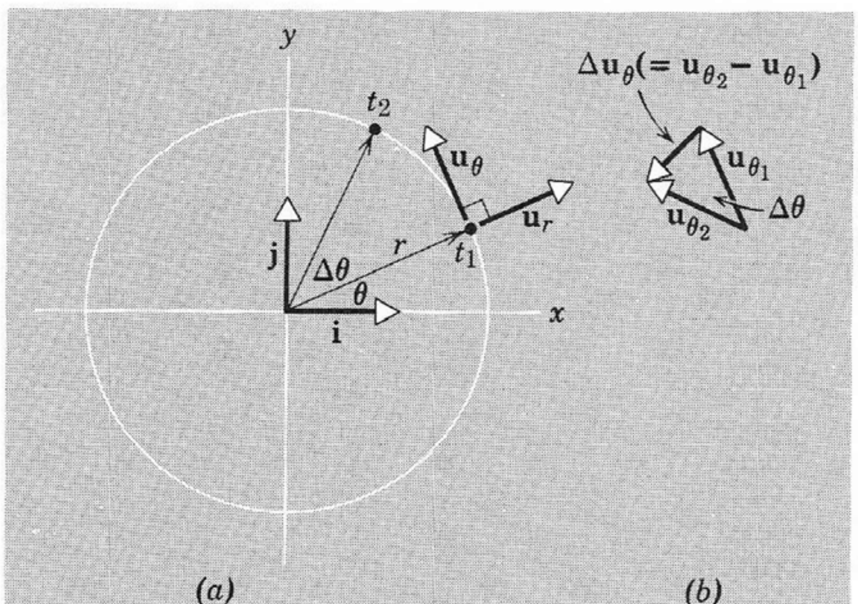


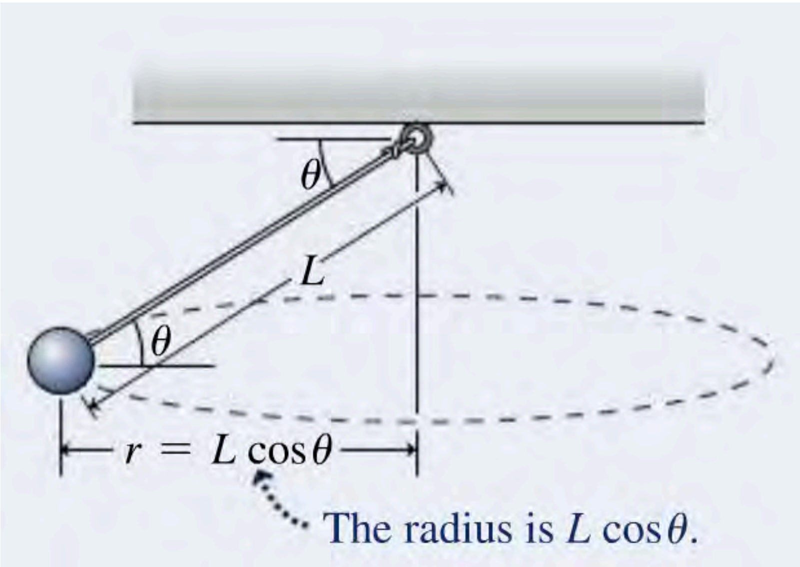
Fig. 4–8 (a) A particle moving counterclockwise in a circle of radius r. (b) The unit vectors $\mathbf{u}_{\theta_1}$ and $\mathbf{u}_{\theta_2}$ at times t_1 and t_2 respectively, and the change $\Delta\mathbf{u}_\theta$ $(= \mathbf{u}_{\theta_2} - \mathbf{u}_{\theta_1})$.

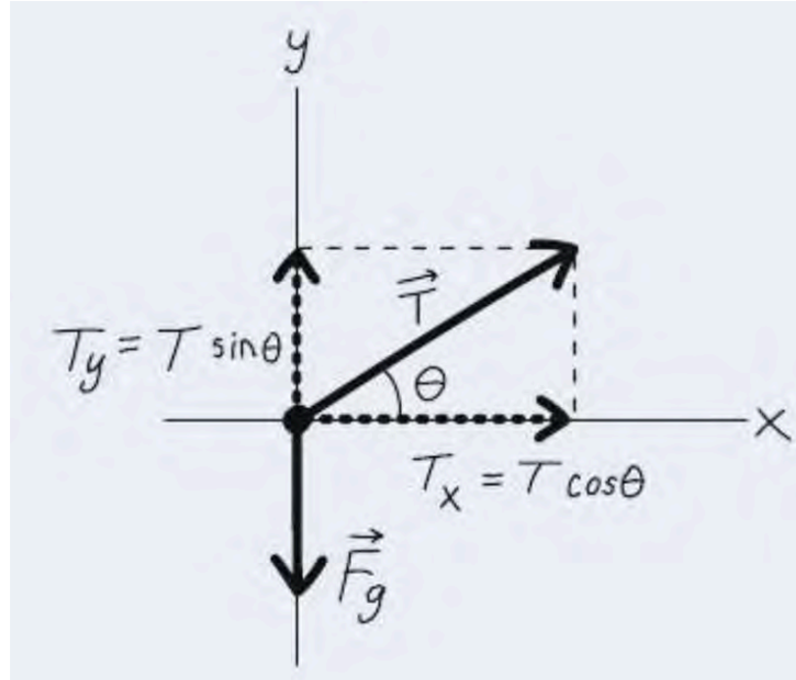
Resnick & Halliday (1966)

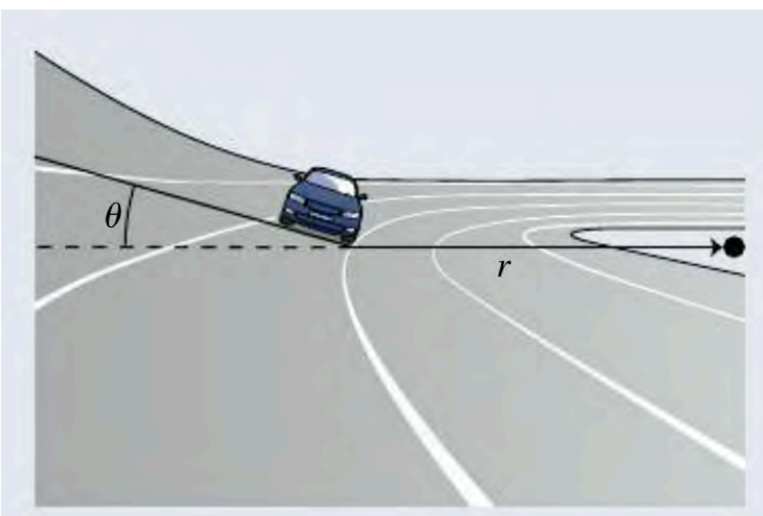
→ "Unit vectors" can readily be extended to polar coordinates

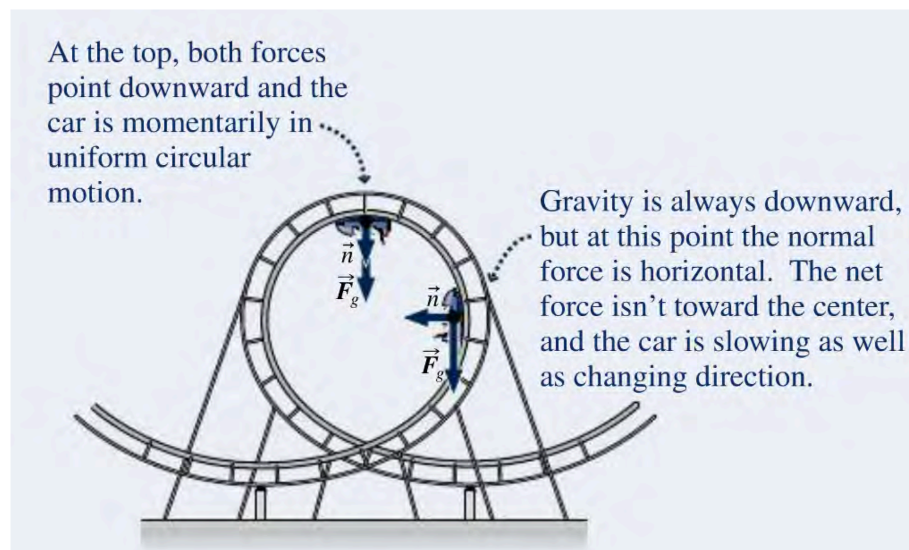
Circular Motion & Force

$$F_{\text{net}} = ma = \frac{mv^2}{r}$$





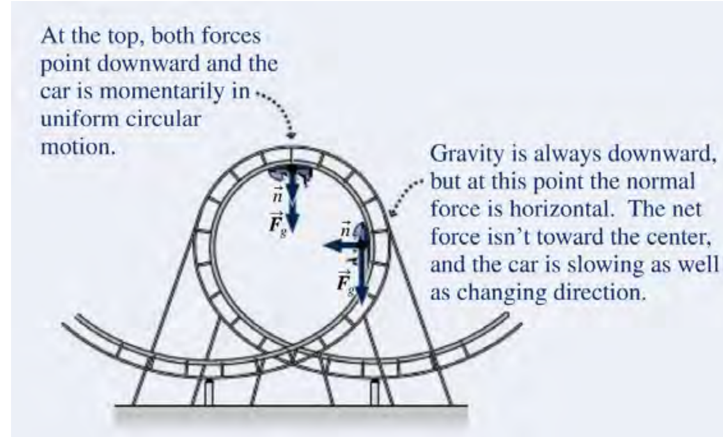




Wolfson

Circular Motion

Wolfson



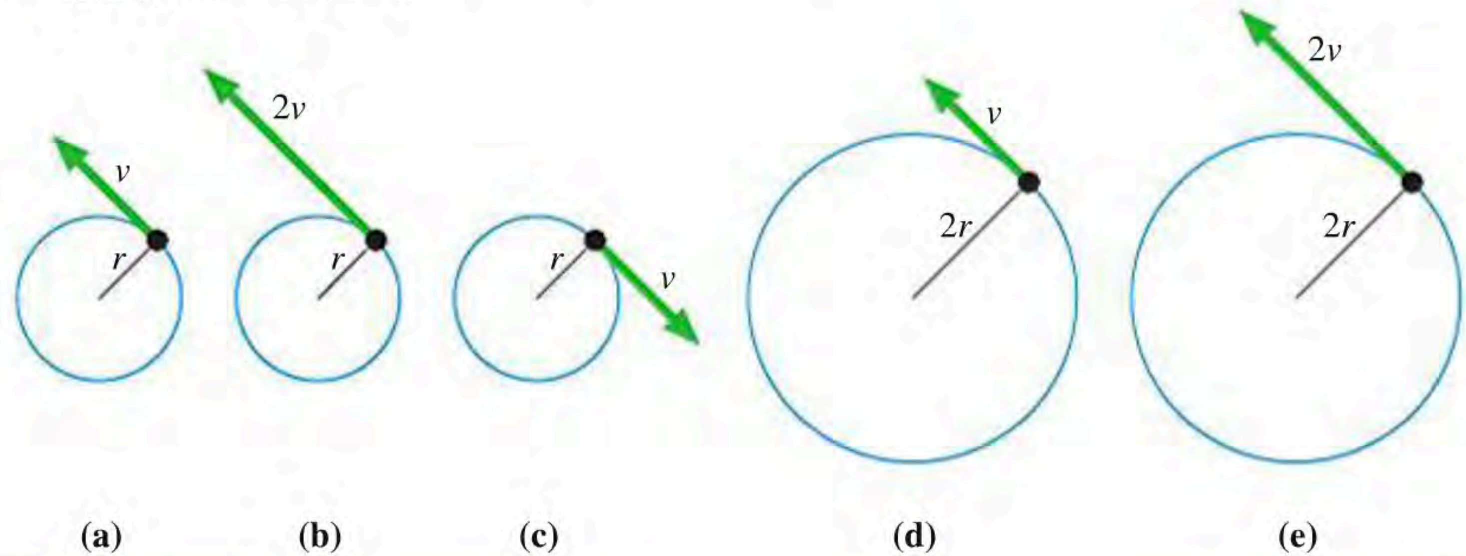
Note: This case isn't uniform circular motion per se....

Rollercoaster thrillseekers left dangling upside down 50ft up for 20 minutes after poncho gets stuck in rails

http://www.dailymail.co.uk/news/article-1271844/Flamingo-Land-rollercoaster-Thrillseekers-left-hanging-upside-50ft-up.html

Ex.

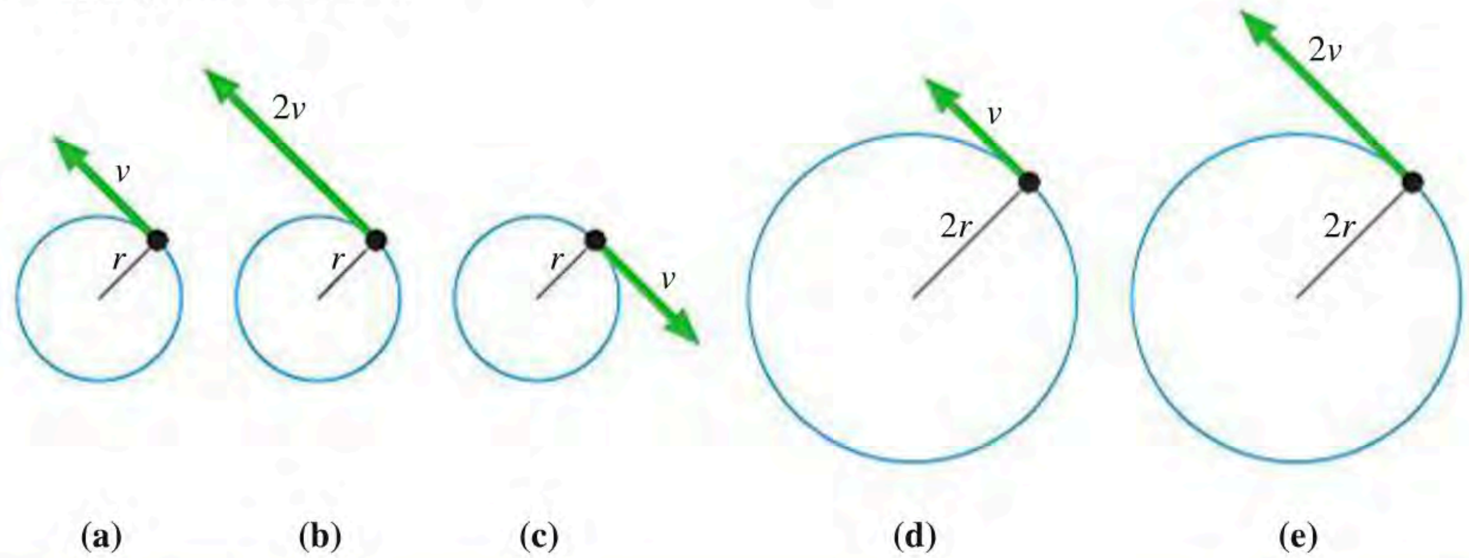
STOP TO THINK 4.6 Rank in order, from largest to smallest, the centripetal accelerations a_a to a_e of particles a to e.



Knight (2013)

Ex. (SOL)

STOP TO THINK 4.6 Rank in order, from largest to smallest, the centripetal accelerations a_a to a_e of particles a to e.



b > e > a = c > d

$$F_{net} = ma = \frac{mv^2}{r}$$

Note: Changing sign of v doesn't affect a

Knight (2013)

Circular Motion

- 1-D kinematics translates directly to circular motion (in polar coords.)

TABLE 4.1 Rotational and linear kinematics for constant acceleration

Rotational kinematics	Linear kinematics
$\omega_f = \omega_i + \alpha\,\Delta t$	$v_{fs} = v_{is} + a_s\,\Delta t$
$\theta_f = \theta_i + \omega_i\,\Delta t + \frac{1}{2}\alpha(\Delta t)^2$	$s_f = s_i + v_{is}\,\Delta t + \frac{1}{2}a_s(\Delta t)^2$
$\omega_f^2 = \omega_i^2 + 2\alpha\,\Delta\theta$	$v_{fs}^{\;2} = v_{is}^{\;2} + 2a_s\,\Delta s$

Knight (2013)

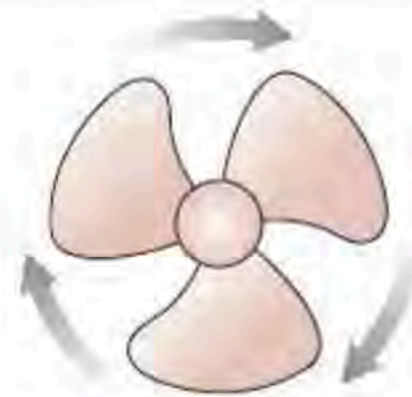
Note:

- You solved several "differential equations" to get these (linear) formulae
- Newton's 2nd Law is a differential equation

Ex.

STOP TO THINK 4.7 The fan blade is slowing down. What are the signs of ω and α?

a. ω is positive and α is positive.
b. ω is positive and α is negative.
c. ω is negative and α is positive.
d. ω is negative and α is negative.



Knight (2013)

Ex. (SOL)

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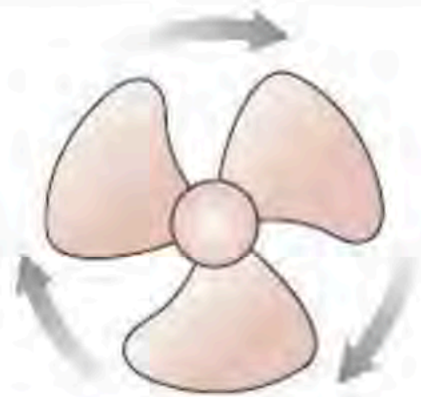
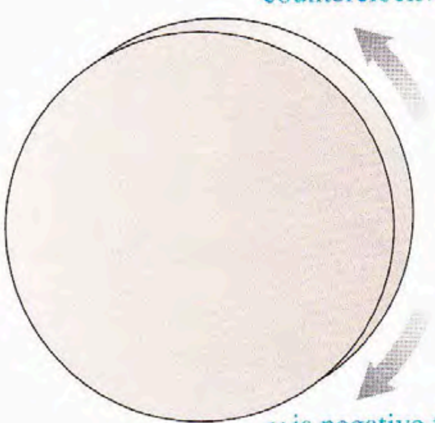


c

FIGURE 4.28 Positive and negative angular velocities.

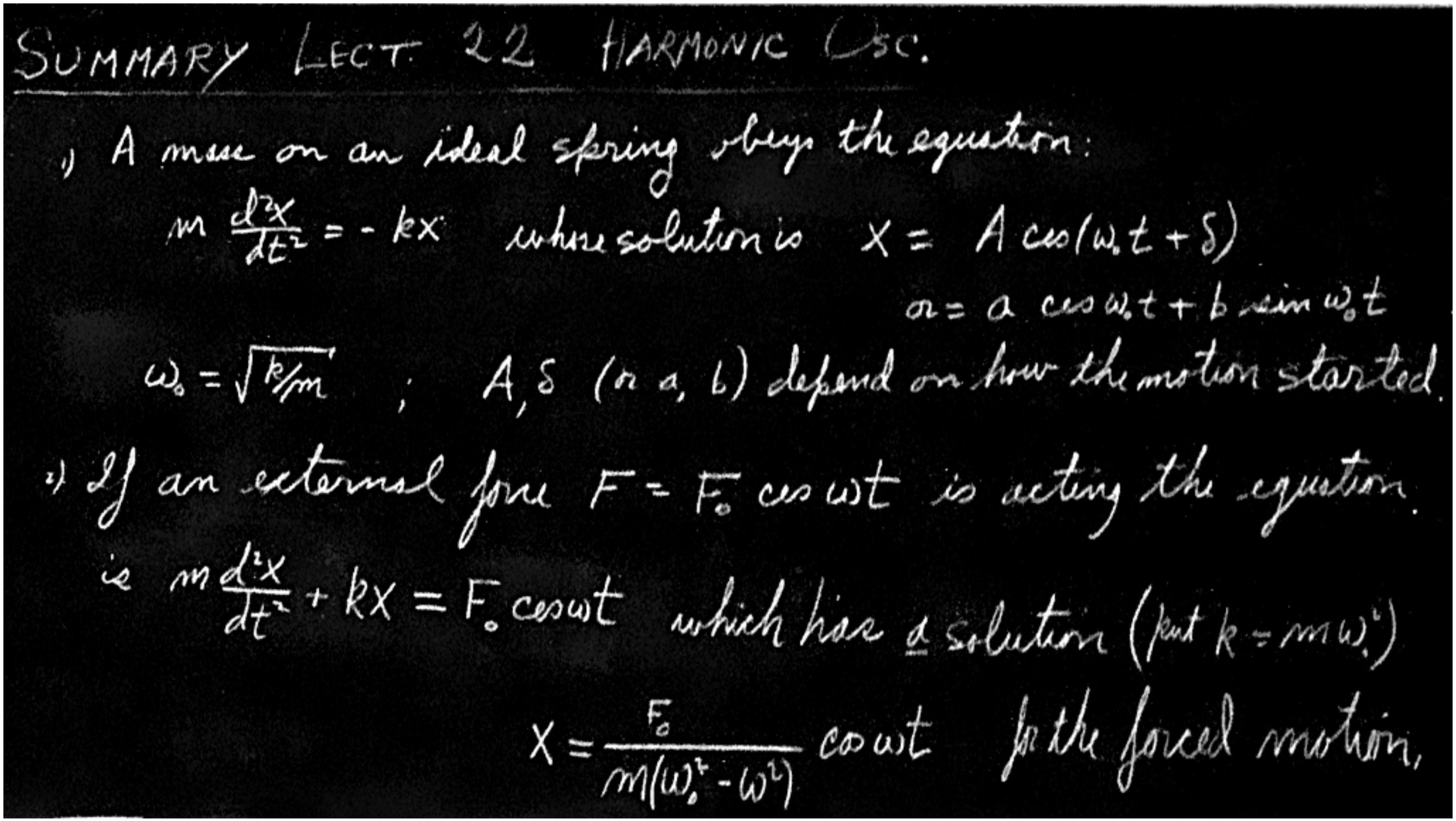


Remember the chosen convention!

Knight (2013)

Looking ahead.....

- We now have most of the pieces in place for one of the most practically useful interdisciplinary examples/concepts: *Harmonic oscillator*



http://www.feynmanlectures.caltech.edu/I_21.html

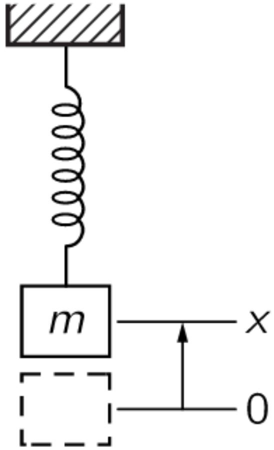
Looking ahead.....

Wolfson Eqn.13.18

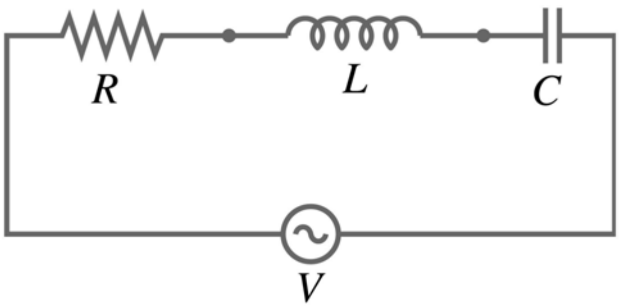
$$m\frac{d^2x}{dt^2} = -kx - b\frac{dx}{dt} + F_d$$

→ Mass-on-a-spring (leads to oscillations)

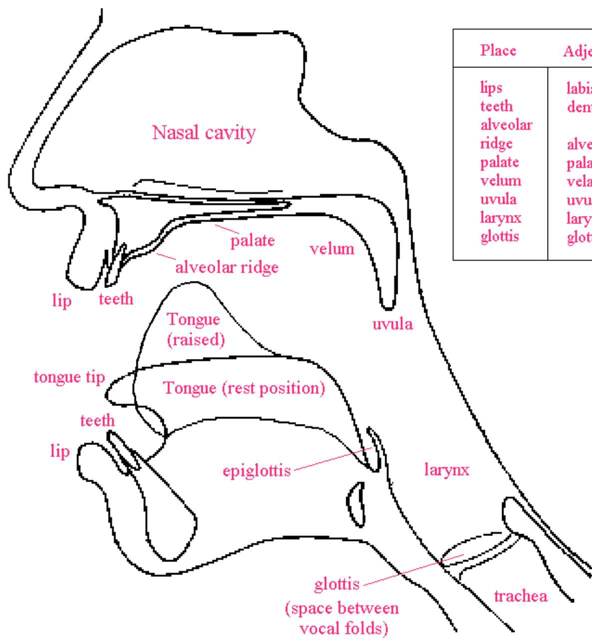
Note: Here the drag is proportional to v (not v^2)



Band-pass filter (RLC circuit)



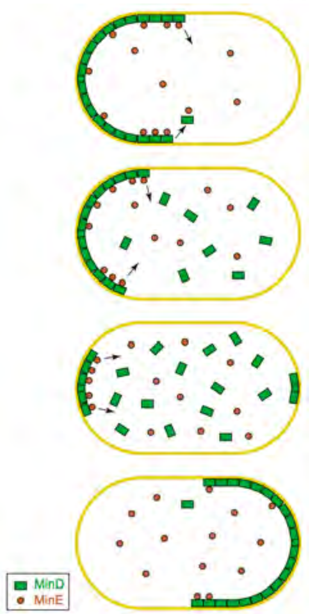
Acoustic phonetics



Place	Adjective
lips	labial
teeth	dental
alveolar ridge	alveolar
palate	palatal
velum	velar
uvula	uvular
larynx	laryngeal
glottis	glottal

https://www.uni-due.de/DI/REV_PhoneticsPhonology.htm

Predator-prey dynamics



Cell biology (Kruse & Julicher, 2005)

Quantum mechanics

$$\hat{H}\,|\psi\rangle = E\,|\psi\rangle$$

→ A key concept is naturally built in to this heuristic: ***Energy*****.....**

..... but let's first return to a previously stated problem

A chain of length x and mass m is hanging over the edge of a tall building and does not touch the ground. How much work is required to lift the chain to the top of the building?

To (eventually) answer this, we'll need some more pieces:

- Definition of *work*
- Integration

$$\text{Work done} = \text{Force} \cdot \text{Distance} \qquad \text{or} \qquad W = F \cdot d.$$

In general, if force is a function $F(x)$ of position x, then in moving from $x = a$ to $x = b$,

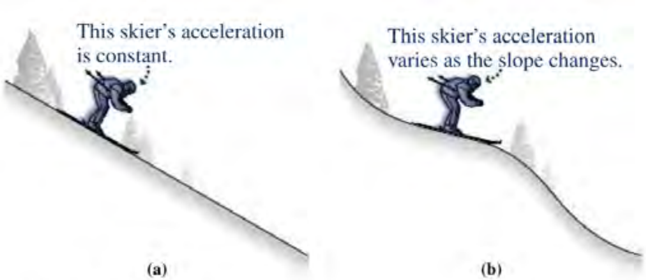


FIGURE 6.1 Two skiers.

Wolfson

$$\text{Work done} = \int_a^b F(x)\,dx.$$

→ We need to further develop the notion of *integration*

Hughes-Hallet et al (2005)

"She brought me my hat, and I knew I was going out into the warm sunshine. This thought, if a wordless sensation may be called a thought, made me hop and skip with pleasure.

We walked down the path to the well-house, attracted by the fragrance of the honeysuckle with which it was covered. Some one was drawing water and my teacher placed my hand under the spout. As the cool stream gushed over one hand she spelled into the other the word water, first slowly, then rapidly."

Helen Keller (1880-1968)

von Baeyer (1984)

<u>Warmth</u>

→ What is “warmth”?

→ Prometheus stole fire from the Gods
(and was punished for eternity by Zeus)

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

Warmth

Tree of Life (Bahrain)

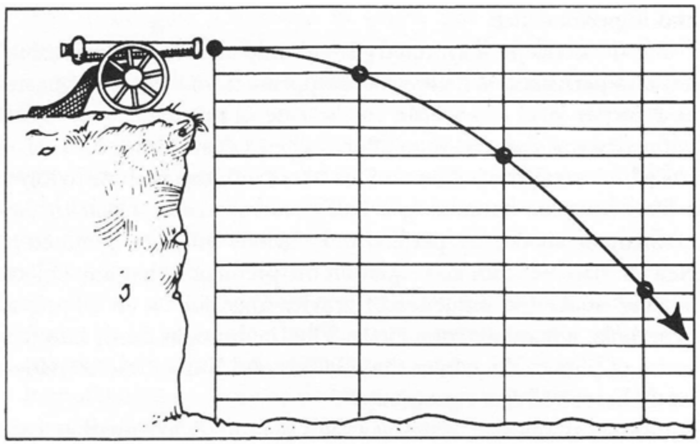
http://www.touropia.com/famous-trees-in-the-world/

→ Implicit here is a key idea: Energy

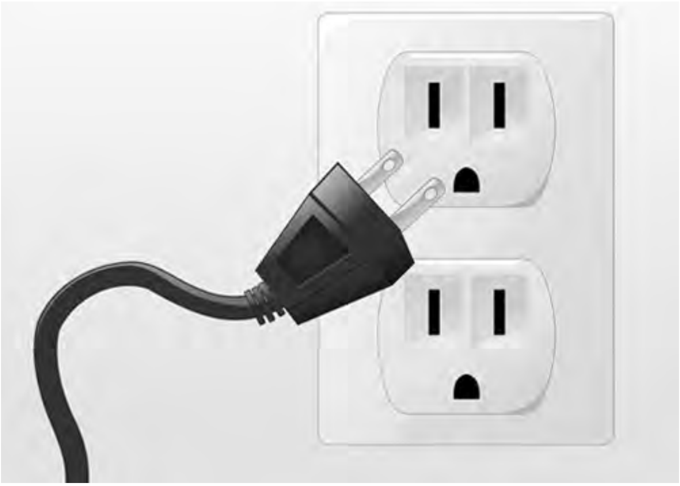
Energy

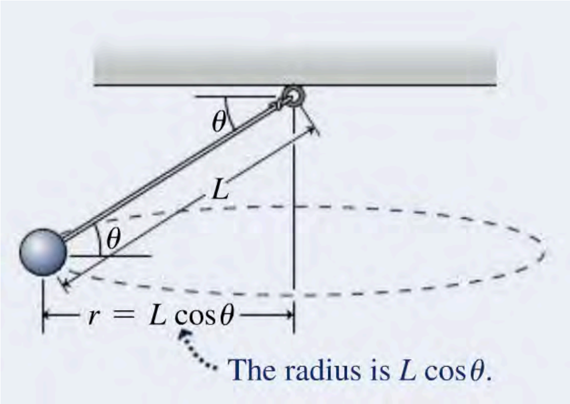
- Notion of warmth is closely tied to *something* being transferred

- But that idea translates more broadly....



von Baeyer

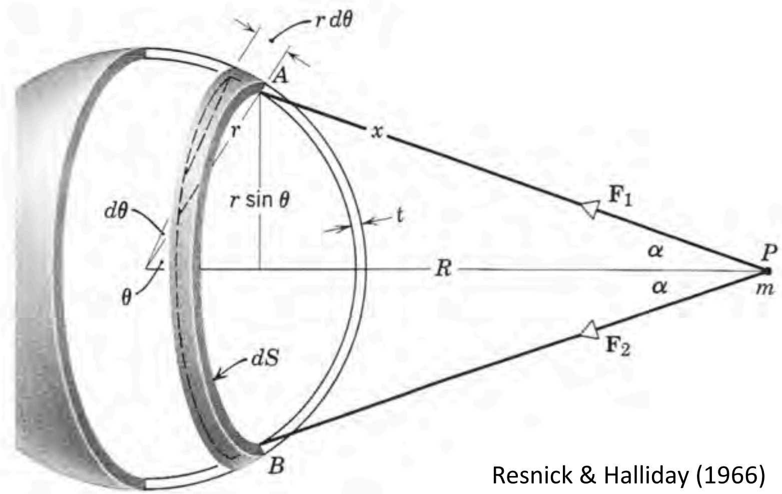




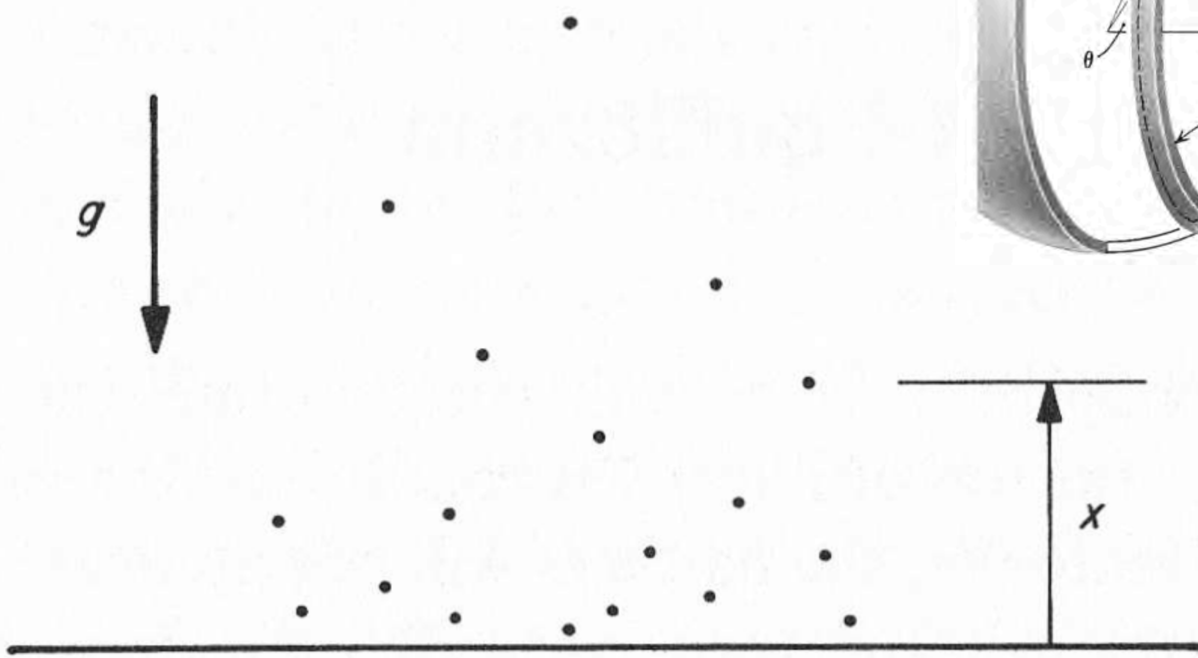
ITER fusion reactor (under construction)

Related Tangent: Density of the atmosphere

➢ Gravity and force have got to tie in here somehow.....

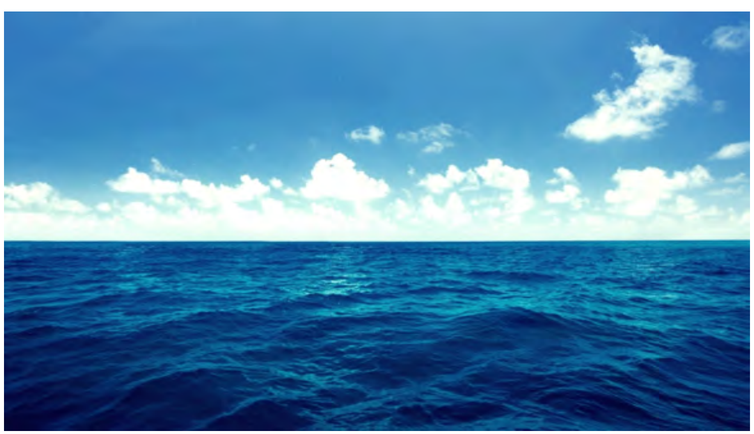


Resnick & Halliday (1966)



Berg (1993)

If gravity pulls everything down (e.g., air molecules), how come everything doesn’t just settle on the surface of the earth?



It does for water, right!?!

→ “Warmth” has to play a role somehow!

Energy

- "Energy" is a fundamental concept in all of science
- Etymology is of Greek origin for "activity"
- Comes in many different flavors/contexts:

Potential

Elastic

Mechanical

Electrical

Gravitational

Thermal

Kinetic

Chemical

Nuclear

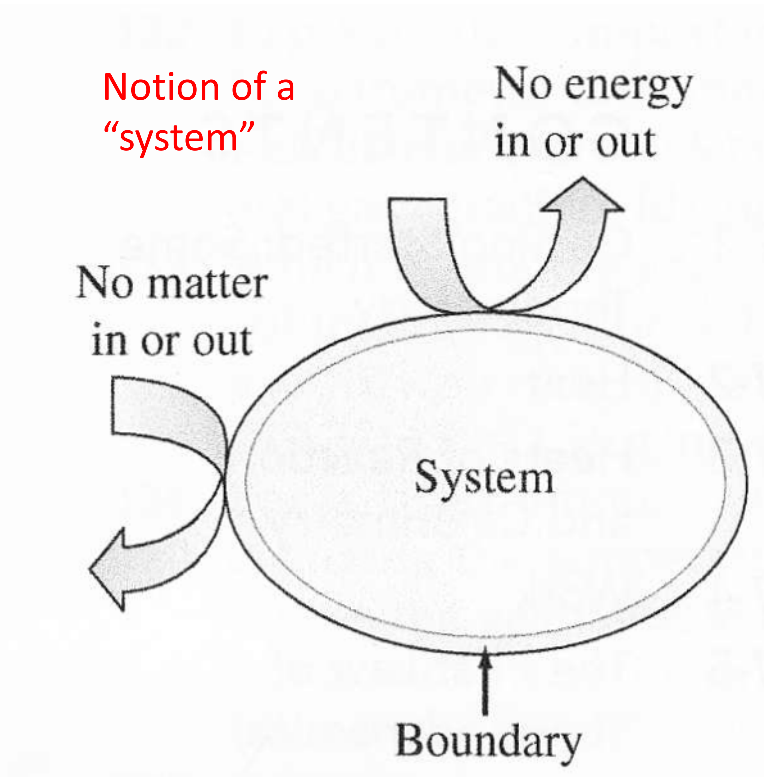
$$E = mc^2$$

→ Somehow, these are all different, but yet are all the same....

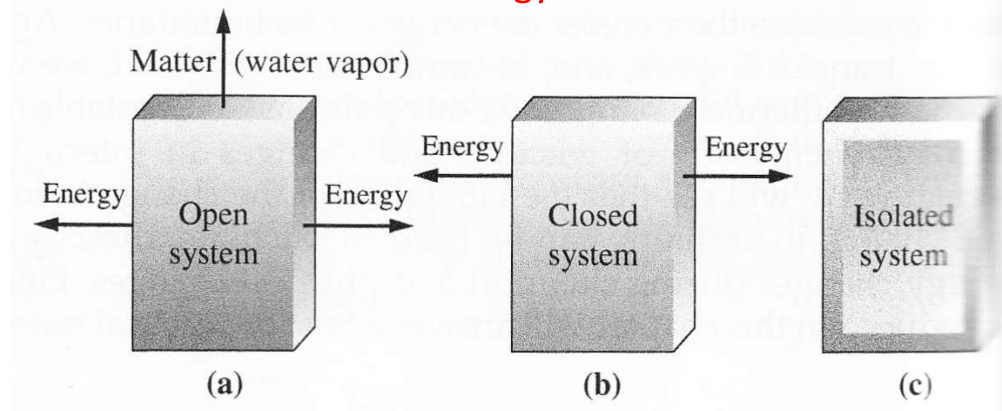
- At the most basic level, "something" has energy and can transfer/receive such from other "somethings" around it....

Interdisciplinary Connection (Chemistry)

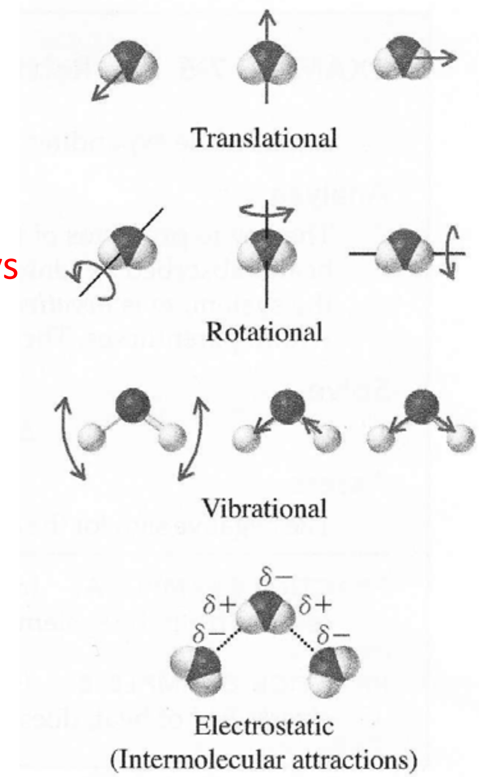
Notion of a “system”



Energy can be transferred



At a molecular level, energy can manifest in a variety of mechanical ways



Energy has units and can be measured

$$1\ \text{cal} = 4.184\ \text{J}$$

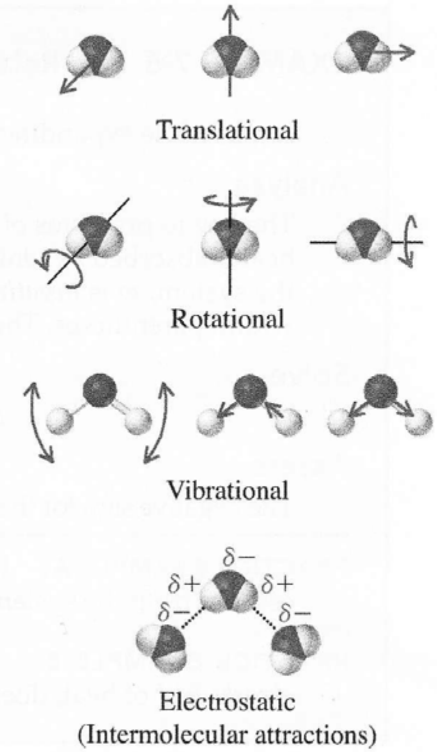
$$\Delta U = q + w$$

First Law of Thermodynamics: Internal energy, heat & work

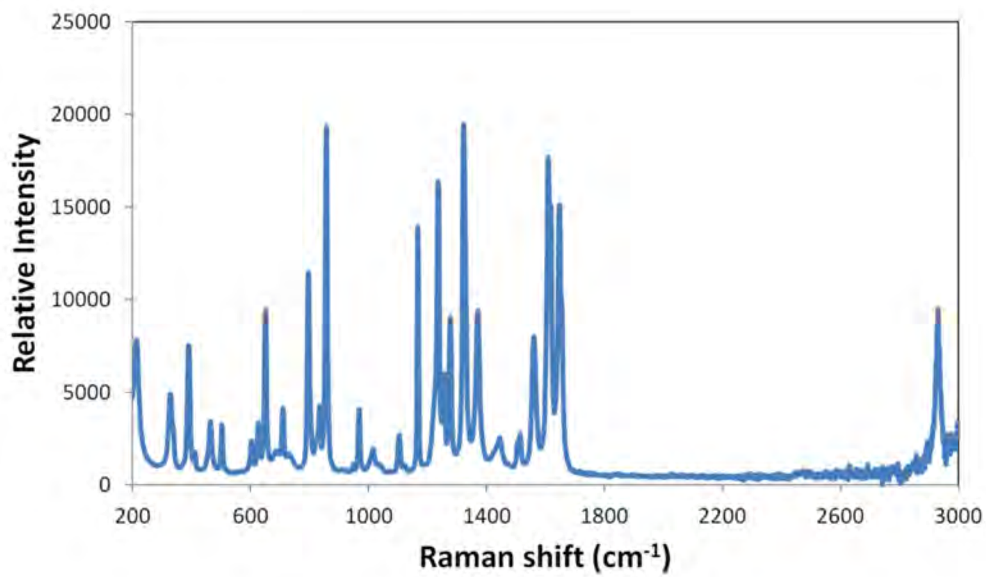
(we’ll come back to work shortly)

Petrucci et al (2011)

Interdisciplinary Connection



Raman Spectroscopy Tackles Pharmaceutical Raw Materials



http://www.laboratoryequipment.com/article/2013/03/raman-spectroscopy-tackles-pharmaceutical-raw-materials

Force + Energy?

- How are these two connected?
- Intuitively.....

Niagara Falls

Robert Moses Niagara Power Plant

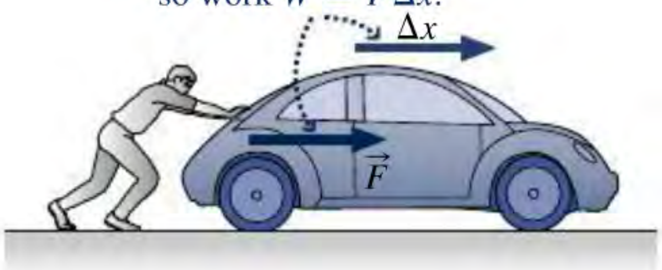
→ Work!

Work

- Work is the energy transferred between systems via an applied force

$$W = \int_{\vec{r}_1}^{\vec{r}_2} \vec{F} \cdot d\vec{r}$$

$$\vec{A} \cdot \vec{B} = AB\cos\theta$$



→ A bit complicated once vectors are factored in (direction matters!). But basically....

Units

(kg m/s^2) * (m) = kg (m/s)^2

= J

For an object moving in one dimension, the work W done on the object by constant applied force $\vec{F}$ is

$$W = F_x \Delta x \qquad (6.1)$$

where F_x is the component of the force in the direction of the object's motion and Δx is the object's displacement.

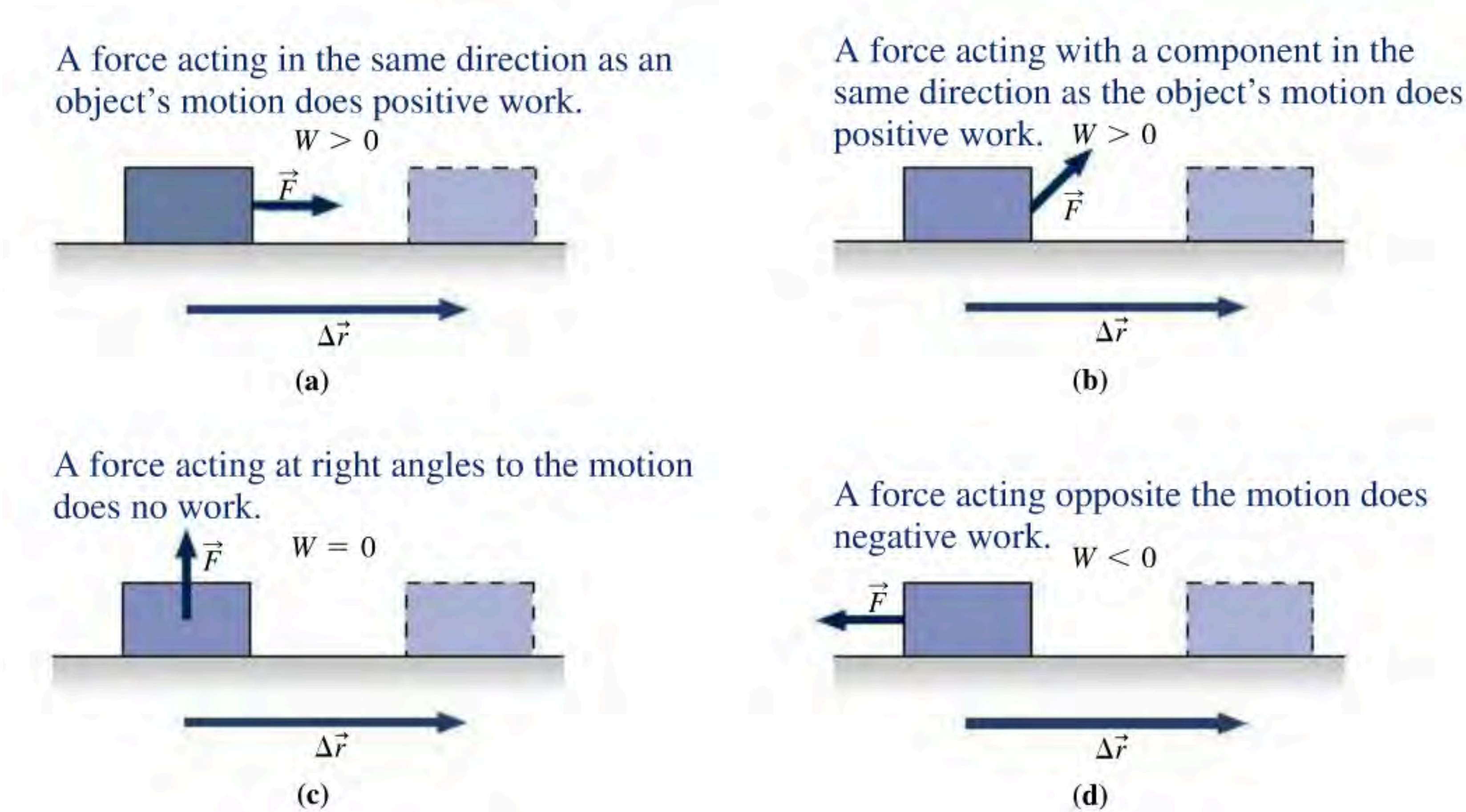
Wolfson

Work

$$W = \int_{\vec{r}_1}^{\vec{r}_2} \vec{F} \cdot d\vec{r}$$

$$W = F_x \Delta x$$

Note: The work (W) here is only that tied to force F. If there are other forces at play, the associated work needs to be calculated separately....



→ So work is energy. Note that unlike force, work/energy is a scalar

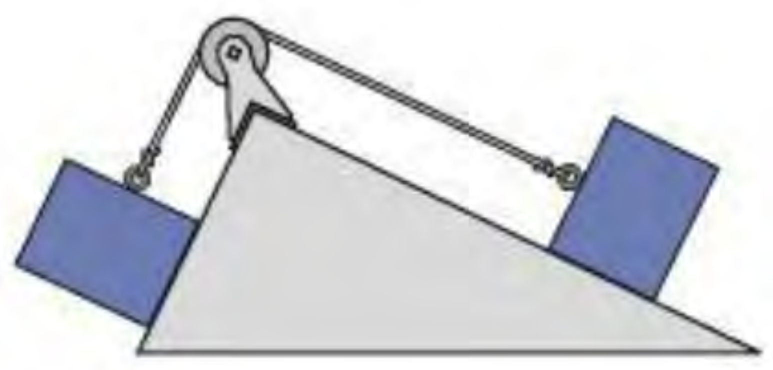
(this makes life much easier downstream!)

Work

- Direction matters! This does make sense intuitively....

$$W = \int_{\vec{r}_1}^{\vec{r}_2} \vec{F} \cdot d\vec{r}$$

$$W = F_x \Delta x$$



→ Think about what direction gravity works in and how changing the angle of the wedge would affect "work"

→ More fun when Earth does its work on the skier when on the steep part!

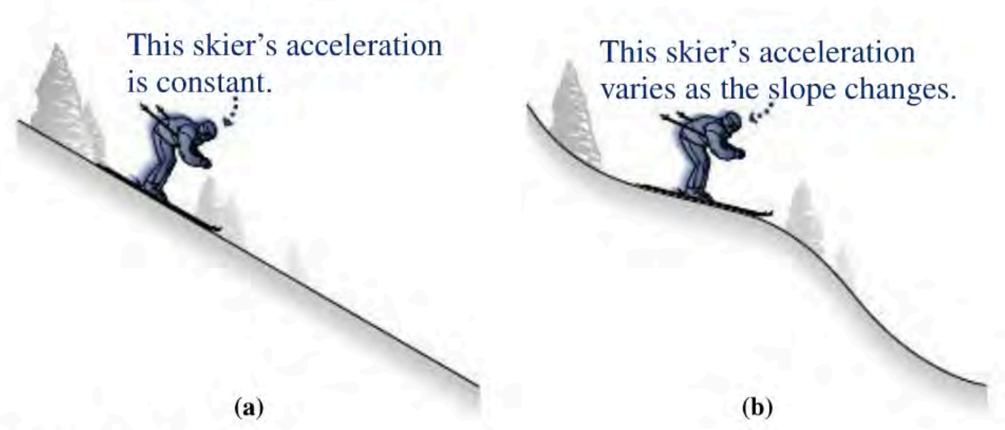


FIGURE 6.1 Two skiers.

Note: When forces are not constant per se, problems can be very hard via Newton's Laws. But they can be much more accessible via the lens of "energy" (as we'll see)

Wolfson

Ex.

How much work is done in lifting

(a) A 5-pound book 3 feet off the floor?

(b) A 1.5-kilogram book 2 meters off the floor?

Hughes-Hallet et al (2005)