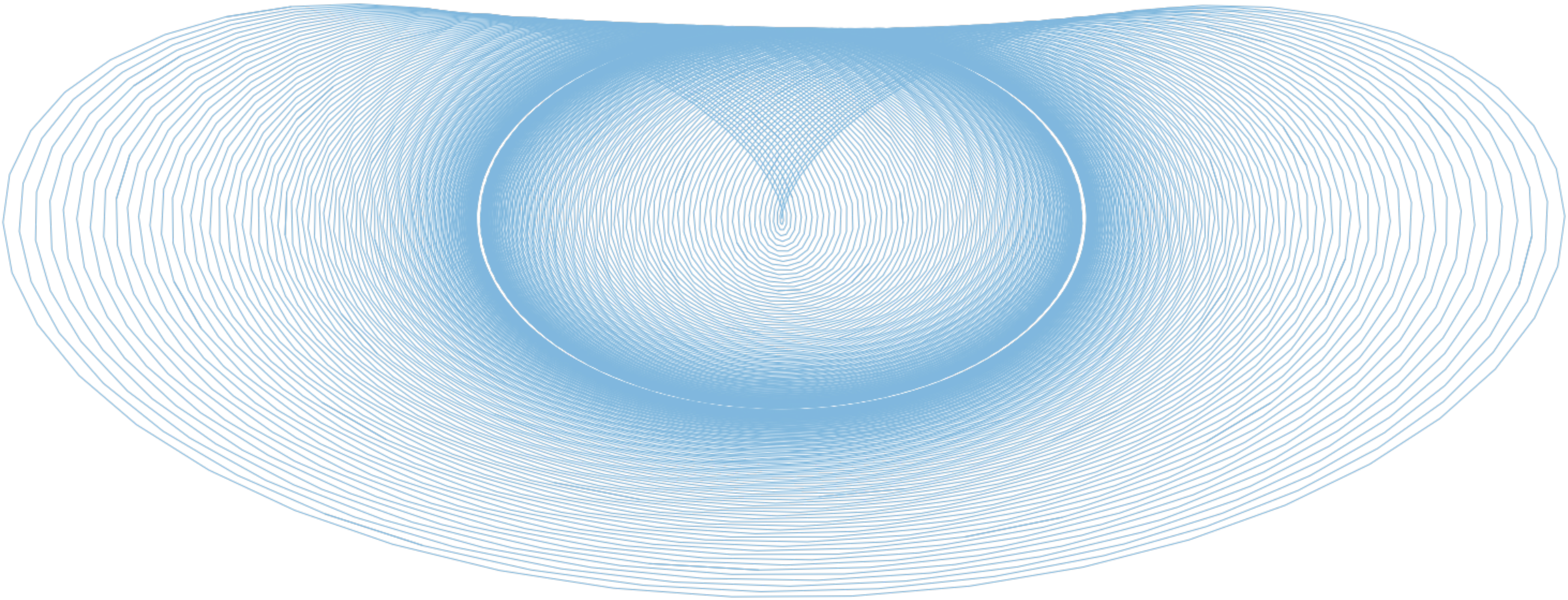
PHYS 1420 (F19)
Physics with Applications to Life Sciences



2019.09.09

<u>Relevant reading</u>:
Kesten & Tauck ch. 2.1-2.3

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63. Match Eight

You have eight matchsticks. True or false: It is possible to remove one matchstick so that what remains is still eight.

True

False

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

→ Basic introduction/overview of kinematics

Some relevant underlying concepts of the day…

- Coordinate systems (chiefly 1-D); Units & standards

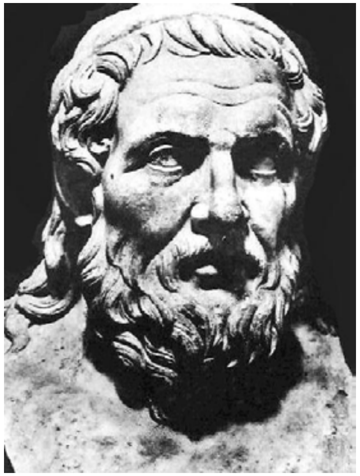
- Position (x) vs. velocity (v) vs. acceleration (a) & associated calculus notions

- Different representations of above values (e.g., graphical, algebraic, etc..)

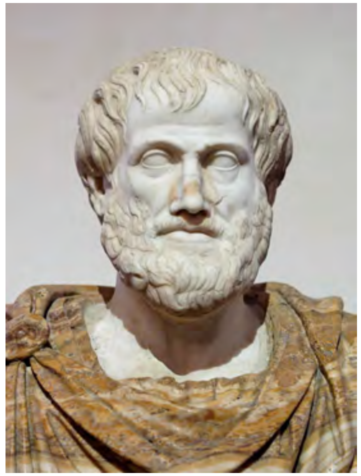
- Notion of a *particle* (re “modeling”)

Mechanics

Apollonius of Perga

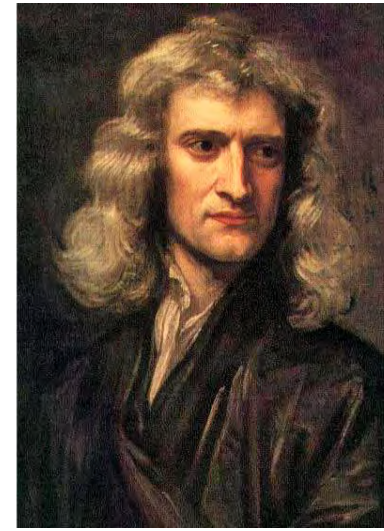


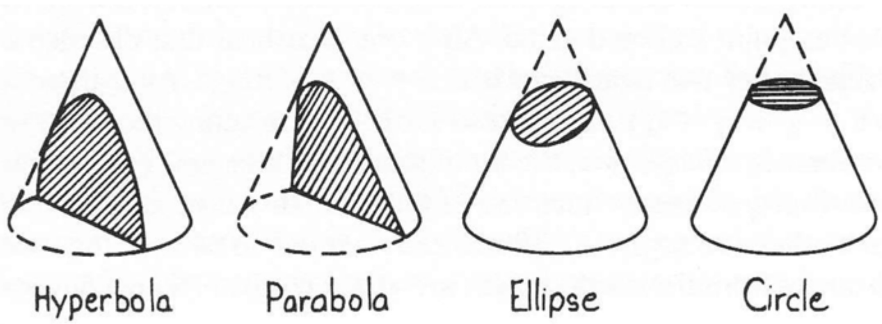
Aristotle

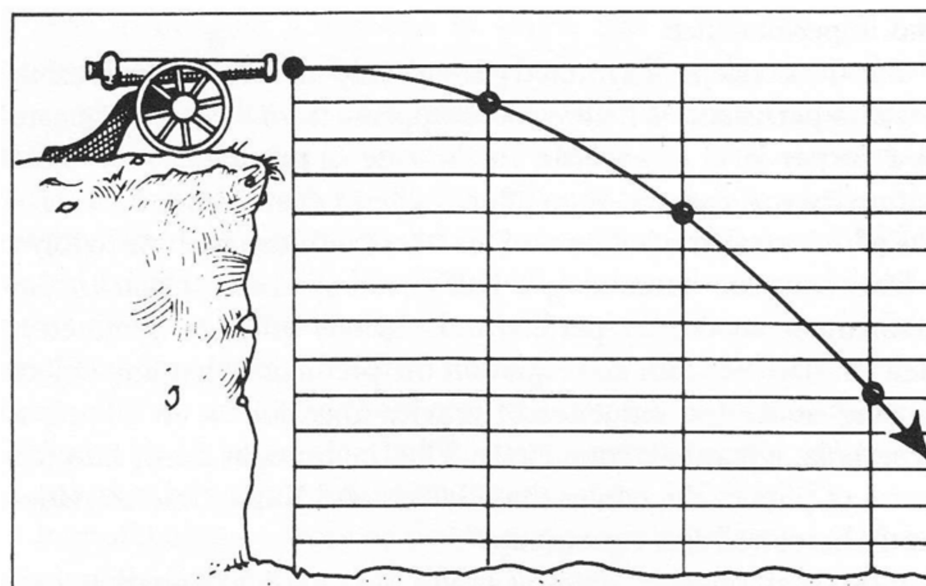


G. Galileo

I. Newton







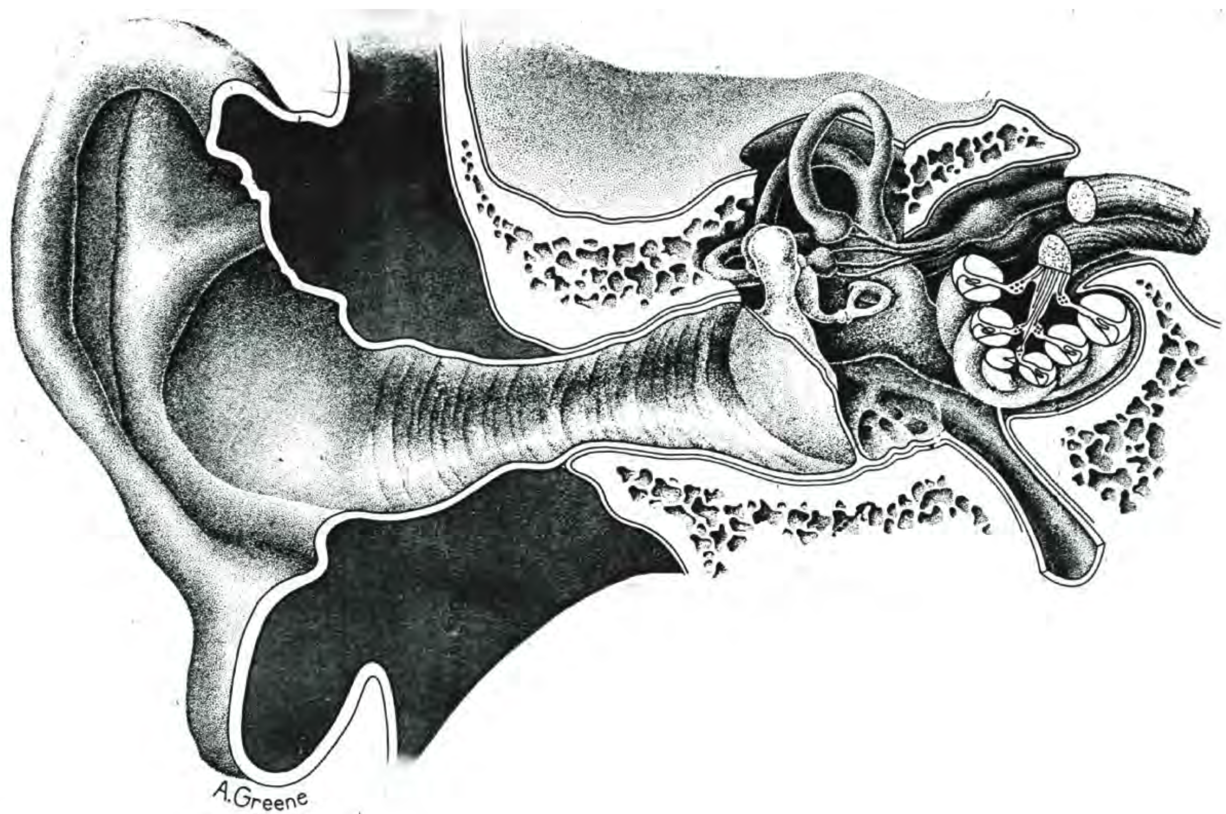
von Baeyer

PNAS

Minimal basilar membrane motion in low-frequency hearing

Rebecca L. Warren[a,1], Sripriya Ramamoorthy[b,1], Nikola Ciganović[c], Yuan Zhang[d], Teresa M. Wilson[d], Tracy Petrie[e], Ruikang K. Wang[f,g], Steven L. Jacques[e,h], Tobias Reichenbach[c], Alfred L. Nuttall[d,2], and Anders Fridberger[a,d,2]

[a]Department of Clinical and Experimental Medicine, Linköping University, SE-58183 Linköping, Sweden; [b]Department of Mechanical Engineering, Indian Institute of Technology Bombay, Mumbai, Maharashtra 400076, India; [c]Department of Bioengineering, Imperial College, London SW7 2AZ, United Kingdom; [d]Oregon Hearing Research Center, Department of Otolaryngology, Oregon Health & Science University, Portland, OR 97239-3098; [e]Department of Biomedical Engineering, Oregon Health & Science University, Portland, OR 97239; [f]Department of Bioengineering, University of Washington, Seattle, WA 98195-5061; [g]Department of Ophthalmology, University of Washington, Seattle, WA 98195-5061; and [h]Department of Dermatology, Oregon Health & Science University, Portland, OR 97239;



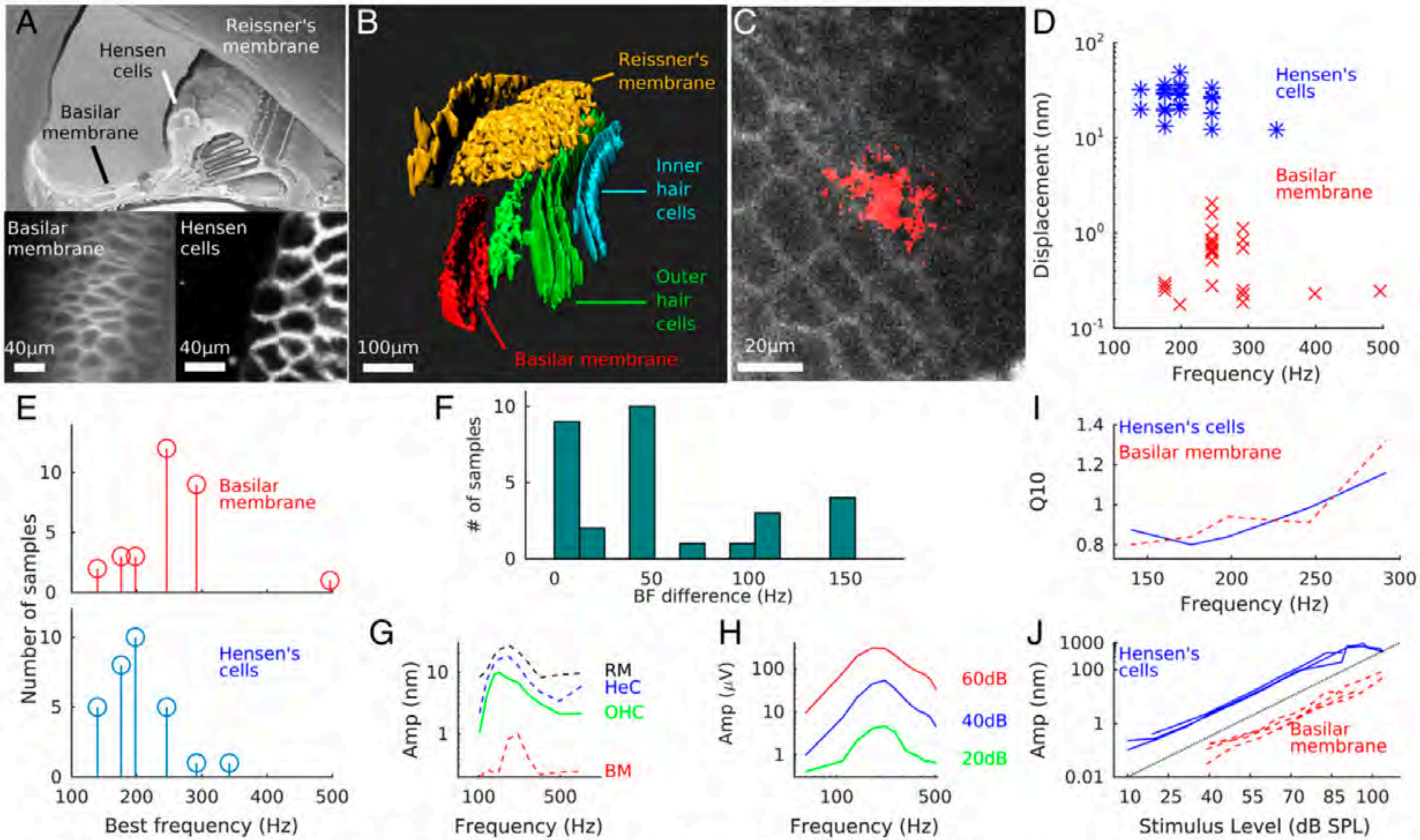
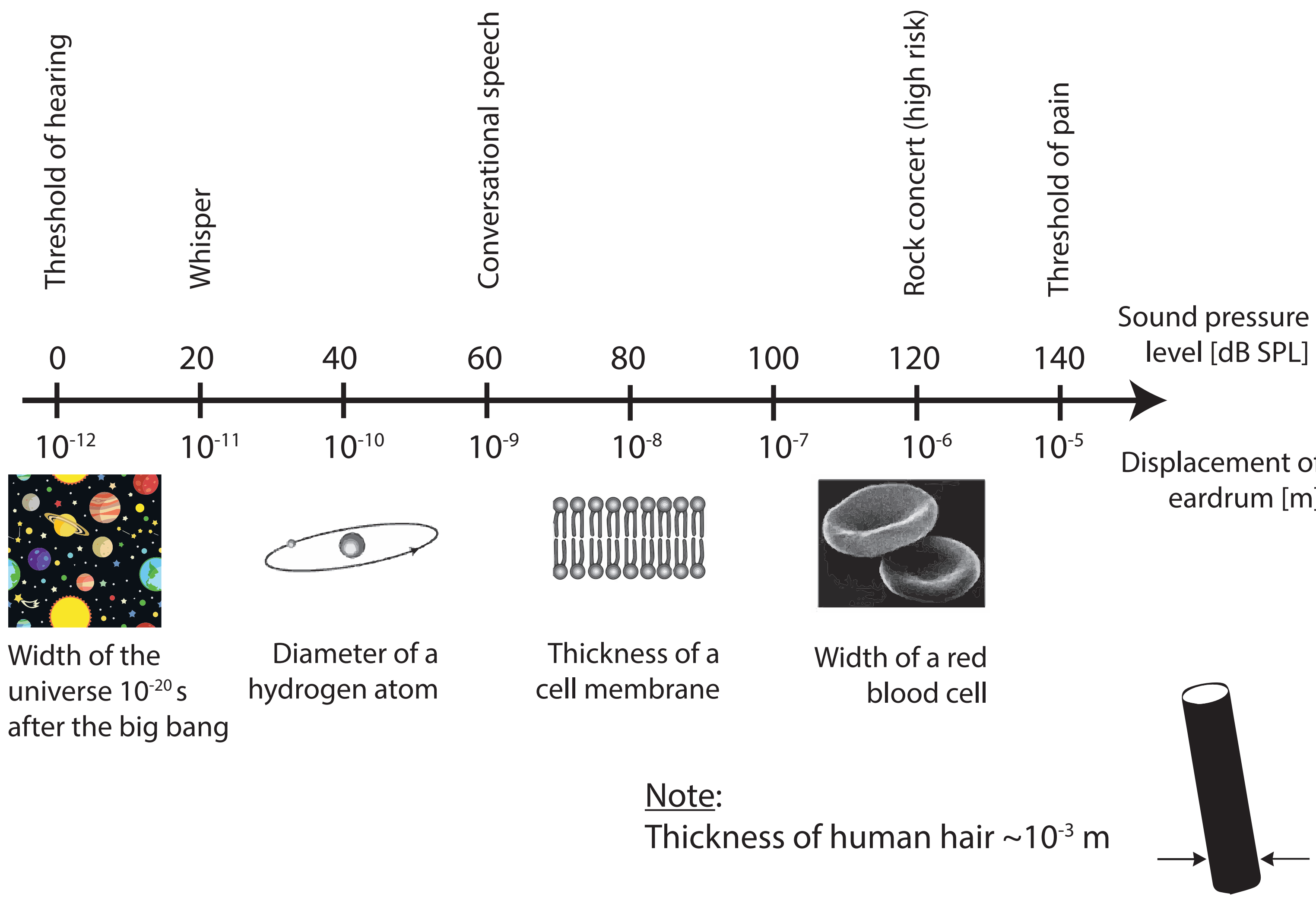


Fig. 1. Sound-evoked movements of the lateral segment of the basilar membrane are small in isolated preparations. (*A*) Schematic drawing of the organ of Corti indicating the approximate measurement locations on the basilar membrane and the Hensen cells. (*Lower Left*) Basilar membrane is identified with confocal microscopy, revealing a honeycomb-like pattern of cells. (*Lower Right*) Hensen cells are found near the stereocilia of the outer hair cells. (*B*) Three-dimensional reconstructions obtained from confocal image stacks with 4-µm section spacing were used for determining the spatial relations between measurement sites. (*C*) Absolute location of the measurement spot was determined by confocal imaging of the focused measurement beam (red dots, here focused on the basilar membrane). (*D*) Peak basilar membrane displacement is smaller than peak Hensen cell vibration. The stimulus level is 59 dB SPL. Note that all sound pressures given in this figure were corrected for attenuation caused by immersion of the preparation in tissue culture medium (*Methods*). (*E*) At 59 dB SPL, basilar membrane vibrations peak at higher frequencies in most preparations. (*F*) Frequency difference ranges from 0 to 150 Hz. In no case was the basilar membrane tuned to a lower frequency than the Hensen cells. BF, best frequency. (*G* and *H*) Mechanical tuning curves are of similar shape as the tuning of the cochlear microphonic potentials. Sound pressure in *G* was 59 dB SPL. Amp, amplitude. (*I*) Sharpness of tuning does not differ between the basilar membrane and the Hensen cells. (*J*) Hensen cells show compressive nonlinearity at levels >85 dB SPL.

Table 1.1 SI Prefixes

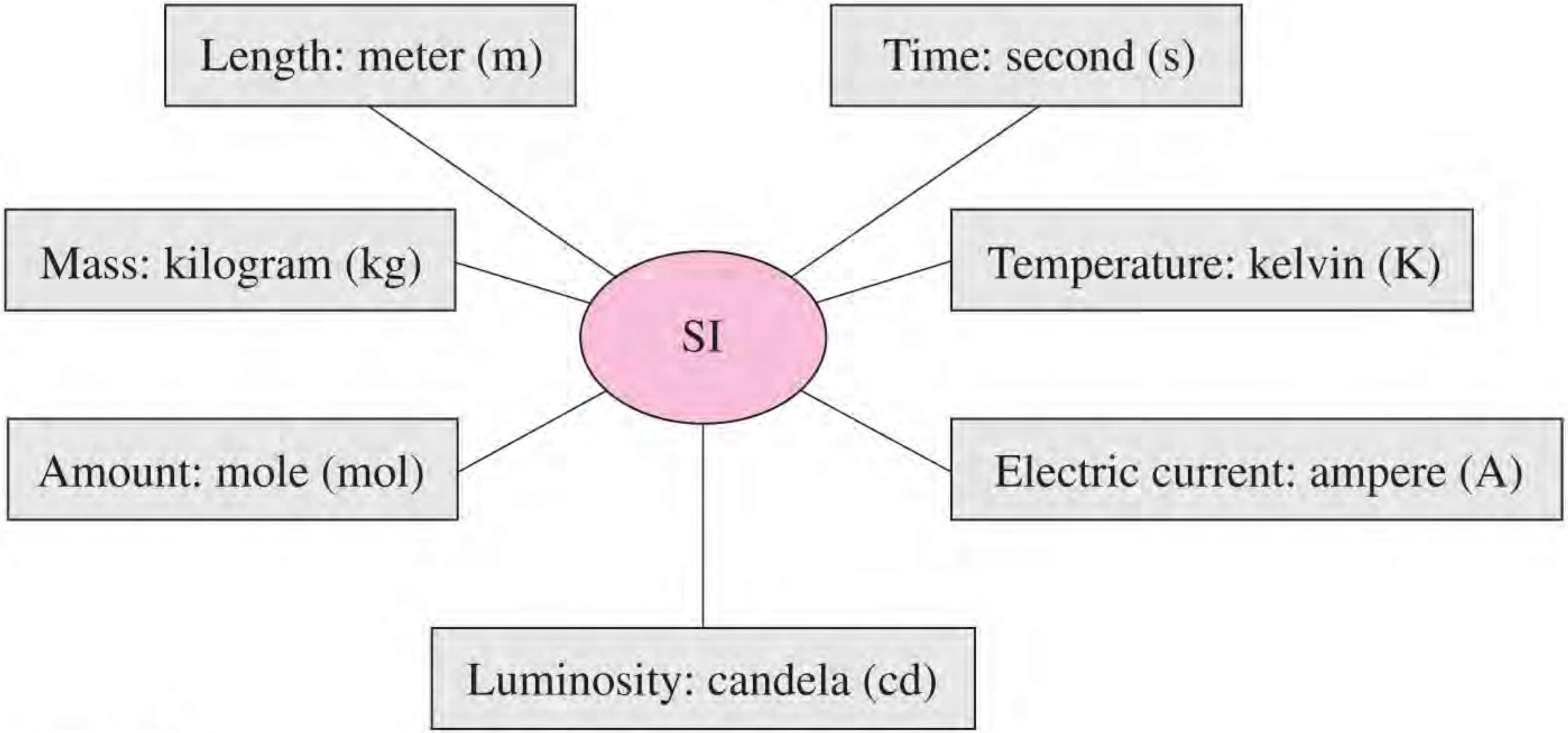
Prefix	Symbol	Power
yotta	Y	10^{24}
zetta	Z	10^{21}
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deca	da	10^{1}
—	—	10^{0}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}
zepto	z	10^{-21}
yocto	y	10^{-24}

→ Gotta know your units/jargon. PRACTICE!



Threshold of hearing
Whisper
Conversational speech
Rock concert (high risk)
Threshold of pain
Sound pressure level [dB SPL]
0
20
40
60
80
100
120
140
10^{-12}
10^{-11}
10^{-10}
10^{-9}
10^{-8}
10^{-7}
10^{-6}
10^{-5}
Displacement of eardrum [m]
Width of the universe 10^{-20} s after the big bang
Diameter of a hydrogen atom
Thickness of a cell membrane
Width of a red blood cell
Note:
Thickness of human hair ~10^{-3} m

Units

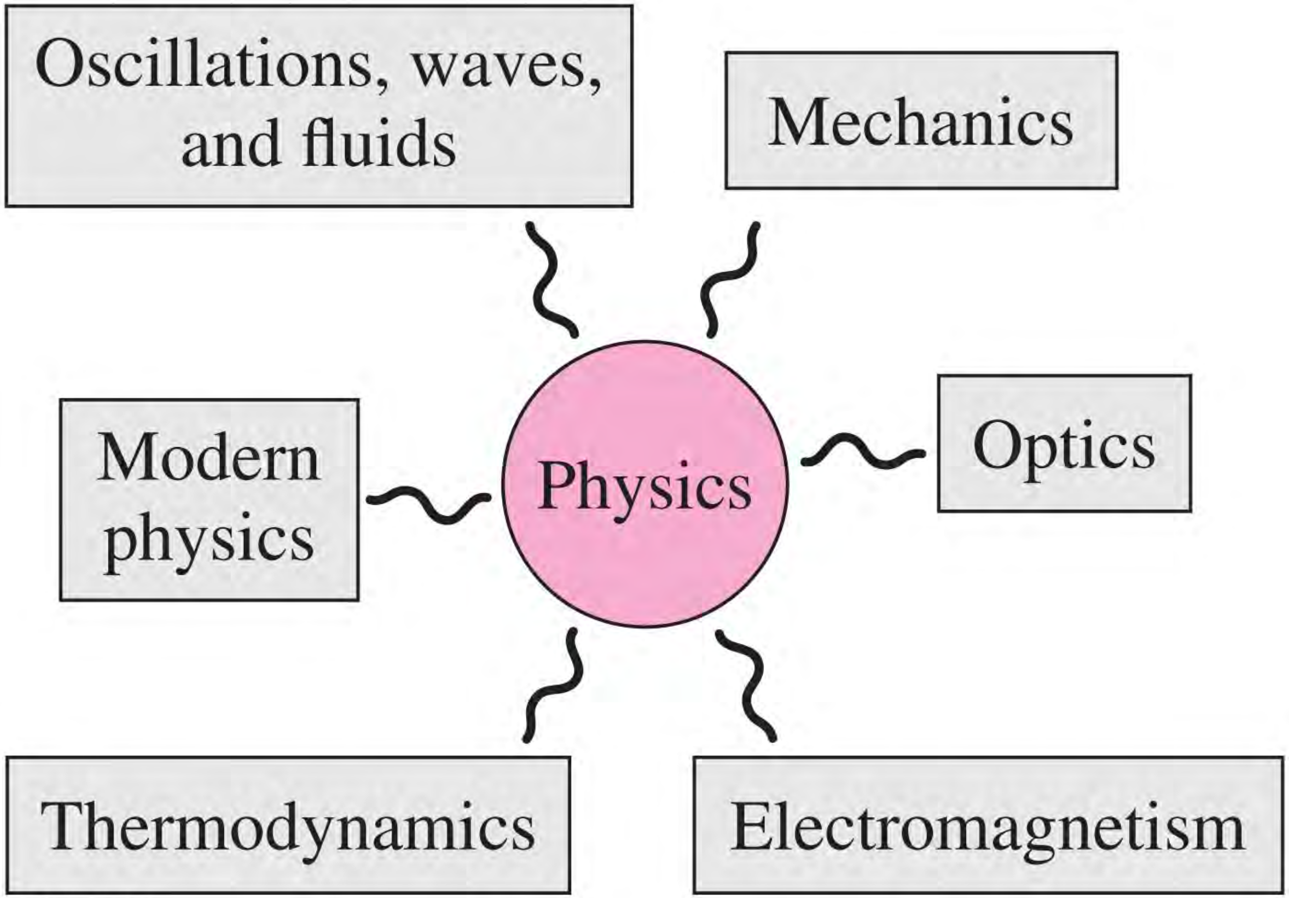


- Deep idea at play here (e.g., different ways of categorizing “stuff”)
- Which of these are obviously tied to “energy” in some way?

Wolfson

Starting point (re “branches” of physics)

Question: What is “modern physics”? Is there an “old physics”?



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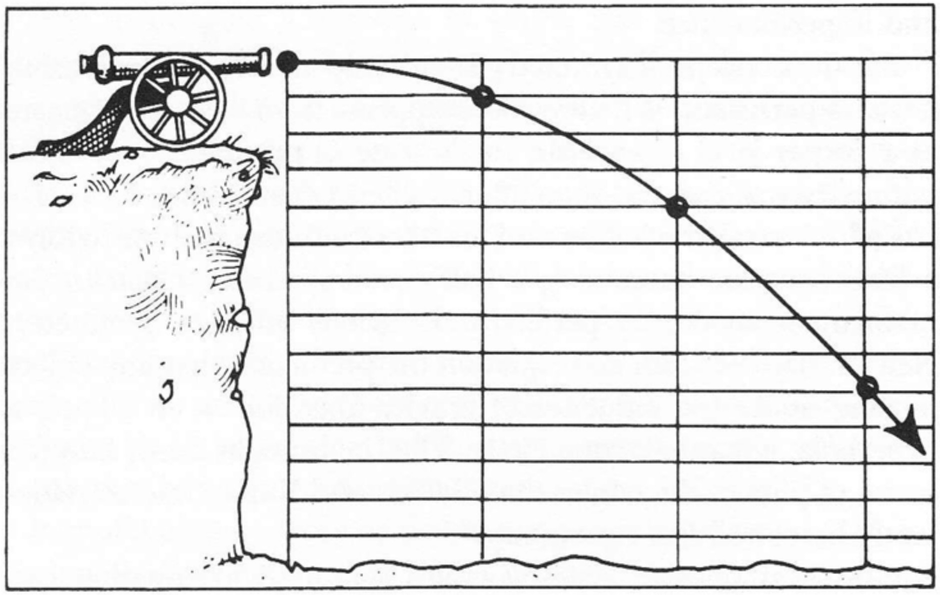
Mechanics → "Change"



- Where is the cannonball?
  "When" matters too, right?

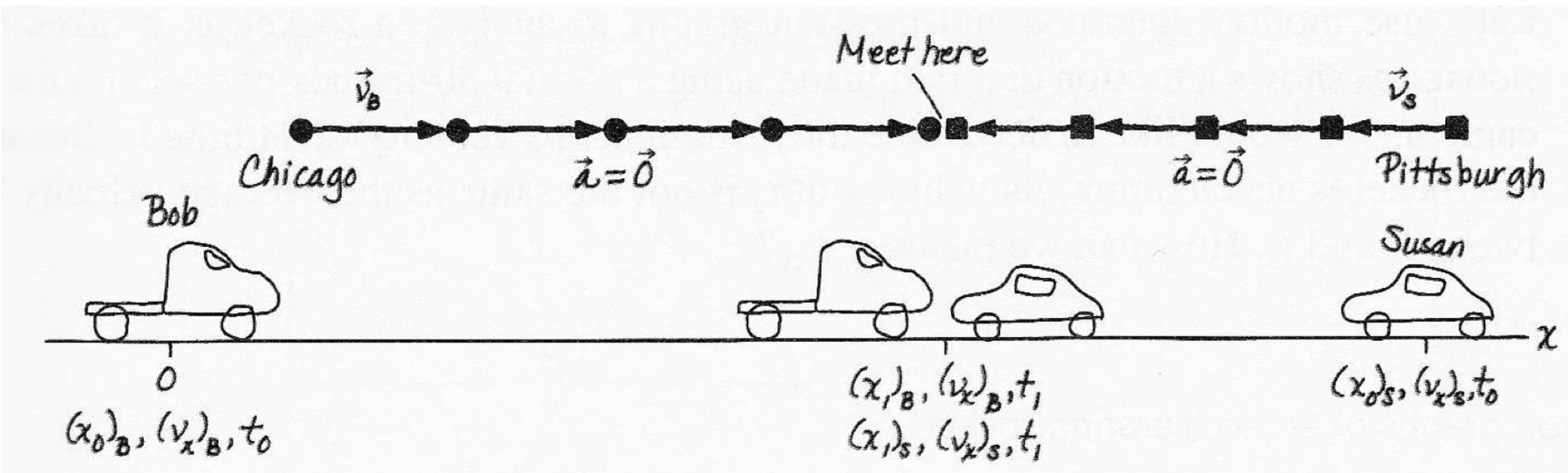
- Let's just consider 1-D for now (e.g., height of the cannonball; we'll come back to 2-D in ch.3)

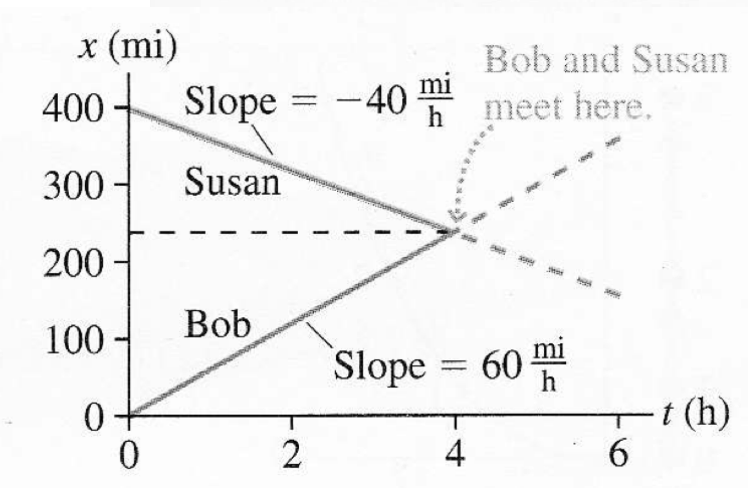
- Consider three basic quantities:
  - Position [m]
  - Speed or velocity [m/s]
  - Acceleration [m/s^2]

- These are all inter-related via how things are ***changing with time***

Ex.

Bob leaves home in Chicago at 9:00 A.M. and travels east at a steady 60 mph. Susan, 400 miles to the east in Pittsburgh, leaves at the same time and travels west at a steady 40 mph. Where will they meet for lunch?





ANS

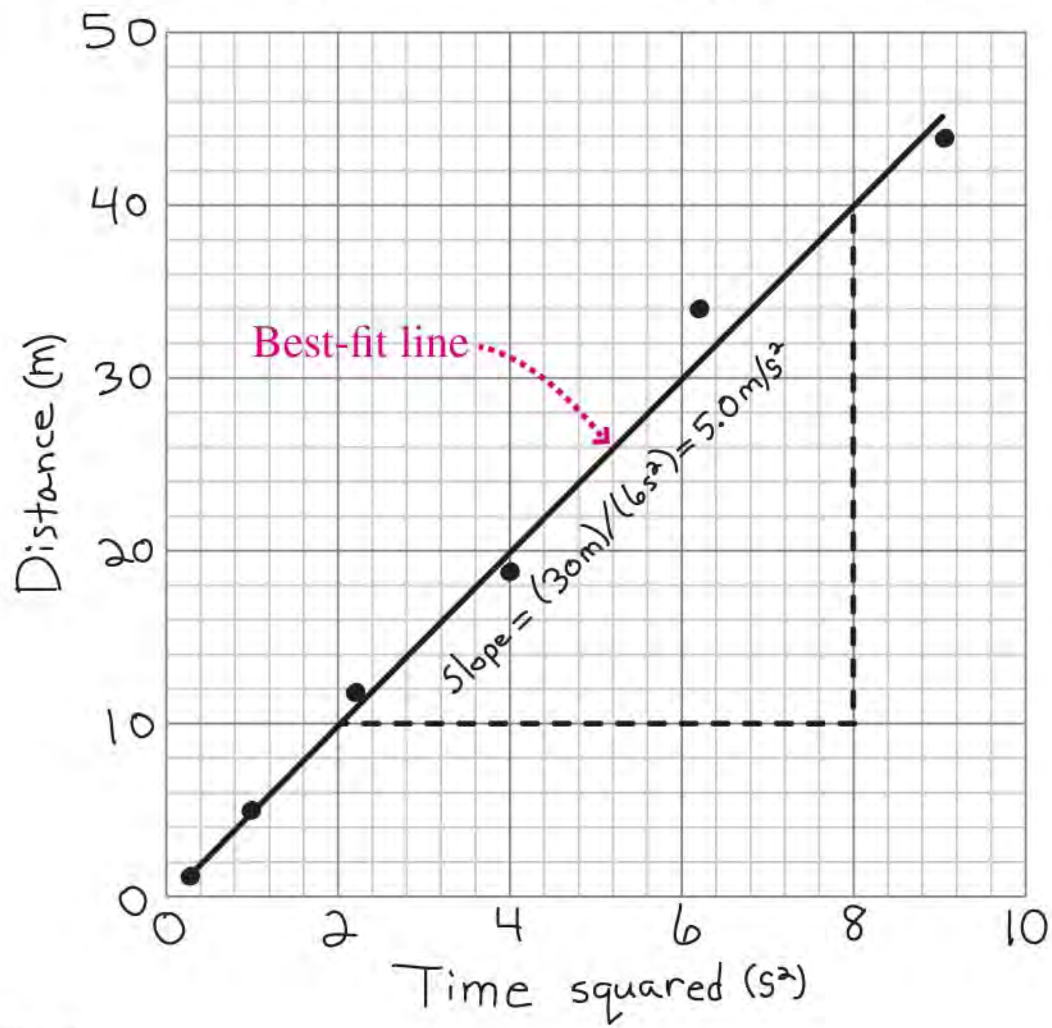
They will meet at ~1 PM approx. 240 miles from Chicago (near Cleveland?)

Knight

Visualizing

Time (s)	0.500	1.00	1.50	2.00	2.50	3.00
Distance (m)	1.12	5.30	12.2	18.5	34.1	43.6

Time Squared (s^2)	0.250	1.00	2.25	4.00	6.25	9.00

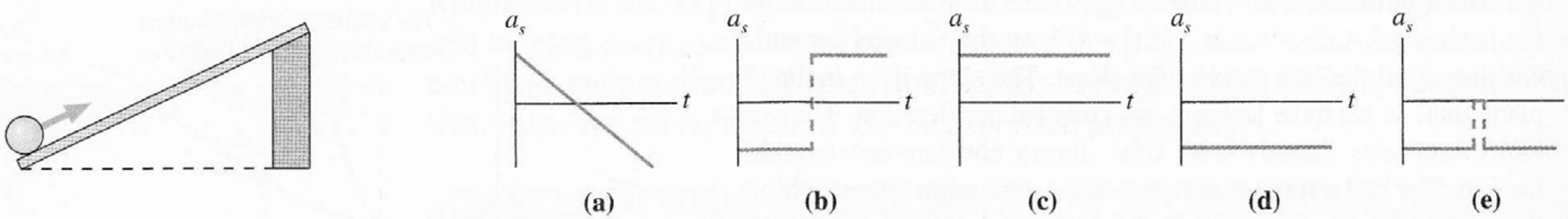


→ There is a LOT going on here. Take some time to stop and reflect....

Wolfson

Ex.

STOP TO THINK 2.5 The ball rolls up the ramp, then back down. Which is the correct acceleration graph?

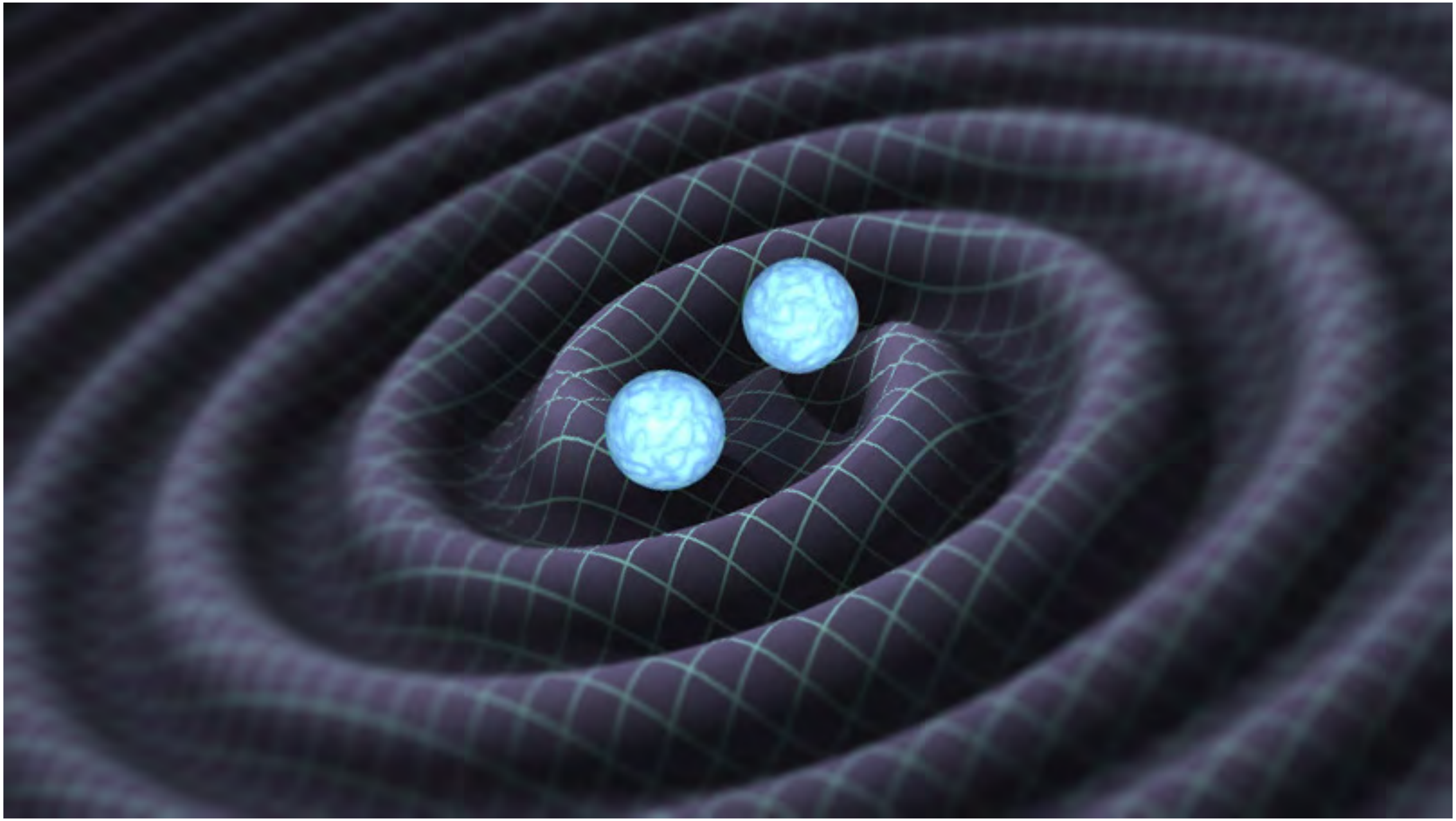


→ Gravity works in a consistent "downward" fashion (and is typically treated within the context of problems involving "constant acceleration"

Aside: What causes gravity? (we'll chiefly return to this next lecture & beyond)

Knight

<u>Aside</u>: What causes gravity?

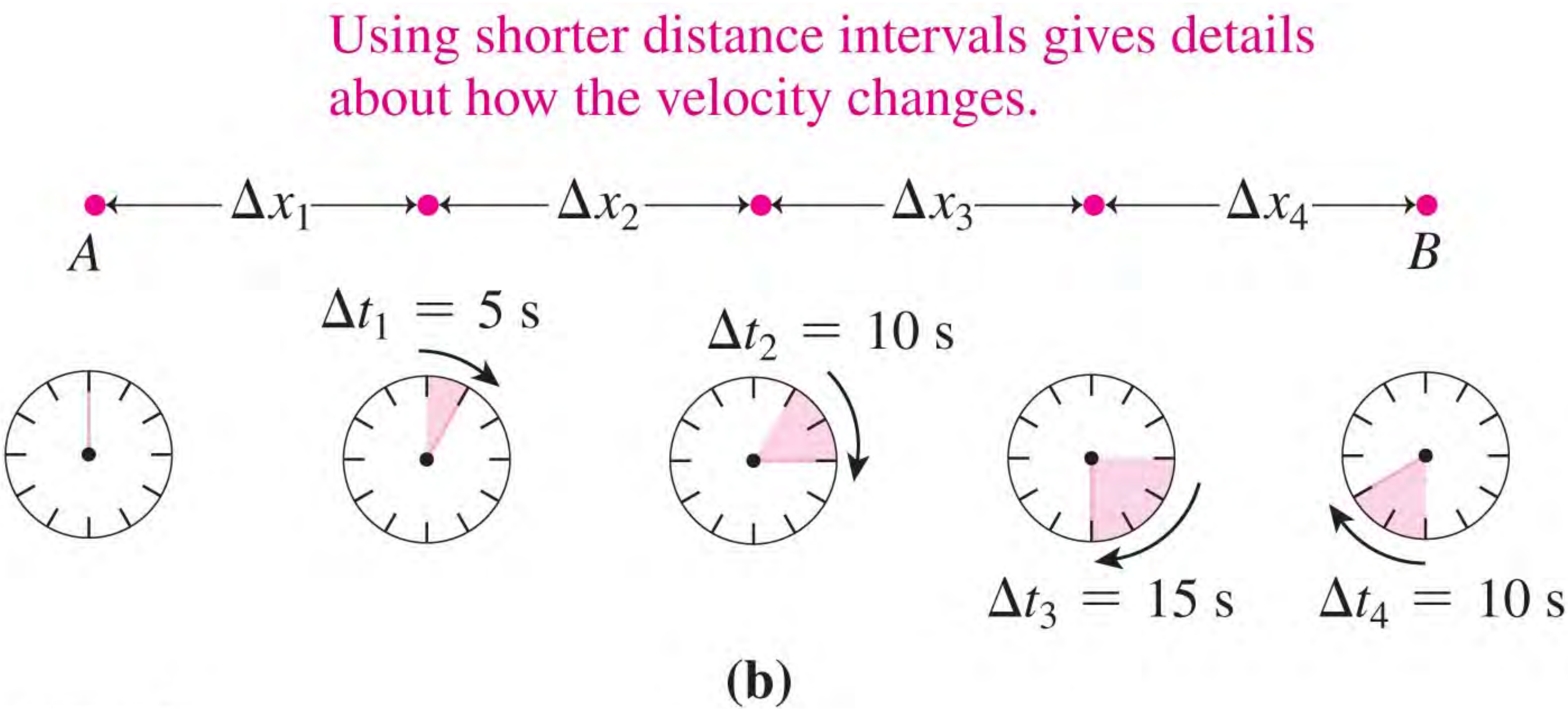


Two black holes collide and form a ripple in spacetime (→ Gravitational Waves)

https://www.ligo.caltech.edu/

<u>Integration</u>: Mathematics & Physics

- Elements of calculus are going to start (nicely/naturally) coming into play....



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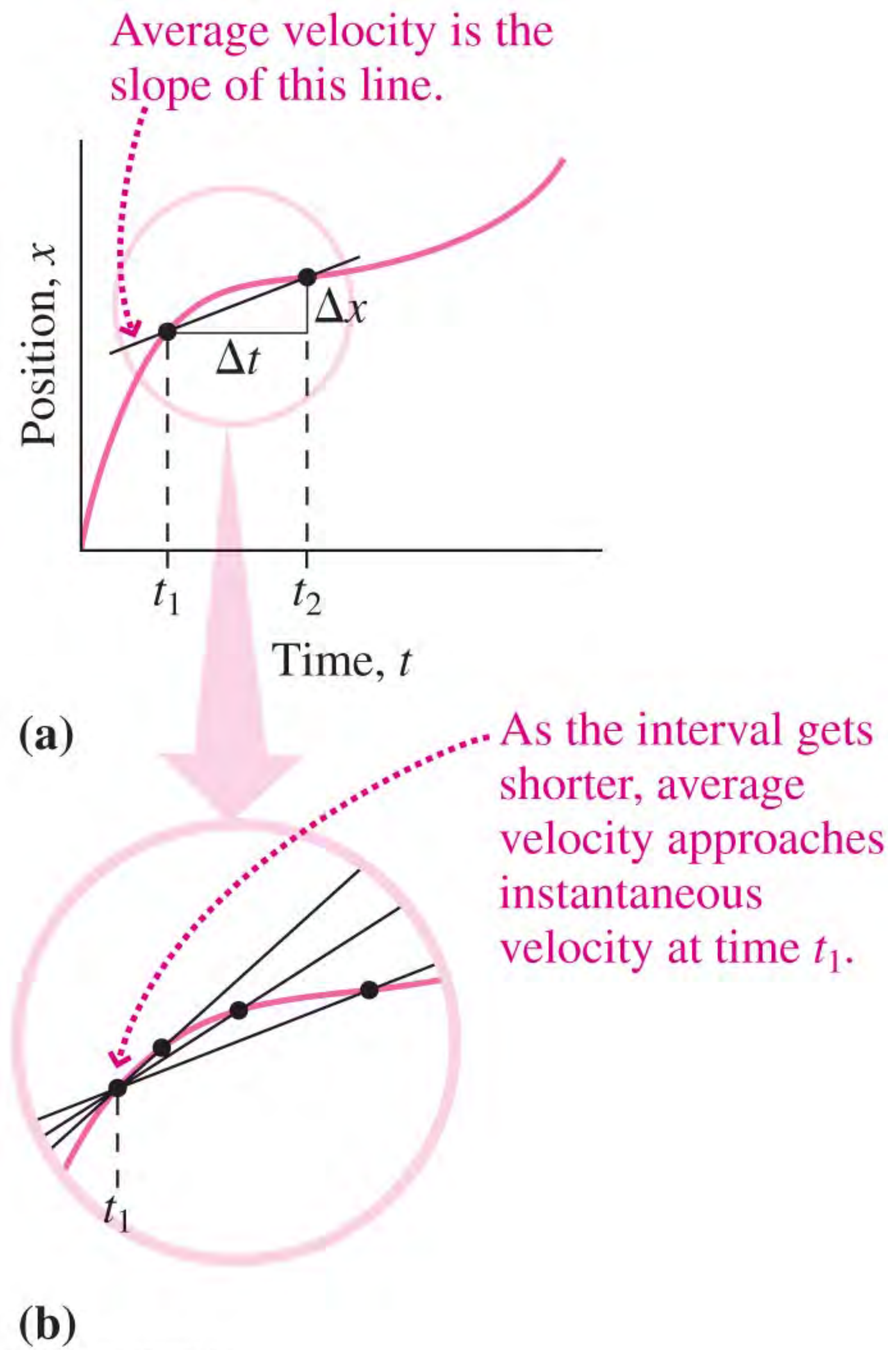
Mechanics & Calculus

→ Consider making Δt smaller and smaller, eventually hitting a "limit"



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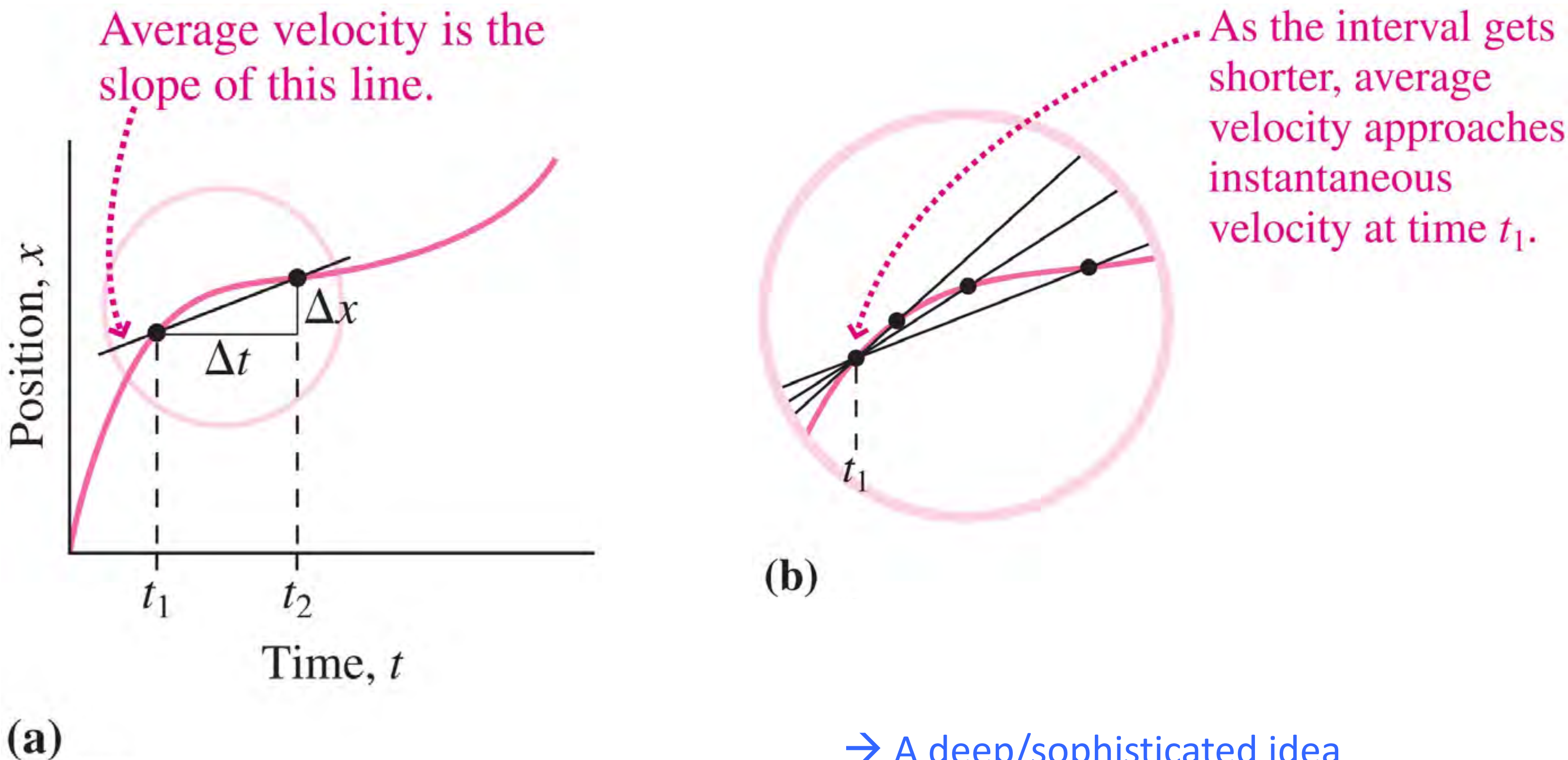
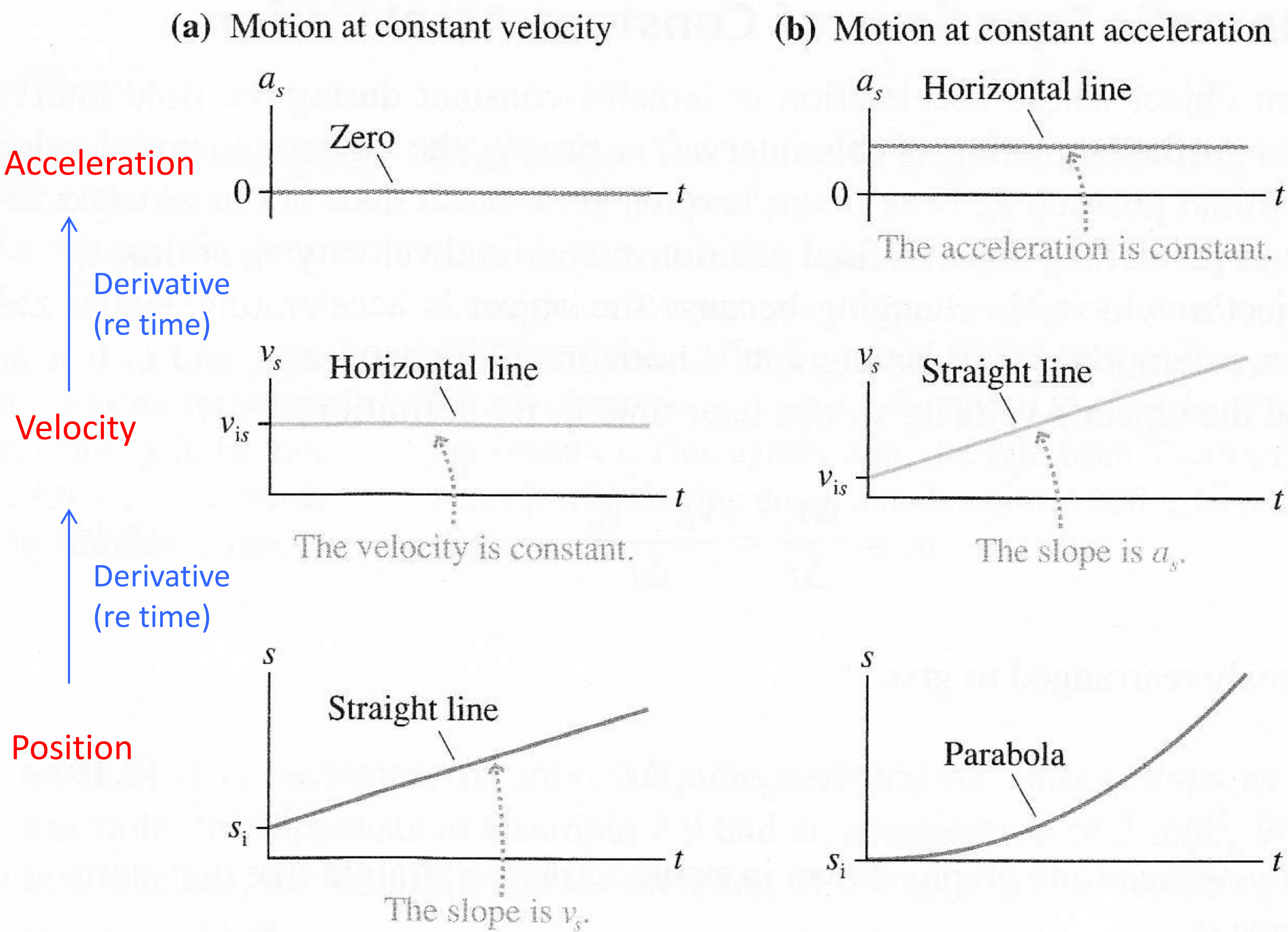
Mechanics & Calculus



→ A deep/sophisticated idea underlies what is going on here....

FIGURE 2.24 Motion with constant velocity and constant acceleration. These graphs assume $s_i = 0$, $v_{is} > 0$, and (for constant acceleration) $a_s > 0$.



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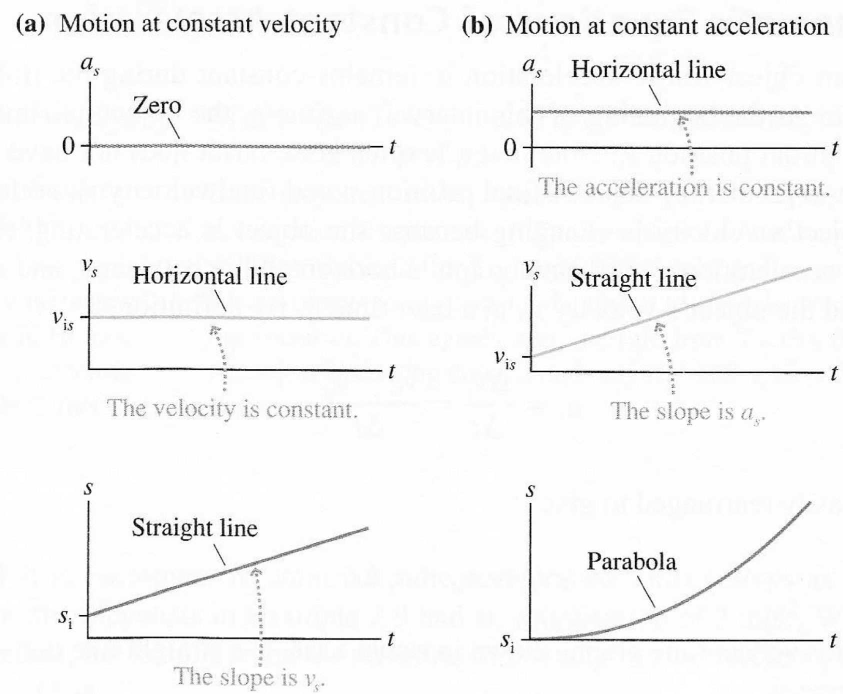
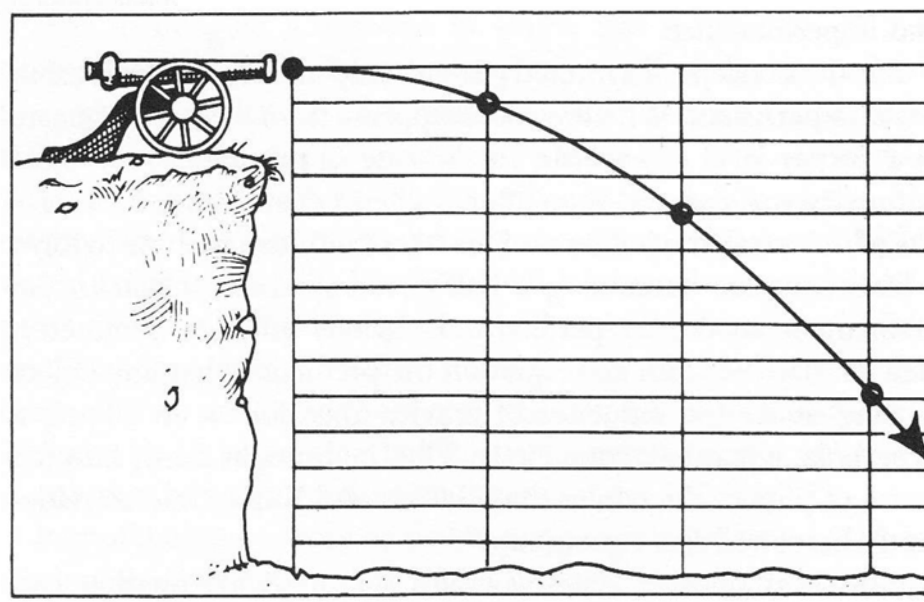




The door swings both ways.....

Position, Velocity, and Acceleration

Derivative Form

If $s = s(t)$ is the position function of an object at time t, then

$$\text{Velocity} = v = \frac{ds}{dt} \qquad \text{Acceleration} = a = \frac{dv}{dt}$$

Integral Form

$$s(t) = \int v(t)dt \qquad v(t) = \int a(t)dt$$

Acceleration

$$\text{Acceleration} \underset{\text{Derivative (re time)}}{\overset{\text{Integrate (re time)}}{\rightleftarrows}} \text{Velocity} \underset{\text{Derivative (re time)}}{\overset{\text{Integrate (re time)}}{\rightleftarrows}} \text{Position}$$

Velocity

Position

→ Sometimes integration is called "anti-differentiation"

	Derivative Form
Position	$r(t)$
Velocity	$v(t) = \frac{dr}{dt}$
Acceleration	$a(t) = \frac{dv}{dt} = \frac{d^2r}{dt^2}$

NOTE: Numerically, integration is typically much easier than differentiation

Ex.

EXAMPLE 2.16 From track to graphs

Draw position, velocity, and acceleration graphs for the ball on the frictionless track of FIGURE 2.35.

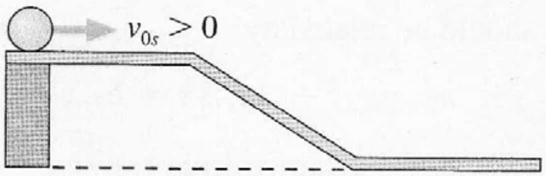


FIGURE 2.35 A ball rolling along a track.

Note: Implicitly buried in the "model" here is the notion that we treat the ball like a "particle" (or better yet, a *point*). That is, we don't worry about its rotation, the moment of intertia, etc… Further, note that we also make other (implicit) simplifications, such as neglecting friction, etc…

→ Generally helpful to consider what (stated & unstated) simplifying assumptions are being made….

Knight

Ex.

EXAMPLE 2.16 **From track to graphs**

Draw position, velocity, and acceleration graphs for the ball on the frictionless track of FIGURE 2.35.

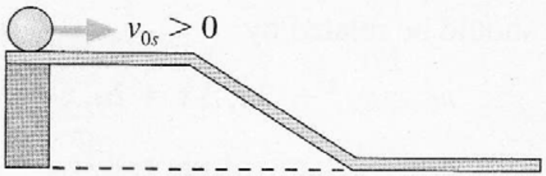
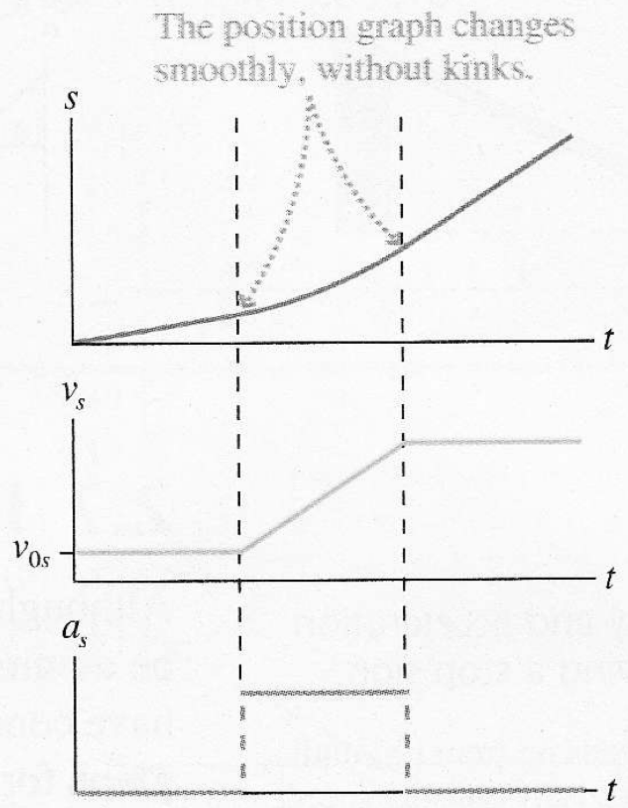


FIGURE 2.35 A ball rolling along a track.

FIGURE 2.36 Motion graphs for the ball in Example 2.16.

ANS



Question: Why is acceleration only non-zero on the downward incline?

Knight

How To Solve It

A New Aspect of Mathematical Method

G. POLYA
Stanford University

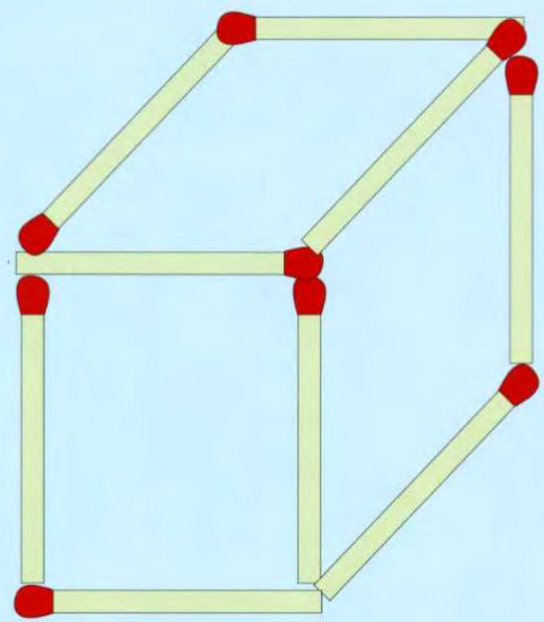
- Have you seen it before? Or have you seen the same problem in a slightly different form?
- *Do you know a related problem?* Do you know a theorem that could be useful?

2. DEVISING A PLAN

- **Second.** Find the connection between the data and the unknown. You may be obliged to consider auxiliary problems if an immediate connection cannot be found. You should obtain eventually a *plan* of the solution.
- Have you seen it before? Or have you seen the same problem in a slightly different form?
- *Do you know a related problem?* Do you know a theorem that could be useful?
- *Look at the unknown!* Try to think of a familiar problem having the same or a similar unknown.
- *Here is a problem related to yours and solved before. Could you use it?* Could you use its result? Could you use its method? Should you introduce some auxiliary element in order to make its use possible?
- Could you restate the problem? Could you restate it still differently? Go back to definitions.
- If you cannot solve the proposed problem, try to solve first some related problem. Could you imagine a more accessible related problem? A more general problem? A more special problem? An analogous problem? Could you solve a part of the problem? Keep only a part of the condition, drop the other part; how far is the unknown then determined, how can it vary? Could you derive something useful from the data? Could you think of other data appropriate to determine the unknown? Could you change the unknown or data, or both if necessary, so that the new unknown and the new data are nearer to each other?
- Did you use all the data? Did you use the whole condition? Have you taken into account all essential notions involved in the problem?

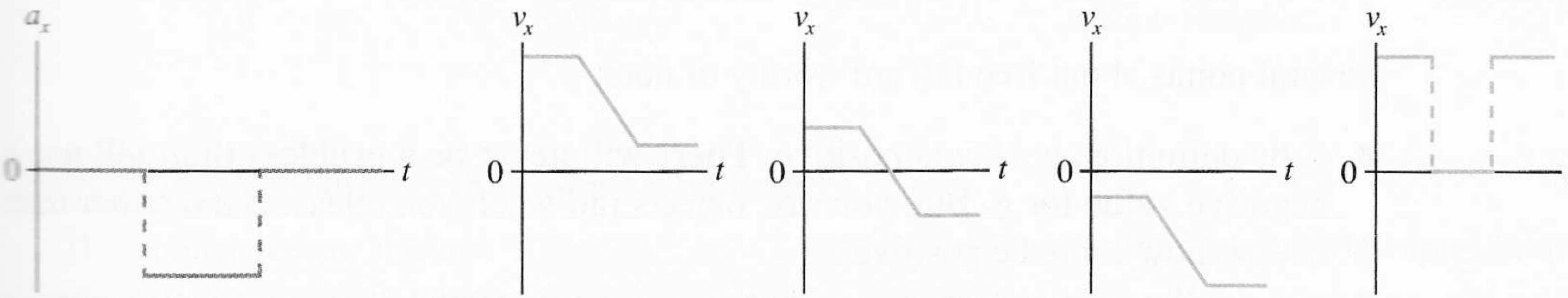
Here are nine matches, which have been arranged on a table to form a figure which looks like a cube.

Suppose two of the matches were removed. How could you rearrange the matches that remained so that they still formed the figure of a cube?



<u>Ex.</u> - Velocity vs Speed

STOP TO THINK 2.4 Which velocity-versus-time graph or graphs go with the acceleration-versus-time graph? The particle is initially moving to the right.



(a) (b) (c) (d)

Ex. - Velocity vs Speed

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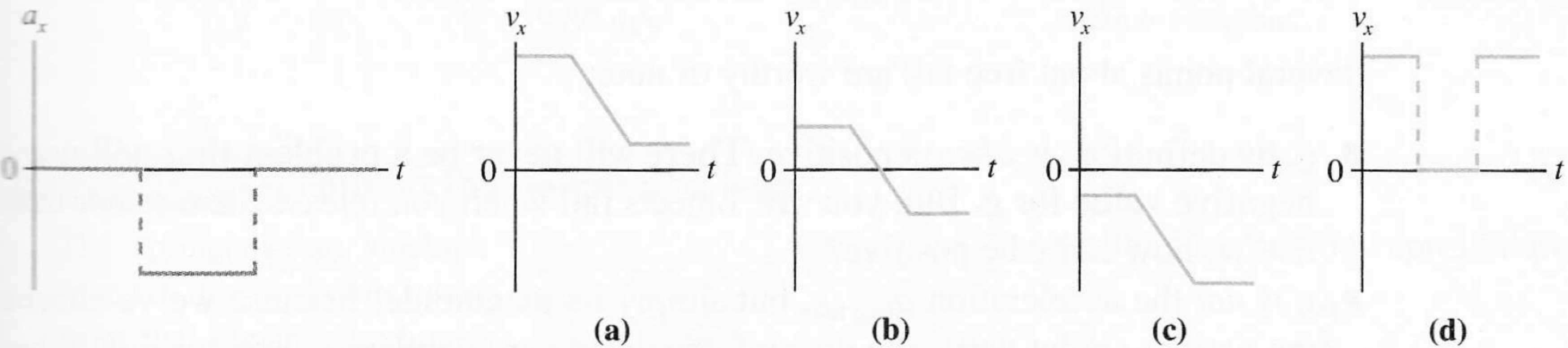


ANS
a & b only (why?)

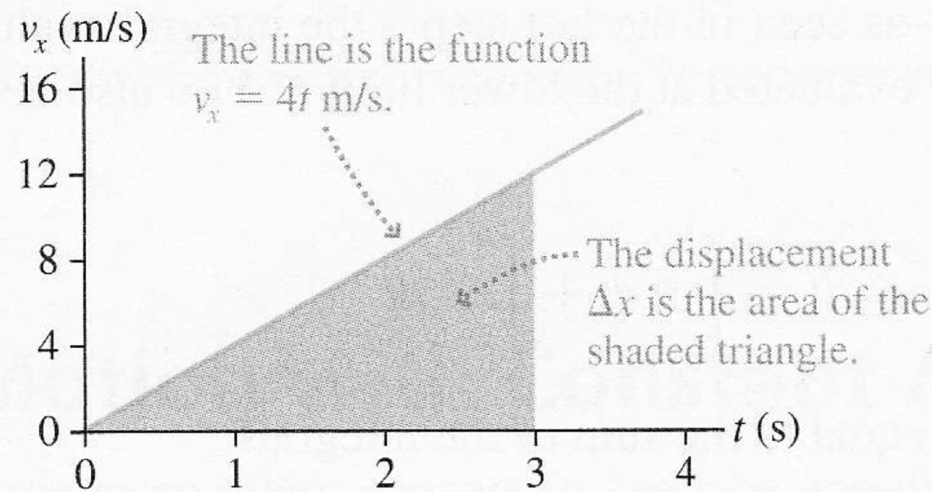
→ Think carefully about what implicit assumptions are built-in to things...

Ex.

	Derivative Form
Position	$r(t)$
Velocity	$v(t) = \dfrac{dr}{dt}$
Acceleration	$a(t) = \dfrac{dv}{dt} = \dfrac{d^2r}{dt^2}$

FIGURE 2.17 shows the velocity-versus-time graph of a drag racer. How far does the racer move during the first 3.0 s?

FIGURE 2.17 Velocity-versus-time graph for Example 2.6.



MODEL Represent the drag racer as a particle with a well-defined position at all times.

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Ex.

	Derivative Form
Position	$r(t)$
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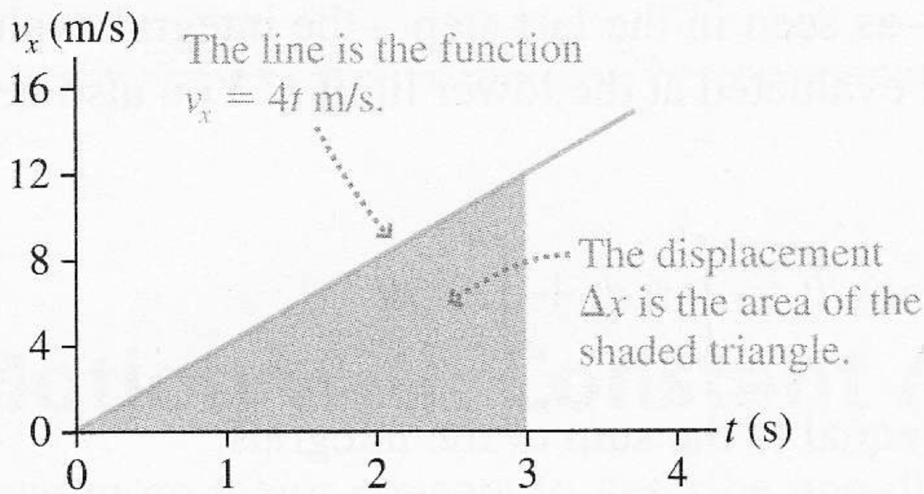


MODEL Represent the drag racer as a particle with a well-defined position at all times.

$$\Delta x = \text{area of triangle between } t = 0 \text{ s and } t = 3 \text{ s}$$

$$= \tfrac{1}{2} \times \text{base} \times \text{height}$$

$$= \tfrac{1}{2} \times 3 \text{ s} \times 12 \text{ m/s} = 18 \text{ m}$$

→ Either way you go (forward or backward), there is a nice geometric representation

Knight

Ex.

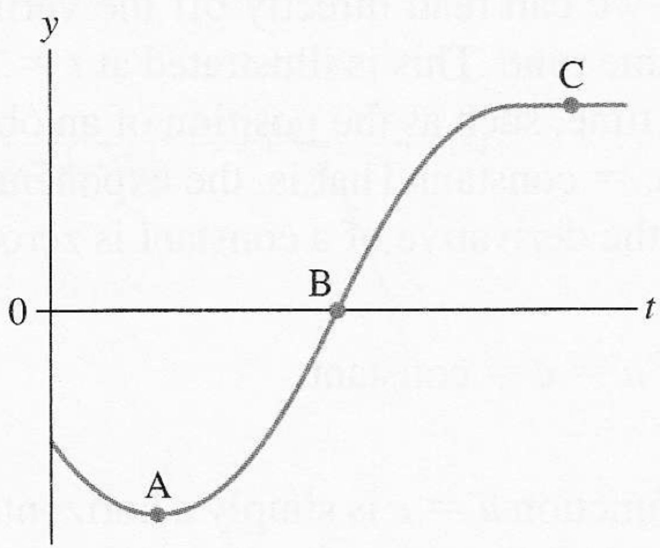
FIGURE 2.10 shows the position-versus-time graph of an elevator.

a. At which labeled point or points does the elevator have the least speed?

b. At which point or points does the elevator have maximum velocity?

c. Sketch an approximate velocity-versus-time graph for the elevator.

FIGURE 2.10 Position-versus-time graph.



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Ex.

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a. At which labeled point or points does the elevator have the least speed?

b. At which point or points does the elevator have maximum velocity?

c. Sketch an approximate velocity-versus-time graph for the elevator.

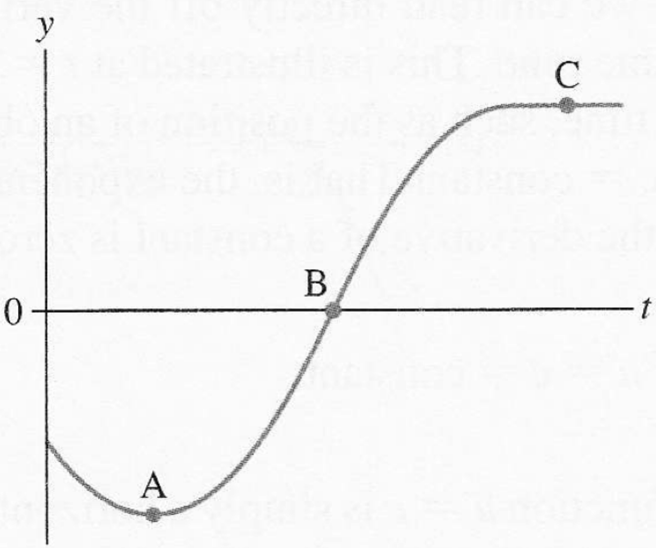
ANS

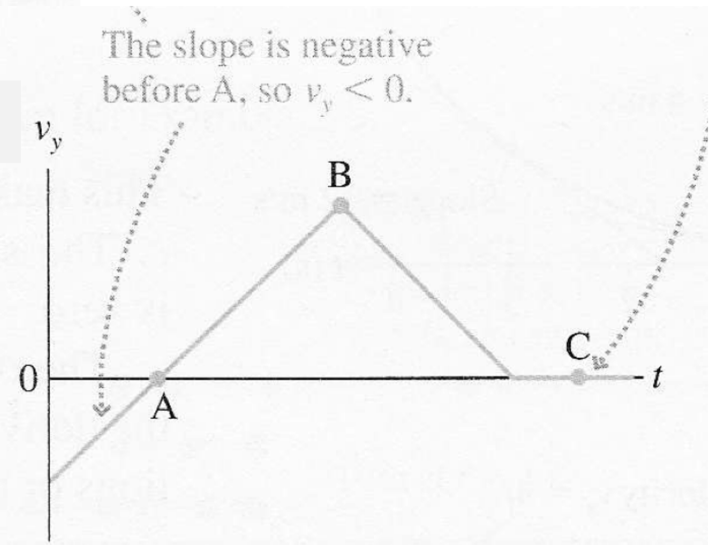
a. a & c

b. b (going up!)

c.

FIGURE 2.10 Position-versus-time graph.





Question: Would a “real” elevator actually do this? Unlikely....

Knight

Equations of motion

Table 2.1 Equations of Motion for Constant Acceleration

Equation	Contains	Number
$v = v_0 + at$	v, a, t; no x	2.7
$x = x_0 + \frac{1}{2}(v_0 + v)t$	x, v, t; no a	2.9
$x = x_0 + v_0 t + \frac{1}{2}at^2$	x, a, t; no v	2.10
$v^2 = v_0^2 + 2a(x - x_0)$	x, v, a; no t	2.11

Question: Where do these formulae (which are useful for solving problems!) come from?

→ Let's derive them!

Position, Velocity, and Acceleration

Derivative Form

If $s = s(t)$ is the position function of an object at time t, then

$$\text{Velocity} = v = \frac{ds}{dt} \qquad \text{Acceleration} = a = \frac{dv}{dt}$$

Integral Form

$$s(t) = \int v(t)dt \qquad v(t) = \int a(t)dt$$

Wolfson

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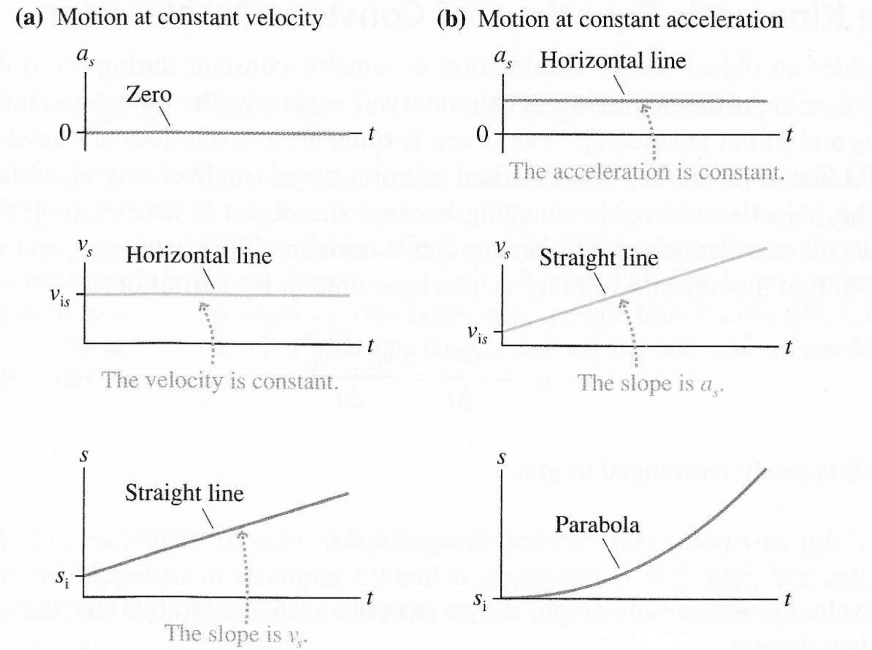
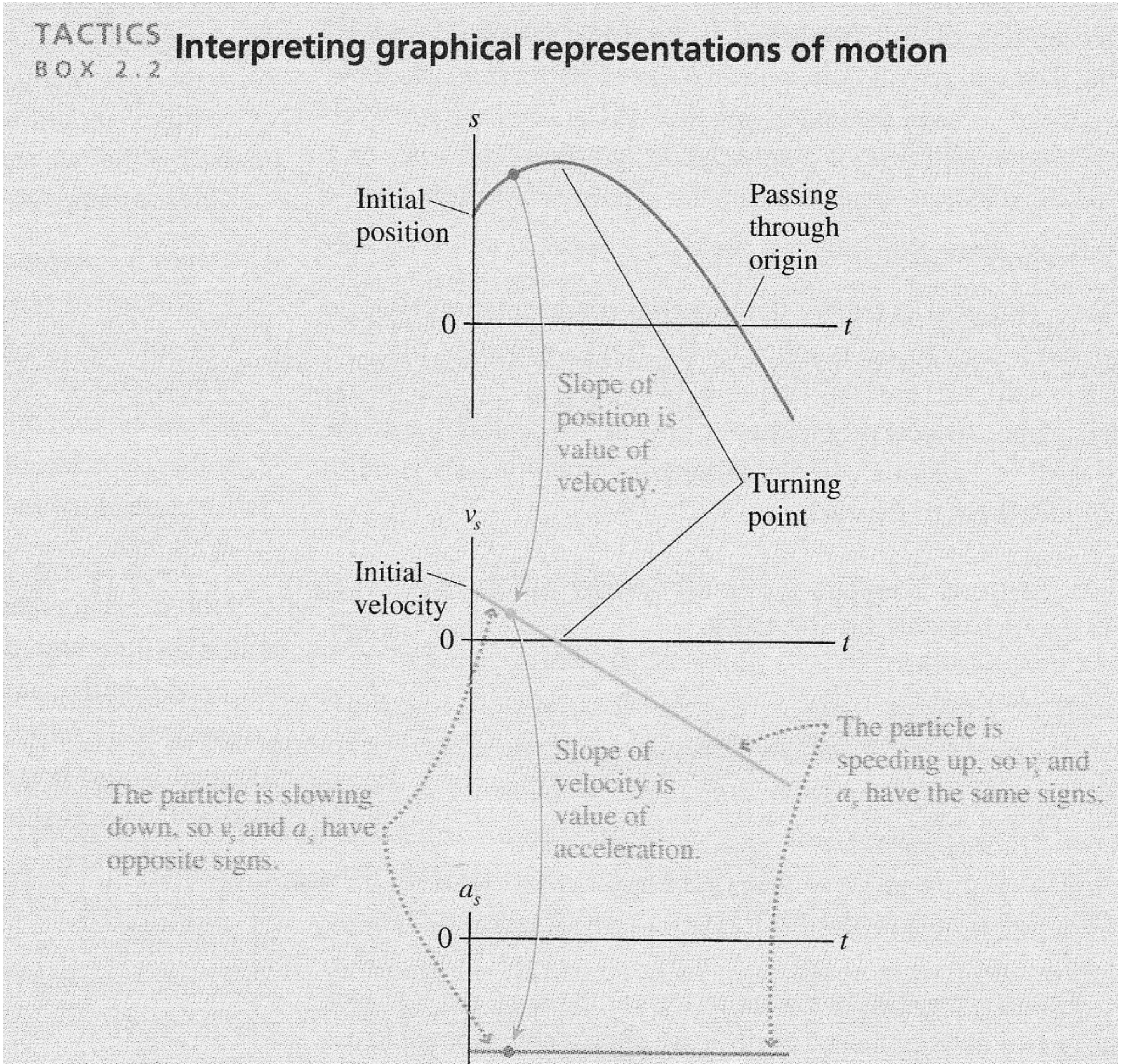
$x = x_0 + v_0 t + \frac{1}{2}at^2$	x, a, t; no v	2.10
$v^2 = v_0^2 + 2a(x - x_0)$	x, v, a; no t	2.11

FIGURE 2.24 Motion with constant velocity and constant acceleration. These graphs assume $s_i = 0$, $v_{is} > 0$, and (for constant acceleration) $a_s > 0$.



→ Convince yourself that these are two sides of the same coin!



→ "Initial conditions" (ICs) matter

Knight

Ex.

A particle's position is given by the function $x = (-t^3 + 3t)$ m, where t is in s.

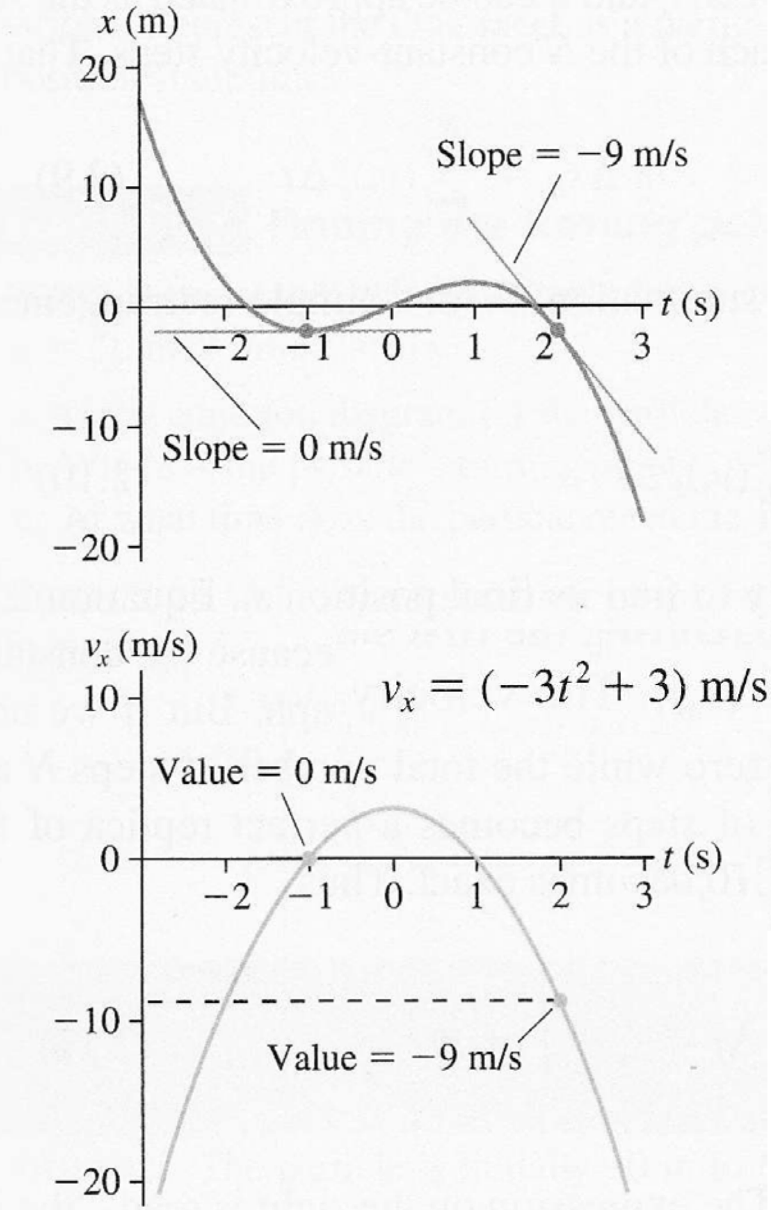
a. What are the particle's position and velocity at $t = 2$ s?

b. Draw graphs of x and v_x during the interval $-3 \text{ s} \le t \le 3$ s.

c. Draw a motion diagram to illustrate this motion.

Knight

FIGURE 2.13 Position and velocity graphs.



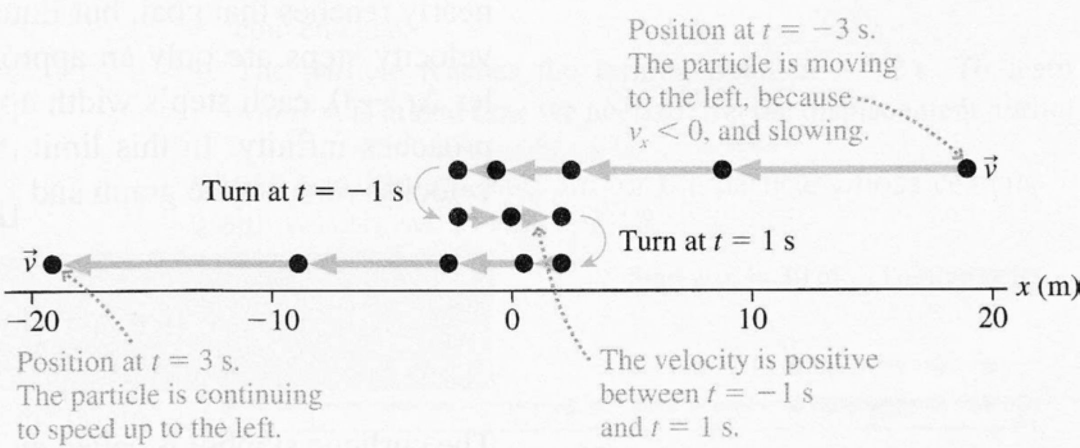
ANS

a. x(2)= -2 m

b. (left)

c. (below; NOTE: “motion diagram” = jargon)

FIGURE 2.14 Motion diagram for Example 2.5.



Knight

Ex. - Velocity vs Speed

a. A bicyclist has a velocity of 10 m/s and a constant acceleration of 2 (m/s)/s. What is her velocity 1 s later? 2 s later?

b. A bicyclist has a velocity of -10 m/s and a constant acceleration of 2 (m/s)/s. What is his velocity 1 s later? 2 s later?

Knight

Ex. - Velocity vs Speed

a. A bicyclist has a velocity of 10 m/s and a constant acceleration of 2 (m/s)/s. What is her velocity 1 s later? 2 s later?

b. A bicyclist has a velocity of -10 m/s and a constant acceleration of 2 (m/s)/s. What is his velocity 1 s later? 2 s later?

ANS

a. v(1)= 12 ms, v(2)= 14 m/s
b. v(1)= -8 m/s, v(2)= -6 m/s

- Speed is how fast something is moving. Velocity is how fast AND in what direction.
- In 1-D, it's relatively simple: the sign carries the information (re velocity)
- In 2-D (and higher), a bit more sophistication is required (→ vectors)

Knight

Forces and all that....

Newton's 2nd Law (const. mass)

Product of object's mass and its acceleration; not a force

$$\vec{F}_{\text{net}} = m\vec{a}$$

Net force: the vector sum of all real, physical forces acting on an object

Equal sign indicates that the two sides are mathematically equal — but that doesn't mean they're the same physically. Only $\vec{F}_{\text{net}}$ involves physical forces.

→ Forces are telling you something about how something else changes (or in some cases, not change)!

Wolfson

Summary

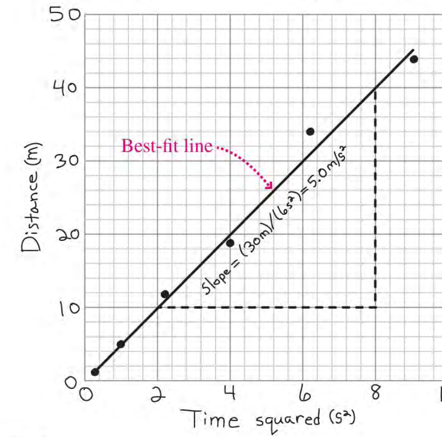
Don't be afraid to think "outside the box"

Table 1.1 SI Prefixes

Prefix	Symbol	Power
yotta	Y	10^{24}
zetta	Z	10^{21}
exa	E	10^{18}
peta	P	10^{15}
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deca	da	10^{1}
—	—	10^{0}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}
atto	a	10^{-18}
zepto	z	10^{-21}
yocto	y	10^{-24}

Start getting (really) comfortable w/ #s

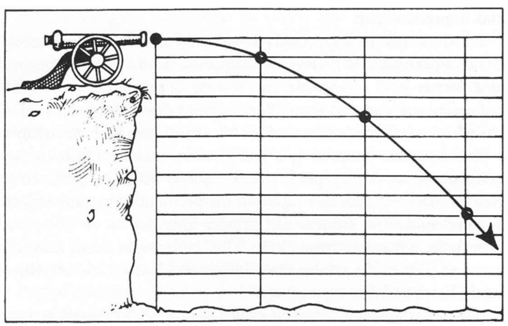
Time (s)	0.500	1.00	1.50	2.00	2.50	3.00
Distance (m)	1.12	5.30	12.2	18.5	34.1	43.6
Time Squared (s^2)	0.250	1.00	2.25	4.00	6.25	9.00



Take your time though....

Table 2.1 Equations of Motion for Constant Acceleration

Equation	Contains	Number
$v = v_0 + at$	v, a, t; no x	2.7
$x = x_0 + \frac{1}{2}(v_0 + v)t$	x, v, t; no a	2.9
$x = x_0 + v_0 t + \frac{1}{2}at^2$	x, a, t; no v	2.10
$v^2 = v_0^2 + 2a(x - x_0)$	x, v, a; no t	2.11



Mechanics, gravity, calculus, etc....

Acceleration

Integrate (re time)

Derivative (re time)

Velocity

Integrate (re time)

Derivative (re time)

Position

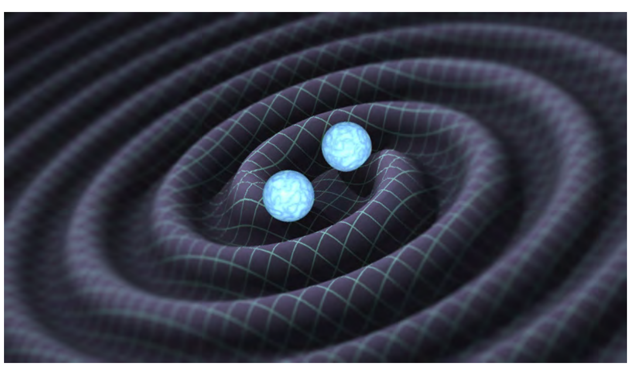
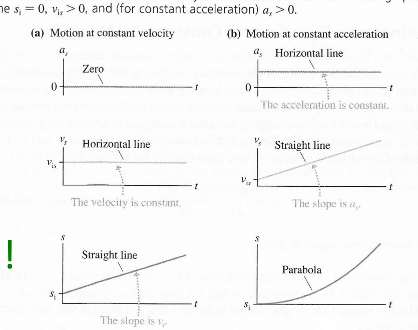


FIGURE 2.24 Motion with constant velocity and constant acceleration. These graphs assume $s_i = 0$, $v_{is} > 0$, and (for constant acceleration) $a_s > 0$.

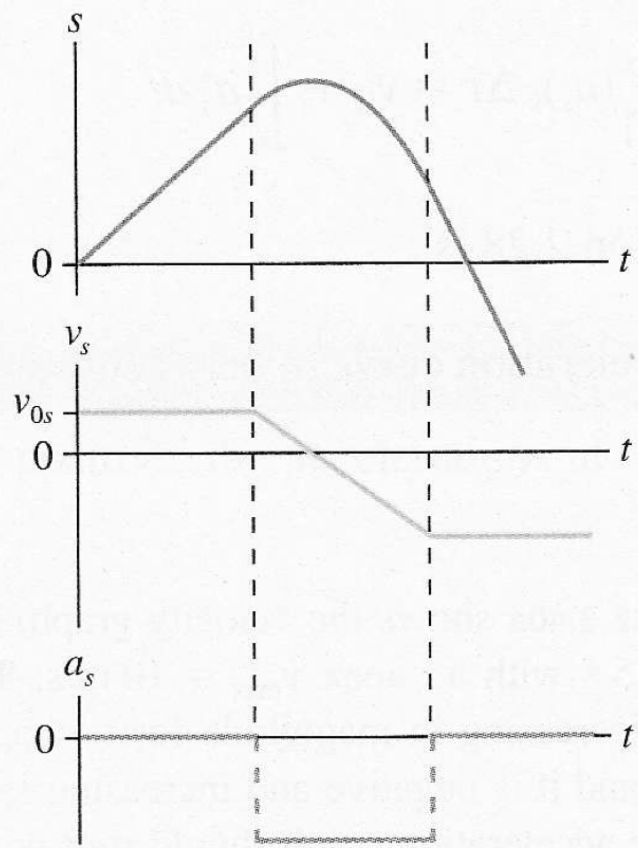


Two sides of the same coin!

Ex. (now you need to go the other "way"!)

FIGURE 2.37 shows a set of motion graphs for a ball moving on a track. Draw a picture of the track and describe the ball's initial condition. Each segment of the track is *straight*, but the segments may be tilted.

FIGURE 2.37 Motion graphs of a ball rolling on a track of unknown shape.



Knight

36. You're driving at speed v_0 when you spot a stationary moose on the road, a distance d ahead. Find an expression for the magnitude of the acceleration you need if you're to stop before hitting the moose.

Ex. - Wolfson Prob. (ch.2)

20. For the motion plotted in Fig. 2.15, estimate (a) the greatest velocity in the positive x-direction, (b) the greatest velocity in the negative x-direction, (c) any times when the object is instantaneously at rest, and (d) the average velocity over the interval shown.

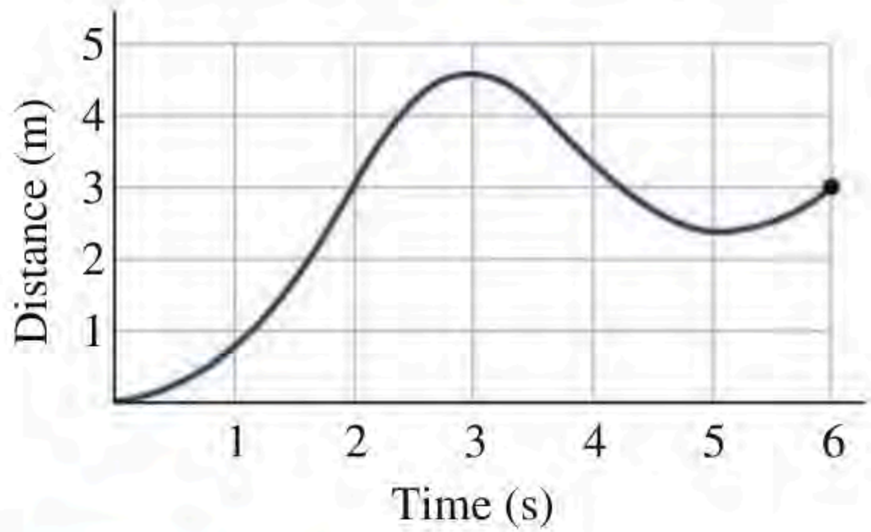


FIGURE 2.15 Exercise 20

Ex. - Wolfson Prob. (ch.1)

22. A year is very nearly $\pi \times 10^7$ s. By what percentage is this figure in error?

SOL

22. **INTERPRET** This problem involves calculating the number of seconds in a year, and comparing the result to $\pi \times 10^7$ s.

DEVELOP From Appendix C we find that 1 y = 365.24 d, and that 1 d = 86,400 s.

EVALUATE Using the conversion equations above, we find that one year is

$$1\ \text{y} = (1\ \cancel{\text{y}})\left(\frac{365.24\ \cancel{\text{d}}}{1\ \cancel{\text{y}}}\right)\left(\frac{86400\ \text{s}}{1\ \cancel{\text{d}}}\right) = 3.156\times10^7\ \text{s}$$

The percent difference e between this result and $\pi \times 10^7$ s is

$$e = \frac{\left(3.142\times10^7\ \text{s} - 3.156\times10^7\ \text{s}\right)}{3.156\times10^7\ \text{s}}(100\%) = -0.44\%$$

ASSESS The approximation $\pi \times 10^7$ s is off by less than half a percent; the negative sign means that it's just a little bit low.

Ex. - Wolfson Prob. (ch.1)

51. The semiconductor chip at the heart of a personal computer is a square 4 mm on a side and contains 10^{10} electronic components. (a) What's the size of each component, assuming they're square? (b) If a calculation requires that electrical impulses traverse 10^4 components on the chip, each a million times, how many such calculations can the computer perform each second? (*Hint*: The maximum speed of an electrical impulse is about two-thirds the speed of light.)