“Why Should I Care?”

Teaching Physics to Non-Believers

Robert E. Thorne

Cornell University

Physics 207 at Cornell

Content: Calculus-based course on mechanics and heat (1st course of 2 semester sequence)

Format: 3 - 1 hour lectures
2 - 1 hour recitations
1 - 2 hour lab each week

Enrollment: 300

Syllabus

- Describing motion along a line: x, v, a relations
- Motion in a plane; projectile motion
- Newton's laws and forces; free-body diagrams
- Circular motion; friction and fluid drag
- Energy; kinetic energy, potential energy; power
- Oscillations: free, driven, damped
- Momentum and impulse; collisions; center of mass
- Torques and static equilibrium; elasticity
- Heat; thermal expansion; heat capacity; heat transport
- Static fluids: pressure, buoyancy, surface tension
- Moving fluids: continuity, Bernoulli, viscous drag and flow
- Traveling and standing waves

Physics 207 Clientele

Major:

Biological and life sciences, chemistry, geology, human ecology, meteorology, english, government, economics, . . . **pre-med/pre-vet**

Academic year:

Freshman:	3%
Sophomore:	55%
Junior:	37%
Senior:	5%

What do you plan to do after graduating from Cornell? **(Select all that apply.)**

Med school	61%
Grad school in the sciences	32%
Get a job	18%
Vet school	5%
Other grad school	5%
Law school	4%
Other professional school	4%
Serve in the military	2%

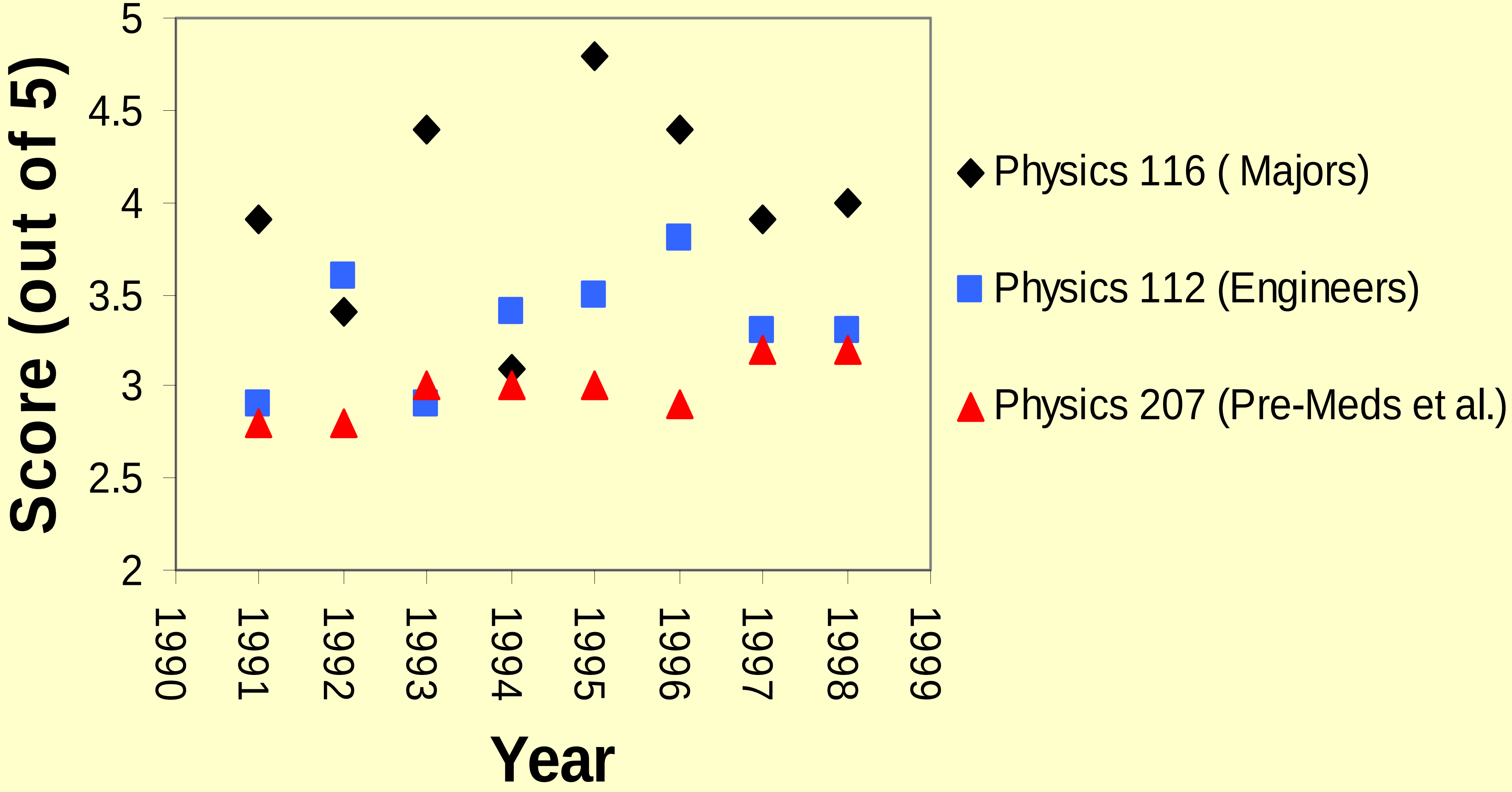
What was your primary reason for signing up for Physics 207?

To fulfill a requirement:	96%
Interested in physics:	3%
Course had great reputation:	1%

What was your attitude towards Physics 207 when you signed up for it? (Select all that apply.)

Sheer terror	18%
Anxious	44%
Afraid it will kill my chance of getting into professional/graduate school	20%
Comfortable: a good chance to develop some useful skills	26%

Overall Course Evaluation



“What adjectives would you use to describe Cornell Pre-Meds?”

“What adjectives would you use to describe Cornell Pre-Meds?”

Brilliant

Driven

Ruthless

Hypercompetitive

Insecure

“What adjectives would you use to describe Cornell Physics Faculty?”

“What adjectives would you use to describe Cornell Physics Faculty?”

~~Brilliant~~

Driven

Ruthless

Hypercompetitive

Insecure

Physics 207 Clientele

> 50% female,

~15% under-represented minority

significant socioeconomic diversity

How can we achieve more diversity in physics if we can't reach these "non-believers"?

Guiding Principles:

These students are smart, curious and motivated.

Physics is fascinating and empowering.

If students don't learn the material and don't like the course . . . it's our fault!!!

Guiding Principles:

Students in physics courses only master a small fraction of the material with which they are presented.

- Focus on fundamental concepts and **keep the math simple**. Leave out tricky details, esoterica, and advanced math.

Guiding Principles:

Physics provides the foundation for analyzing data and solving problems across the sciences and engineering.

- Emphasize “transferable skills” and their relevance to future careers:

  plotting data, sketching functions, dimen-sional analysis, proportional reasoning, orders of magnitude, approximate models, estimation, exponentials, power-laws . .

Guiding Principles:

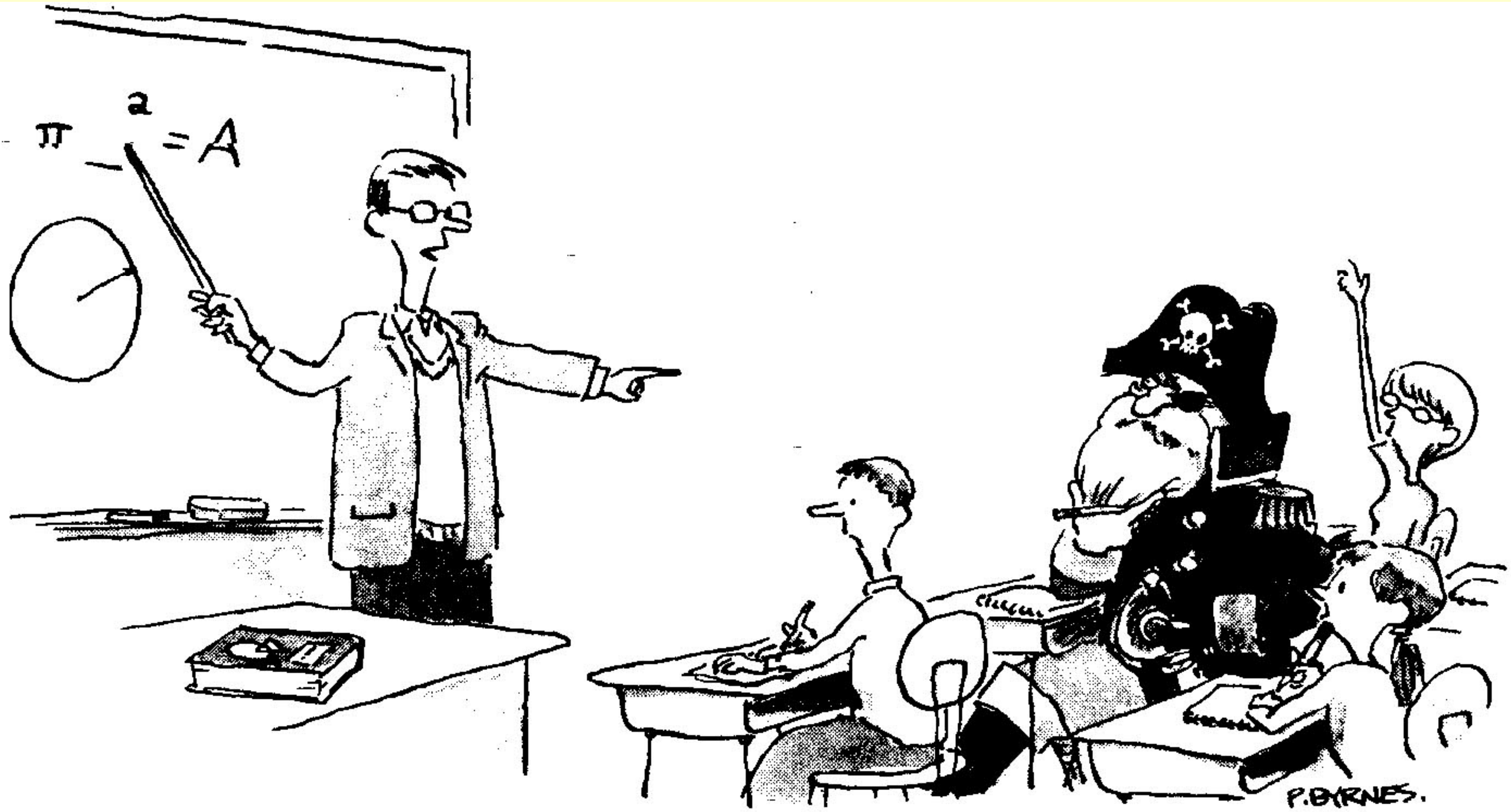
Life science/premed students see very little math in their other science courses.

The math that trips them up is not calculus, but high-school level math.

How much use of the following pre-calculus mathematics skills have you made in your previous science (NOT MATH) courses at Cornell?

Trigonometry (triangles, sines and cosines in relations between sides)?

none	33%
a little	29%
some	28%
a lot	11%



"Pi what squared? Long John, you should be able to get this."

Proportional reasoning (if I double x, what happens to y?) ?

none	12%
a little	34%
some	38%
a lot	16%

Sinusoidal functions of time or position, e.g., $x(t) = A \cos(\omega t + \phi)$

none	63%
a little	22%
some	12%
a lot	4%

Order of magnitude estimates / "back of the envelope" calculations?

none	31%
a little	32%
some	31%
a lot	7%

Zeros, limits and asymptotes of simple functions?

none	37%
a little	31%
some	22%
a lot	8%

Semi-log plots, i.e., graphs of log(y) versus x, or y versus log(x)?

none	37%
a little	35%
some	24%
a lot	5%

Log-log plots, i.e., plots of log(y) versus log(x); use to extract power law exponent b in $y = A\,x^b$?

none	51%
a little	30%
some	15%
a lot	4%

Guiding Principles:

Life science/premed students see very little math in their other science courses.

- Provide pre- and early-course tutorial support in **“elementary scientific mathematics”** so that they can focus on learning physics, not math.

Student comments from course evaluations in Physics 207:

Student comments from course evaluations in Physics 207:

"I hate physics!"

Student comments from course evaluations in Physics 207:

"I hate physics!"

"Physics makes me feel dumb!"

Guiding Principles:

Most students don't hate physics.

They hate how physics makes them feel about themselves.

“There are, of course, other ways in which schools represent a psychic fall; and teachers, the guardian angels of its trajectory. Although schools in a democracy purport to exist for the creation of “a level playing field,” it does not take us long to discover that level playing fields exist mainly to sort out winners from losers. Unless we came from a large family with parents who went out of their way to play favorites, school was our first introduction to the idea of relative merit. . .”

“But that oppressive sense of minute gradation, of success not as a mansion of many rooms but as a ladder of infinite rungs — where does that exist but in a classroom, or in the imagination of the adult who still sits there?”

“‘Taking your degree’ is the most precise phrase in all of education: that is what we take from our first day of kindergarten, our *degree* of relative worth. The educational apple of Adam’s Fall . . . did not give us the knowledge of good and evil but of good, better and best, world without end.”

From “Why We Hate Teachers” by Garret Keizer, published in *Harper’s*, September 2001.

- Provide emotional support and encourage-ment to struggling students.
- **"You're not dumb! This stuff is challenging. Be patient with yourself."**
- Send out regular supportive emails.
- Eliminate tricks, surprises, and needlessly punitive practices. Maintain an even, predictable flow.

- Use a pragmatic, non-inflammatory grading system.

Exam questions: straightforward variants of homework and lab problems; high score of 100 ok.

“Absolute” grading, i.e., no curve.

85-100% = A, 70-85% = B, 55-70% = C.

Don’t set median to a C+! Who said we need to be the “weed-out” course?

Don’t rub their noses in the fact that they can’t master everything in one semester.

Guiding Principles:

Every grade of D or F we award represents a failure on our part.

Wastes student time and university resources; creates bad PR; and lowers the median.

- Intervene early and often.
- Get non-performers out of the course and into remedial courses.

Guiding Principles:

Get students involved!

- Ask multiple choice questions during lecture that illustrate important concepts.
- Involve them in lecture demonstrations.
- Quiz them while they are doing lab experiments.
- Use regular on-line surveys.

Student comments from course evaluations in Physics 207:

"Why I am forced to take this course?"

"What use is this stuff to my major?"

Many students are driven by a desire to do something useful or lucrative, not by "truth and beauty."

Many have little idea of why or how physics may be relevant to their future careers.

Many students continue to view physics as irrelevant *even after taking high school and college physics courses*.

Illustrate physics with applications from many disciplines, to emphasize the interconnectedness of science, to show how phenomena and theory in distinct areas are interleaved into a complex, self-consistent tapestry.

Because of the central role of Physics, we are best positioned to give our students the "big picture".

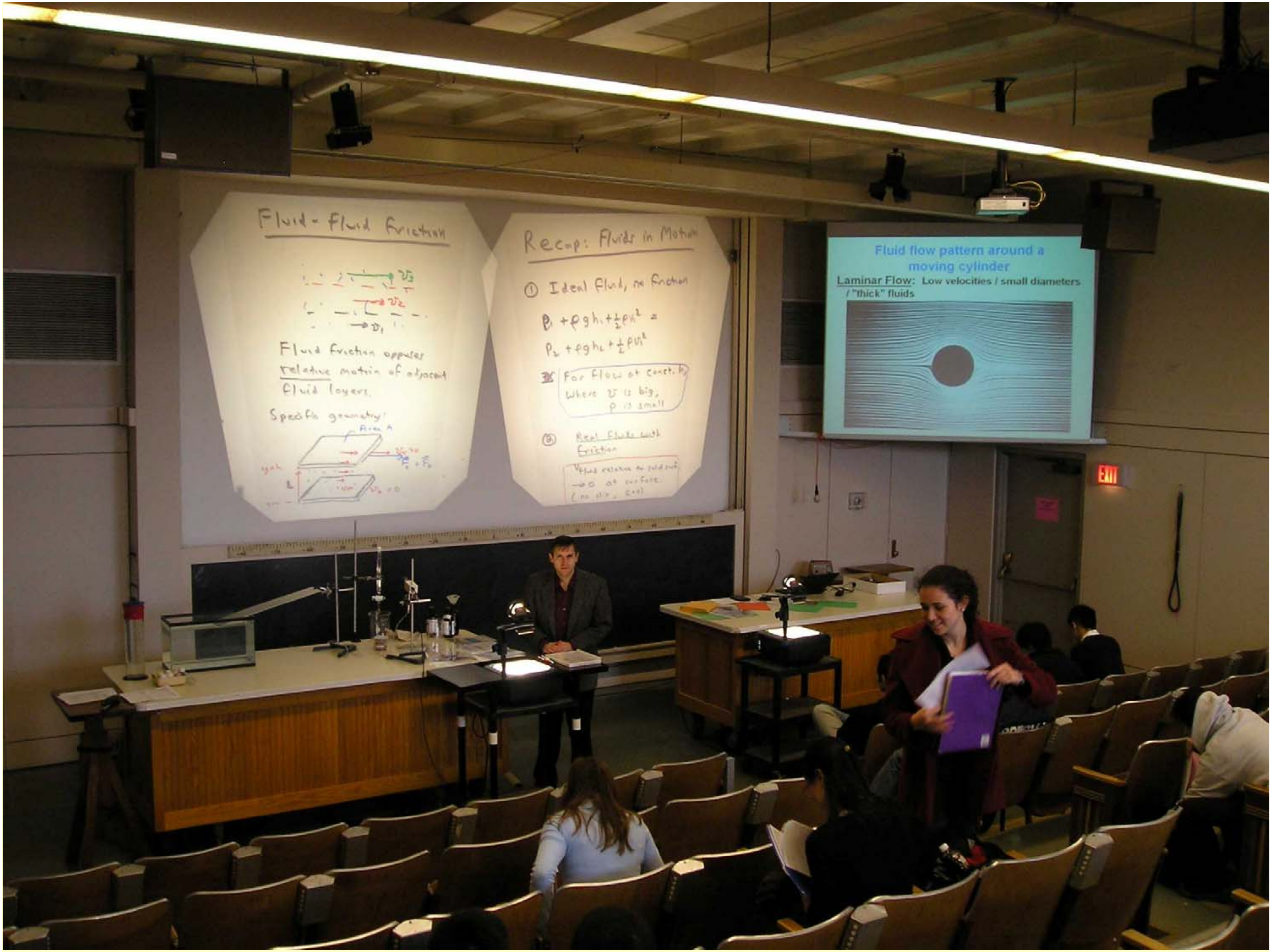
Avoid "Physics for Biologists" or "Physics for Engineers"

“Weinberg provides one of the clearest arguments I have ever read against the relevance of astrology, telekinesis, creation-ism and other “would-be” sciences, as he politely refers to them. Why do scientists feel completely free to ignore such subjects without even extending to them the courtesy of an examination? Weinberg argues:

‘What [these people] are missing is the sense of the connectedness of scientific knowledge. We do not understand everything, but we understand enough to know that there is no room in our world for telekinesis or astrology. What possible physical signal from our brains could move distant objects and yet have no effect on any scientific instruments? . . . In fact, I do not think that most people who believe in astrology imagine that it works the way it does because of gravitation or any other agency within the scope of physics; I think they believe that astrology is an autonomous science, with its own fundamental laws, not to be explained in terms of physics or anything else. One of the great services provided by the discovery of the pattern of scientific explanation is to show us that there are no such autonomous sciences.’”

Pedagogy in Physics 207

- On-line tutorial in elementary scientific mathematics
- Pre-lecture PowerPoint shows containing announcements, physics news, trivia, humor
- Transparency notes mixed with in-class polling
- Demonstrations (2-3 / lecture)
- >100 PowerPoint shows illustrating applications
- Cooperative learning sessions
- Labs tightly coupled with lecture


Fluid flow pattern around a moving cylinder
Laminar Flow: Low velocities / small diameters / "thick" fluids
EXIT

1
2
3
4
5

PERCENTAGES
TOTAL
TIME
STOP

Pedagogy in Physics 207

- **Pre-lecture PowerPoint shows** containing announcements, physics news, trivia, humor
- Transparency notes mixed with in-class multiple choice questions
- Demonstrations
- PowerPoint shows illustrating applications
- Cooperative learning sessions
- Labs tightly coupled with lecture

If you miss work because of illness:

- **Get a note from your doctor** and give it to your TA.

- Make up missed lab work **the same week** in another lab. **Have the lab TA sign your yellow sheet.** If you cannot make up the lab that week, obtain data from another student and turn in your own analysis of the data. Indicate the source of your data.

- **Do missed homework, coop problems and turn them in, even if they are late.** You'll get partial credit even if you don't have a note, provided they're not too late.

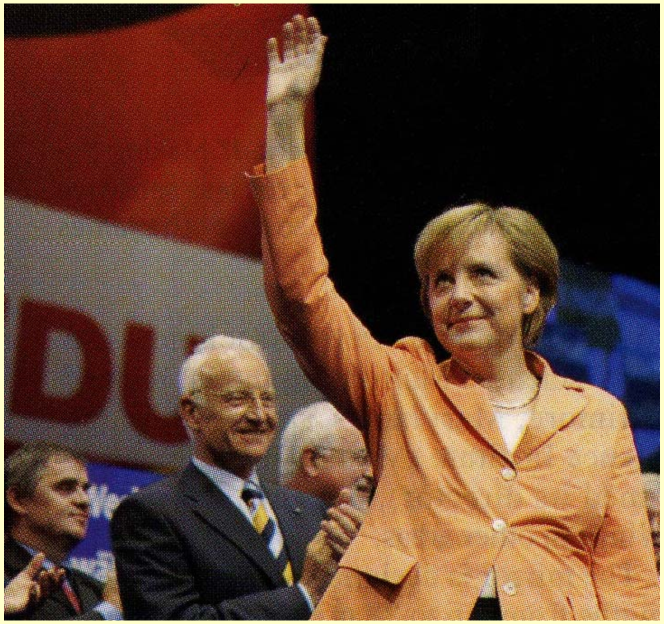
"Thank goodness you're here. I can't accomplish anything without a deadline."

Assignment 1 is due today.

International News:

Berlin - German opinion polls predict that the country will elect its **first chancellor trained in the natural sciences** later this month. A victory for the Christian Democratic Union on **September 18** over the ruling Social Democrats would mean a government led by **Angela Merkel**, **who holds a Ph.D. in physical chemistry**. She would also be the country's first female chancellor.

International News:



The influential newspaper *Süeddeutsche Zeitung* wrote that Merkel had demonstrated both **meticulousness and tenacity** in her 1986 dissertation on the **calculation of rate constants in hydrocarbon decomposition reactions. Such qualities, the paper said, could be usefully applied to the equally complex problems facing Germany.**

Science, 2 Sept. 2005

Today's Trivia

To play some parts of an etude by Chopin, a pianist needs to be able to **read** and **play 3,950 notes** in two and a half minutes =**150 seconds**.

Average notes/second ~ **26**

Average time to play each note ~ 0.038 s

Speed of neural impulses down the arm ~ **80 m/s**

~ **180 mi/h**

Time to travel from brain to finger ~ 0.015 s

“He was expected to read a lecture on mathematics (broadly construed) each week during the academic term and deposit a copy in the university library. But he disregarded this obligation far more than the fulfilled it. When he did lecture, students were scarce. Sometimes he read to bare room or gave up and walked back to his chambers.”

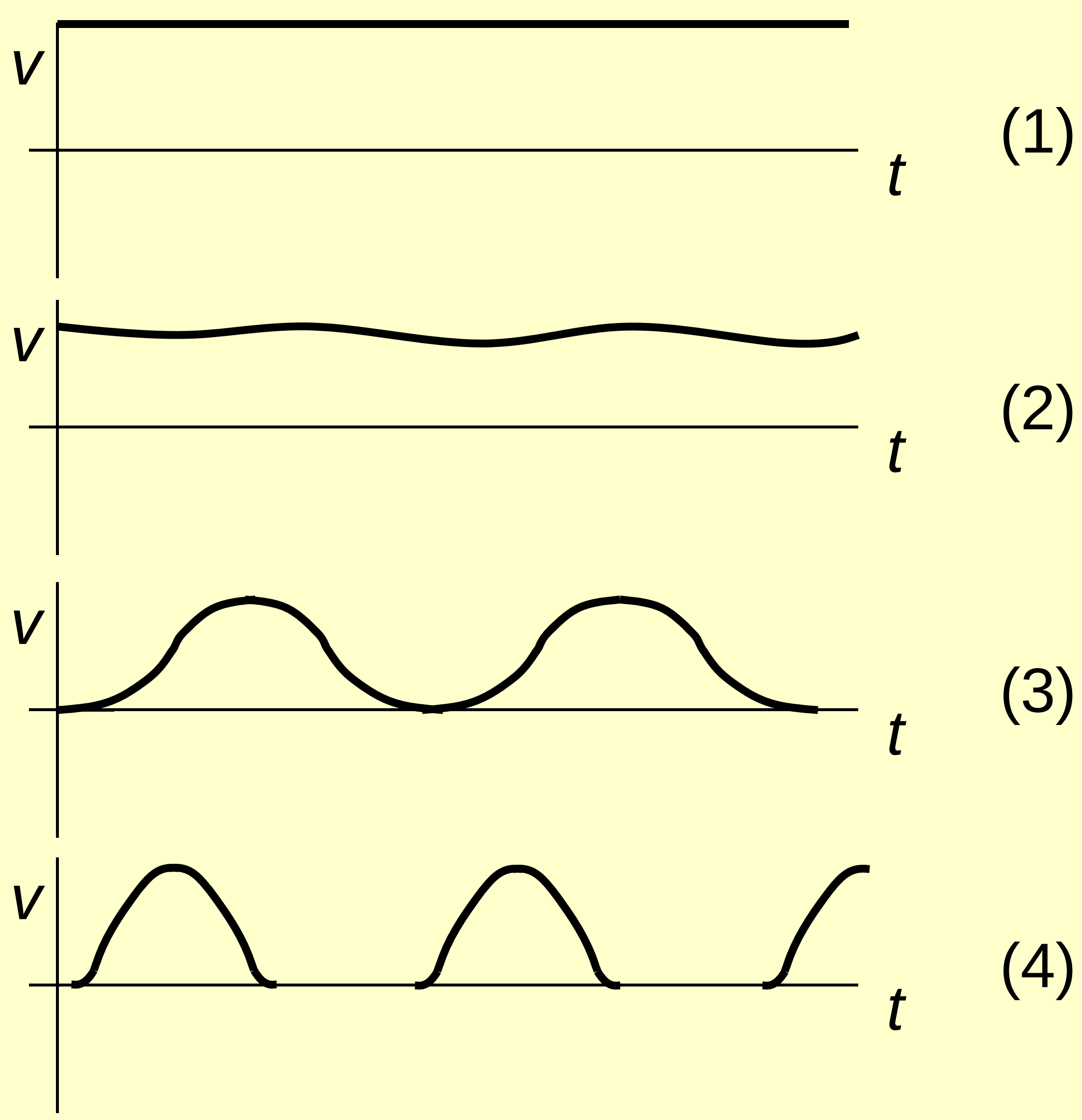
Isaac Newton by James Gleick

What role does thermal expansion play in forming the Taugannock Amphitheatre?

Pedagogy in Physics 207

- Pre-lecture PowerPoint shows containing announcements, physics news, trivia, humor
- Transparency notes mixed with **in-class multiple choice questions** (interactive learning / peer instruction)
- **Demonstrations**
- **PowerPoint shows illustrating applications**
- Cooperative learning sessions
- Labs tightly coupled with lecture

Which of the following *v*-*t* graphs best describes the horizontal motion of a foot relative to the ground during ordinary walking?



An object is thrown on flat ground at some angle with respect to the horizontal.

How does the time for the object to reach the apex of its flight compare with the time for it to fall from the apex to the ground?

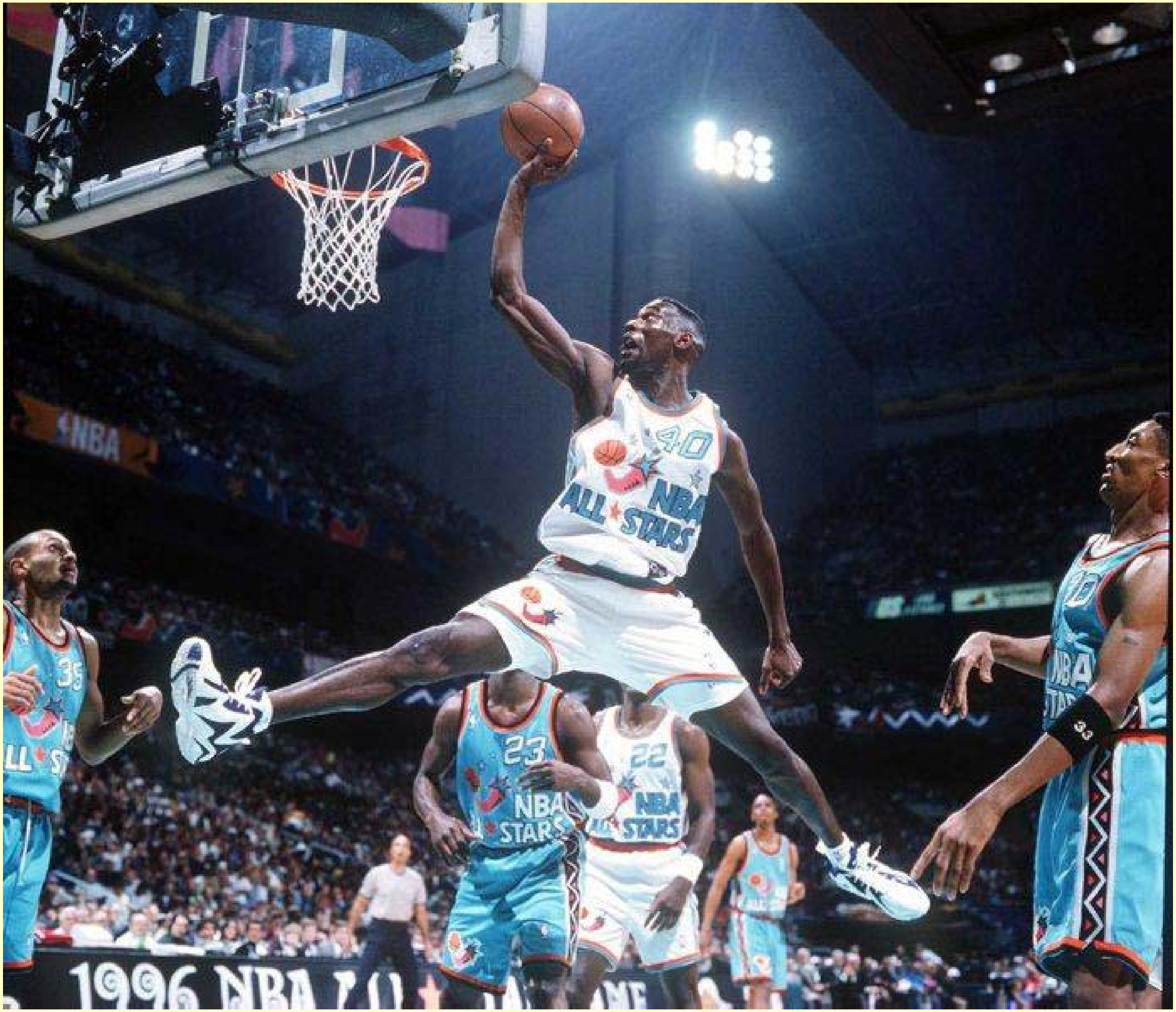
time going up / time going down = ?

1. $1/2$
2. $1/\sqrt{2}$
3. 1
4. $\sqrt{2}$
5. 2

An object is thrown on flat ground at some angle with respect to the horizontal. The object rises to a vertical height y_{max} before returning to the ground.

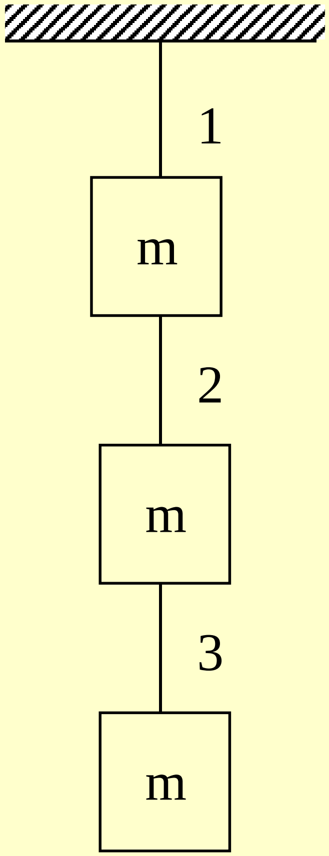
During its flight, how does the time the object spends with $y>y_{max}/2$ compare with the time it spends with $y<y_{max}/2$?

1. More time in lower part.
2. The same.
3. More time in upper part.

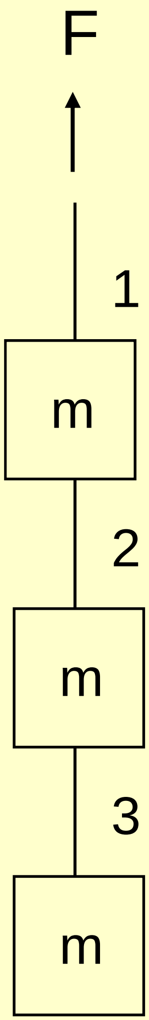

40
NBA
ALL STARS
23
22
35
NBA
1996 NBA

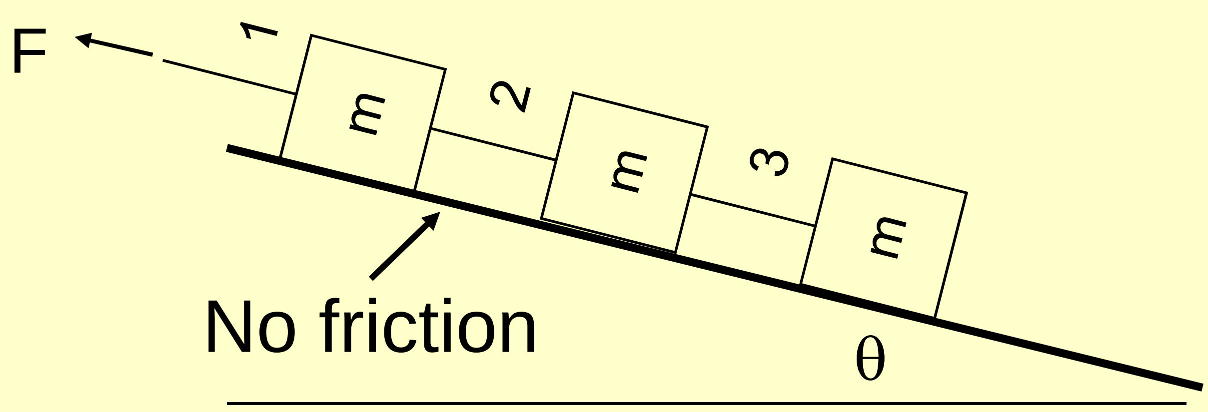
$T_1/T_3=?$

1. 1/3
2. 1/2
3. 1
4. 2
5. 3



a=0



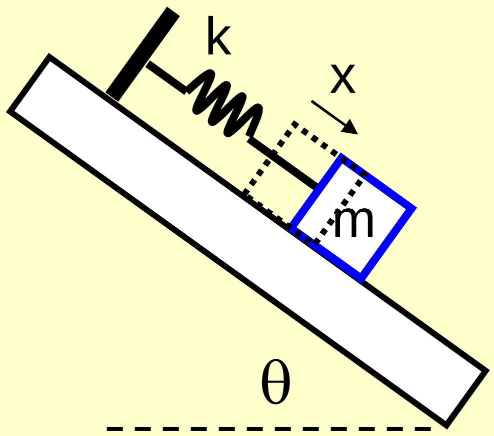


In both cases, **$T_1/T_3 = 3$**

If we add more masses, eventually rope 1 will break.

Coal trains

The spring has stretched an amount x. What is the angle θ? (Assume the surface on which the mass slides is frictionless.)



θ=?

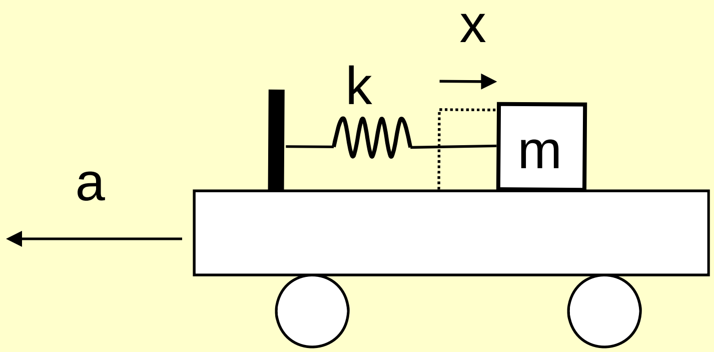
1. $\sin^{-1}(kx/mg)$

2. $\sin(kx/mg)$

3. $\cos^{-1}(kx/mg)$

4. $\cos(kx/mg)$

The spring has stretched an amount x.
What is the acceleration a?
(Assume the surface on which the mass m slides is frictionless.)



a=?

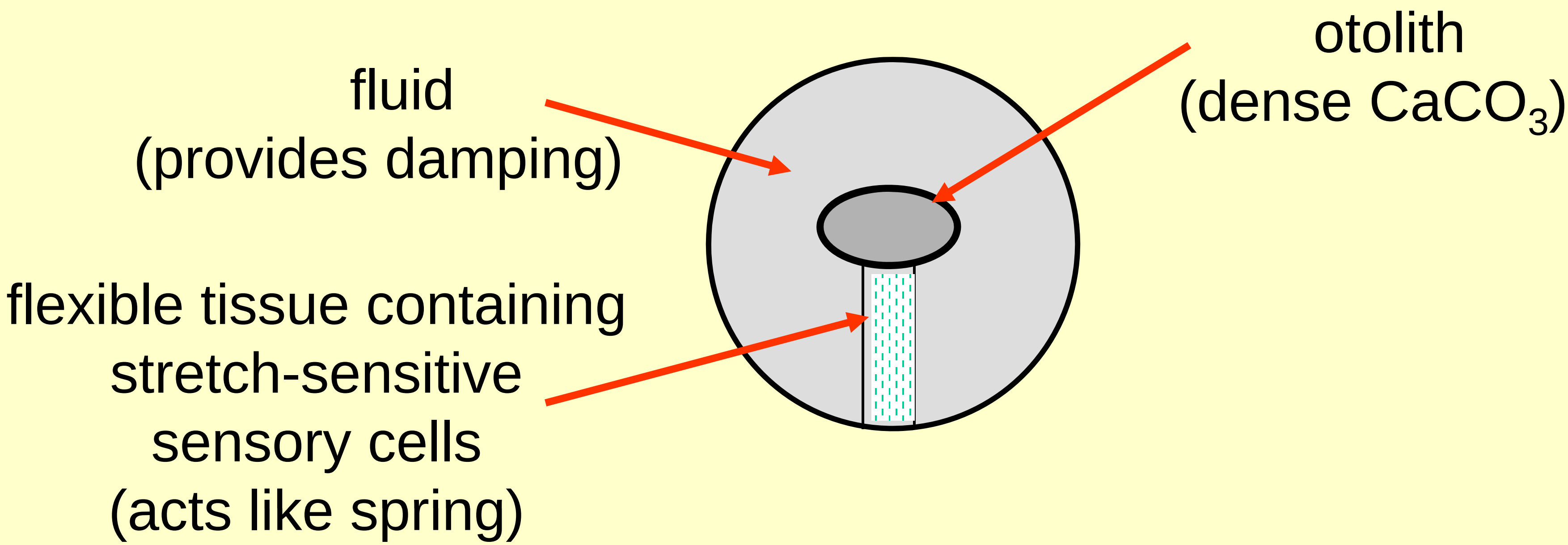
1. a=kx/m

2. a=k x m

3. a=kx

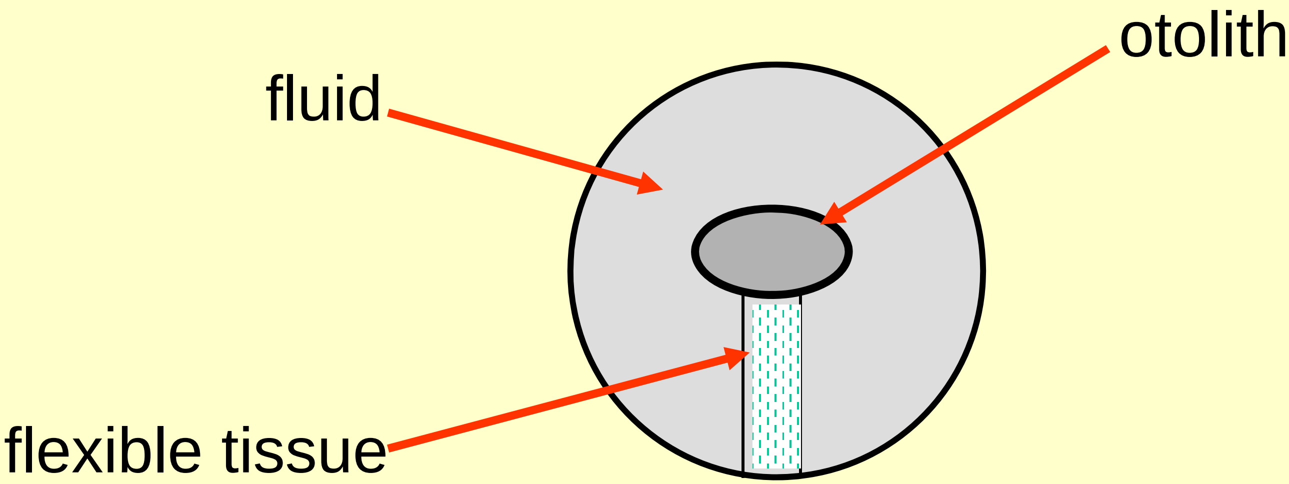
4. Insufficient information

Otolith Organ

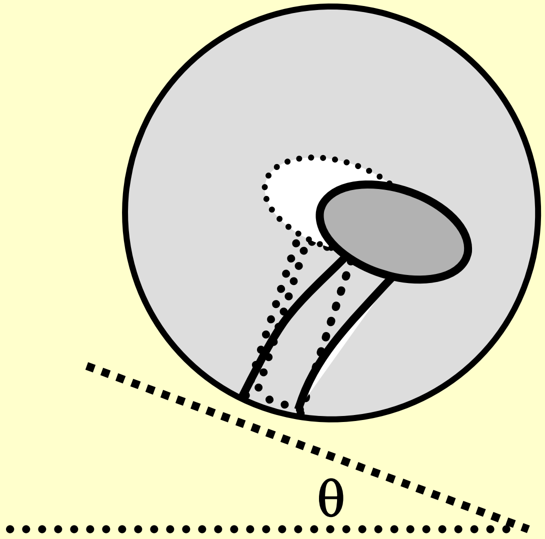


•All vertebrates have at least 2 or 3 in each ear.

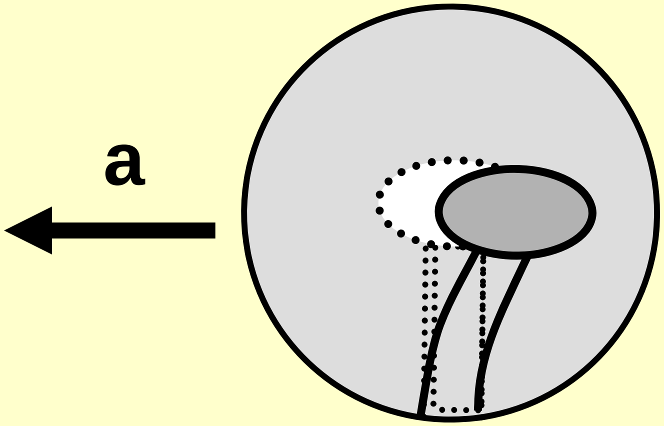
Measures orientation and acceleration.



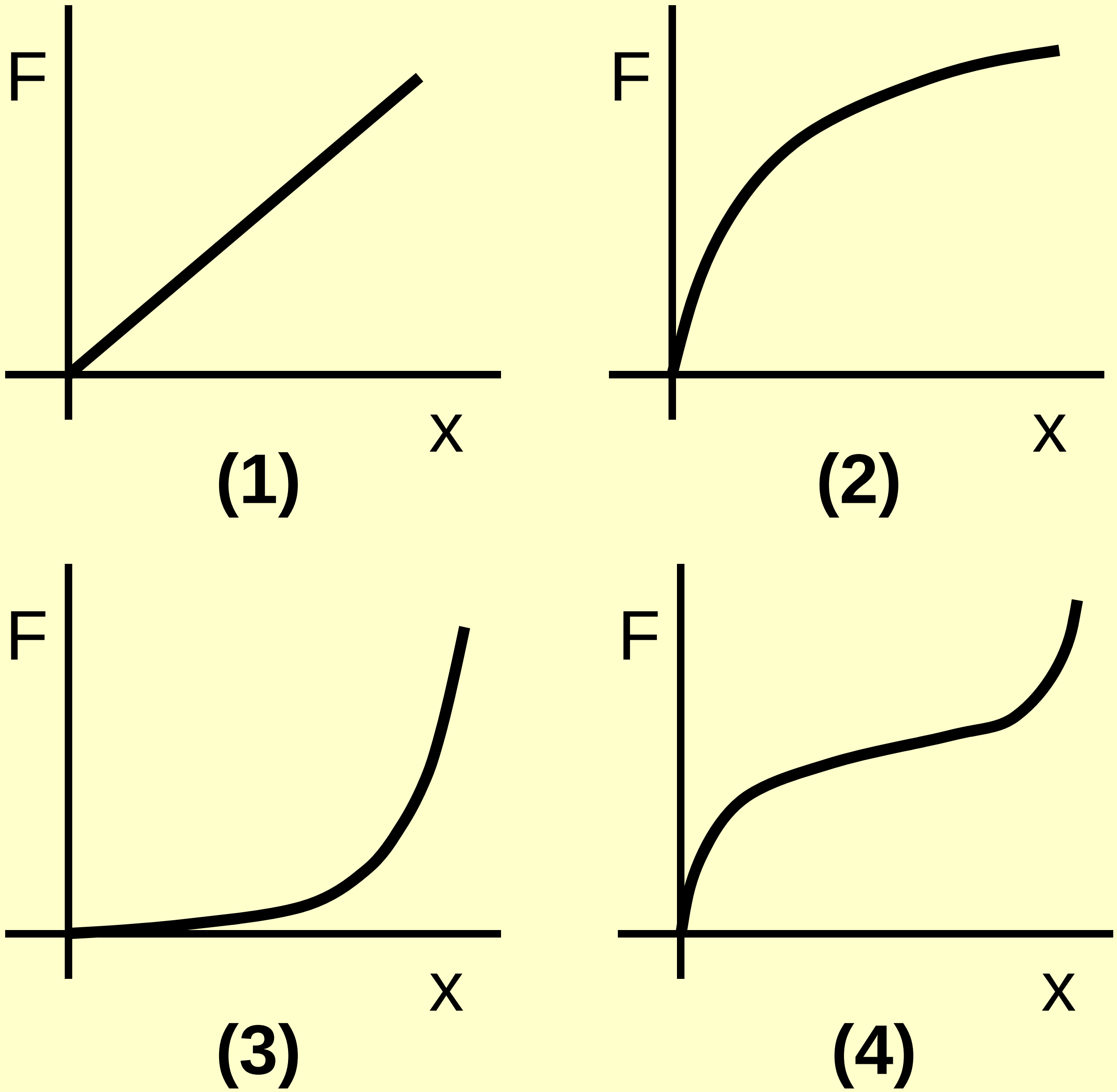
Detecting orientation:



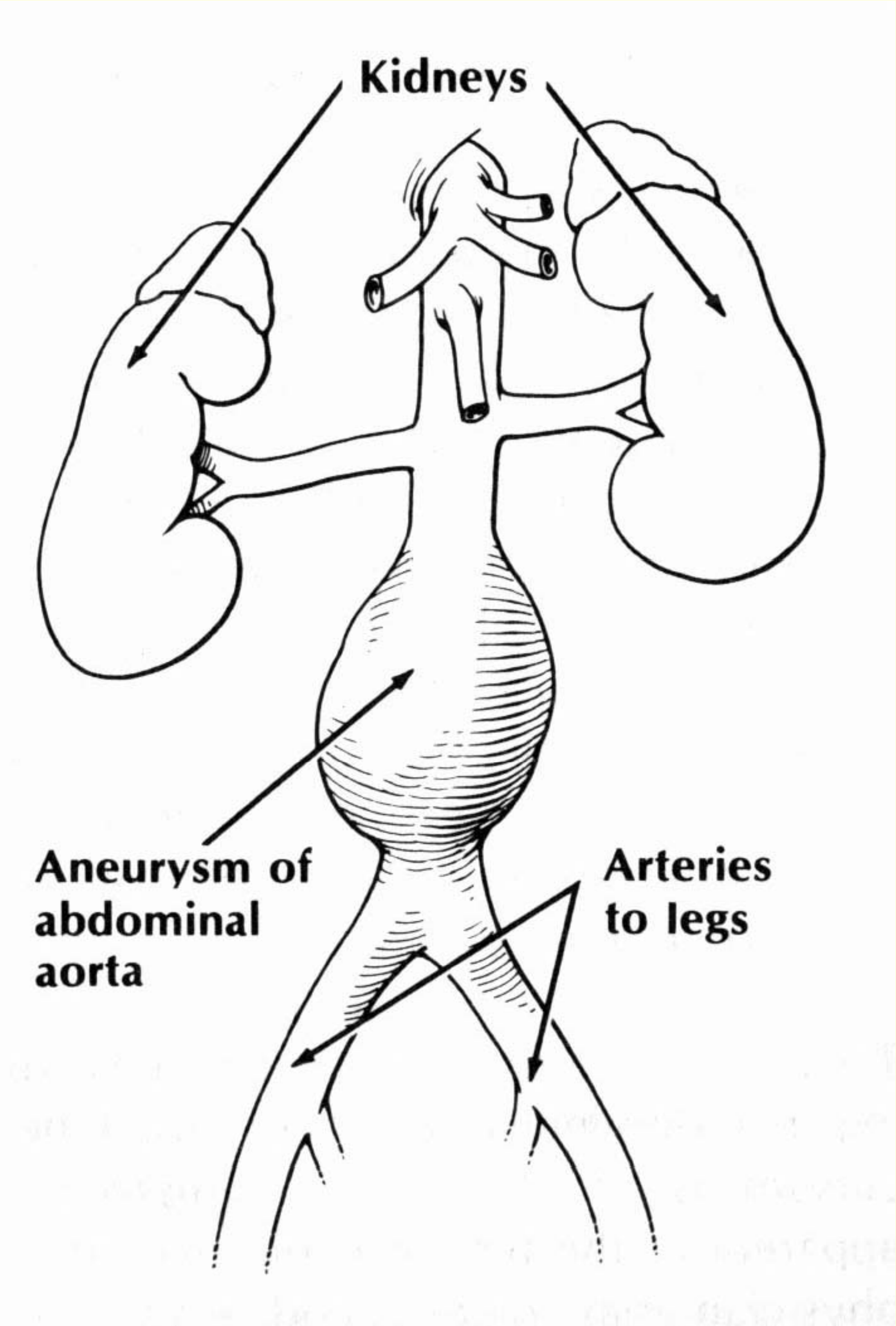
Detecting acceleration:



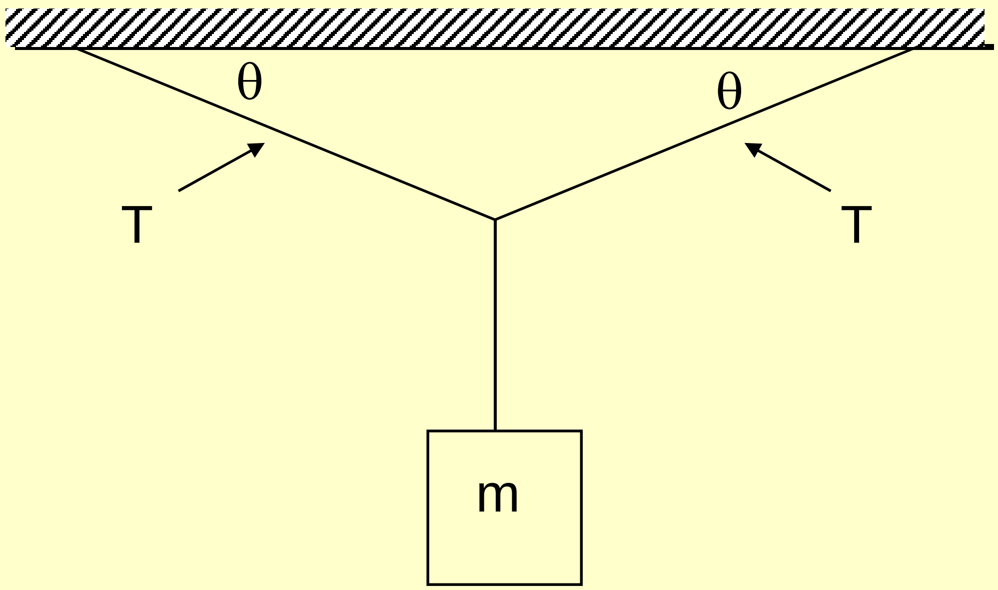
Which of the following best describes the force vs. displacement (F-x) curve for an earlobe?



Aortic Aneurysm:



Why do Tennis Nets Sag?



T=?

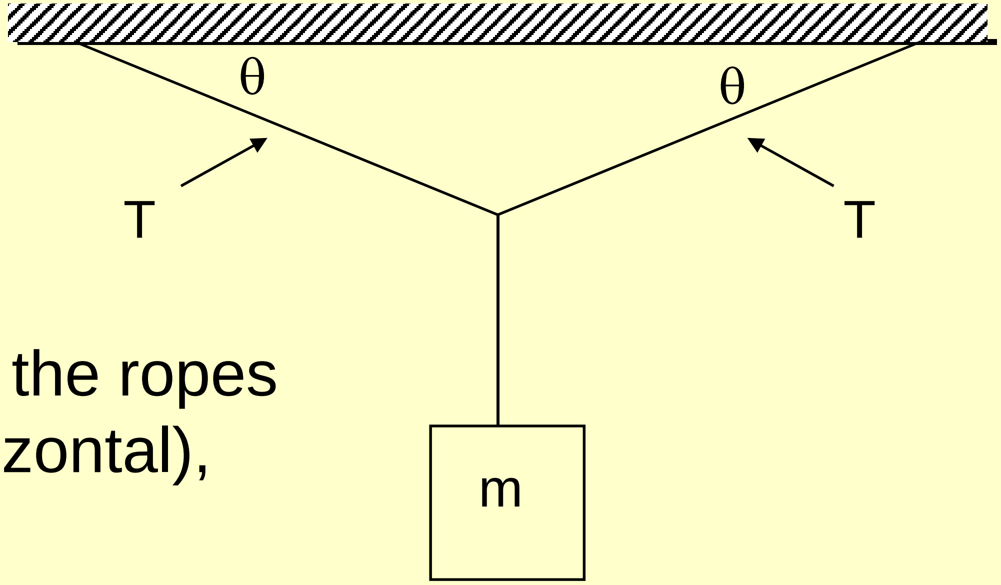
1. mg

2. mg /sin(θ)

3. mg / cos(θ)

4. mg / 2 sin(θ)

5. mg / 2 cos(θ)



As $\theta \to 0$ (i.e., the ropes approach horizontal),

$T \to ?$

1. 0
2. mg / 2
3. mg
4. 2mg
5. ∞

Other Applications

- sag of power lines
- power line and pole snapping by trees, ice
- plucking of guitar strings
- retrieving your car from a ditch

How does the drag force exerted on a cyclist moving at v=55 km/h compare with the force exerted on a cyclist moving at v=27 km/h?

D (55 km/h) / D (27 km/h) $\approx$?

(1) 1/4

(2) 1/2

(3) 1

(4) 2

(5) 4

Air Drag in Cycling:

$$D = (1/2)\, C\, \rho\, A\, v^2$$

World Speed Records:

200 m, flying start:
71.3 km/h (~45 mi/h)

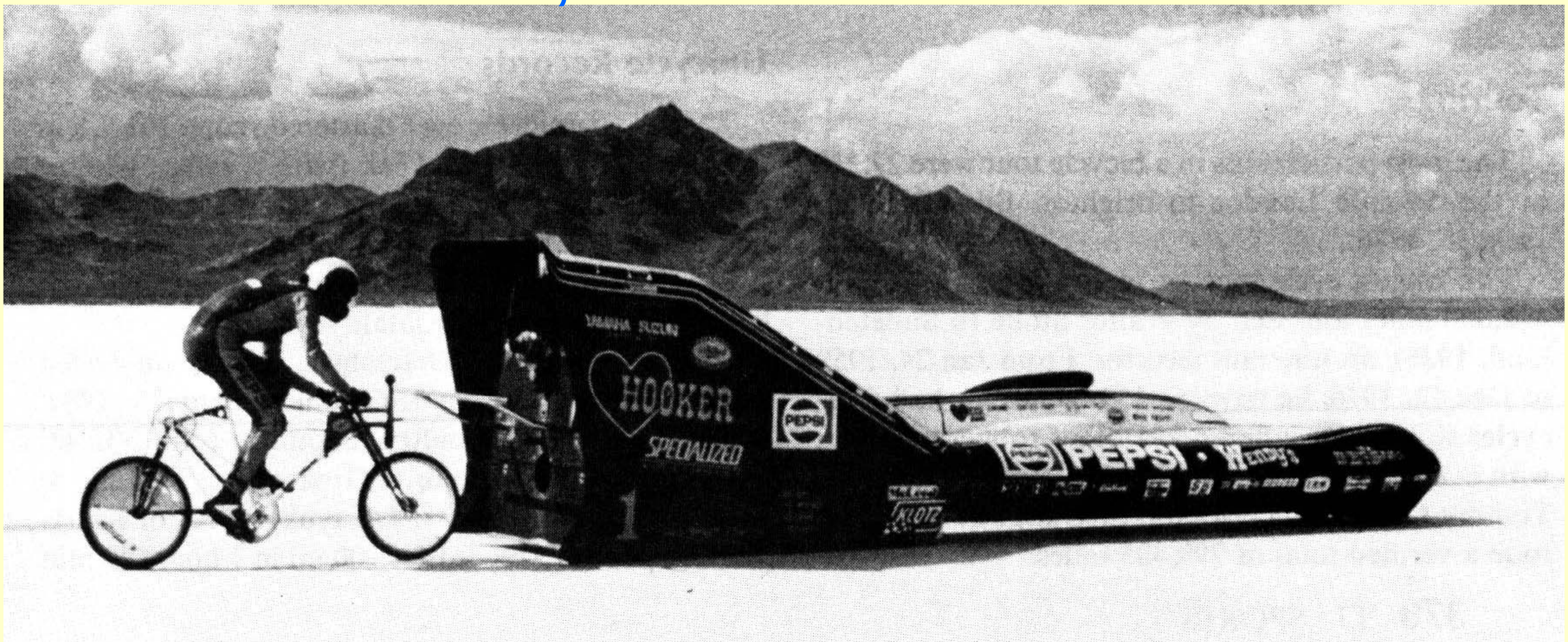
1 hour:
55.3 km/h (~35 mi/h)

Air Drag in Cycling:

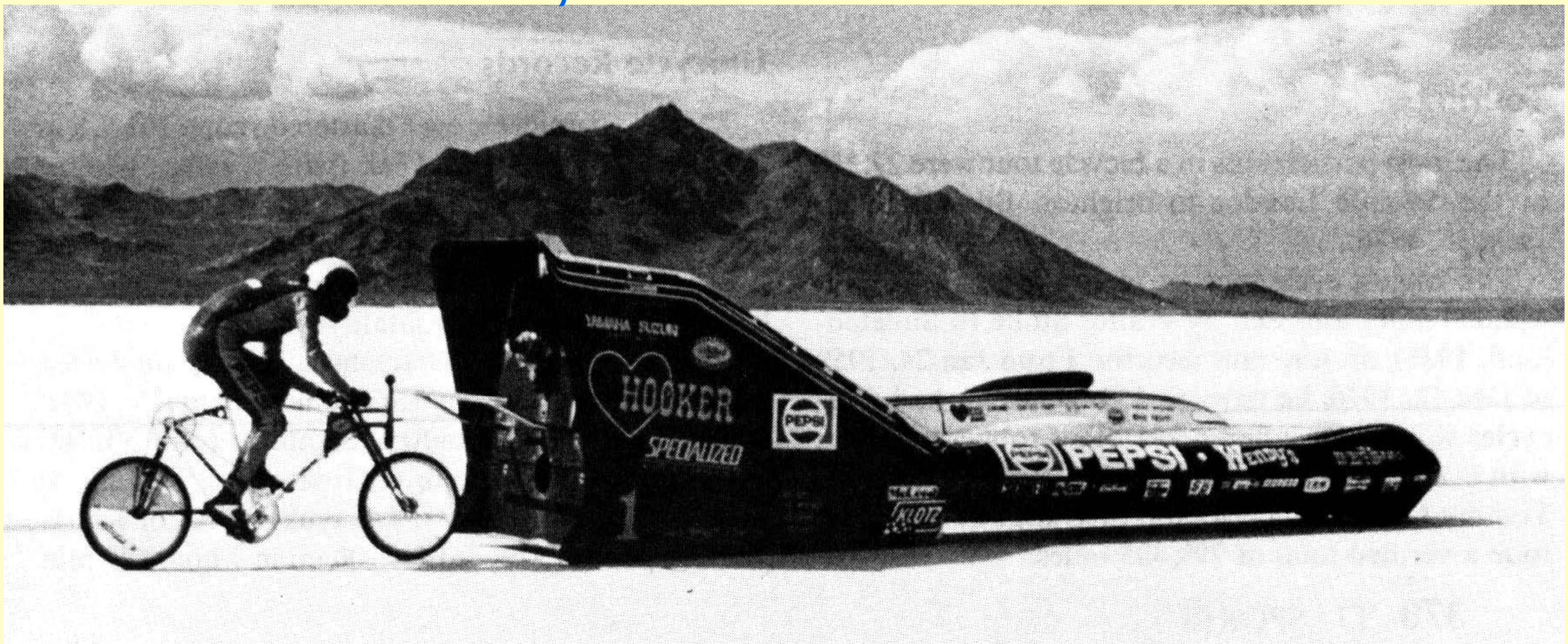
$$D = (1/2)\ C\ \rho\ A\ v^2$$

How fast could you cycle if you could eliminate air drag?

Bonneville Salt Flats, Utah:



Bonneville Salt Flats, Utah:

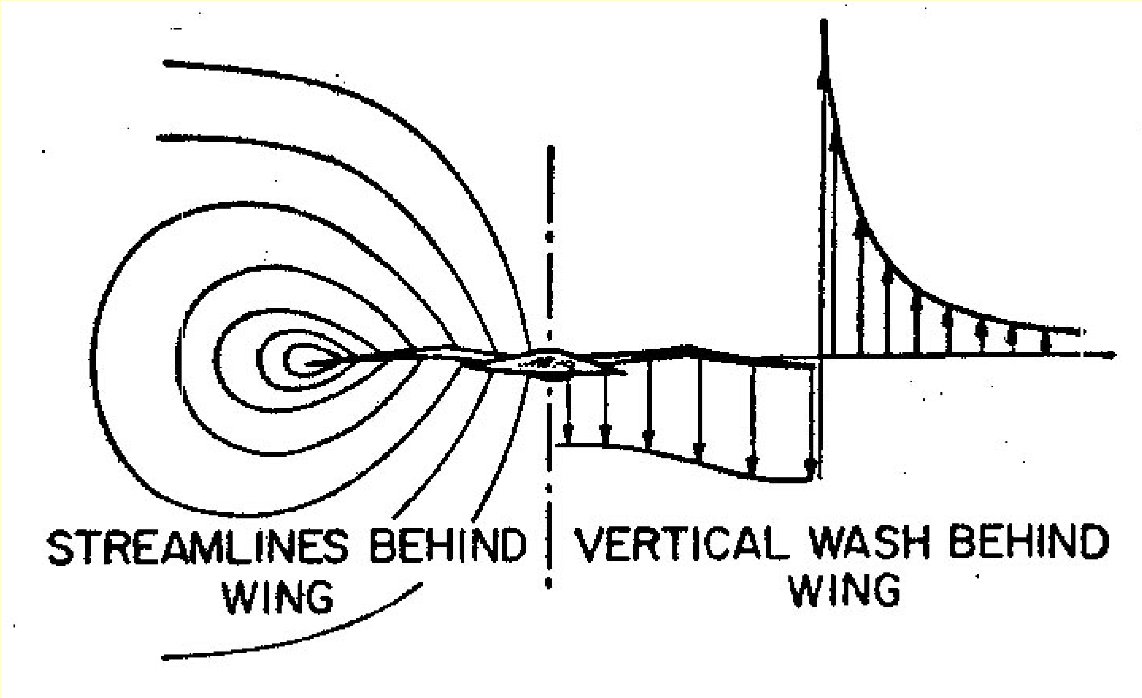


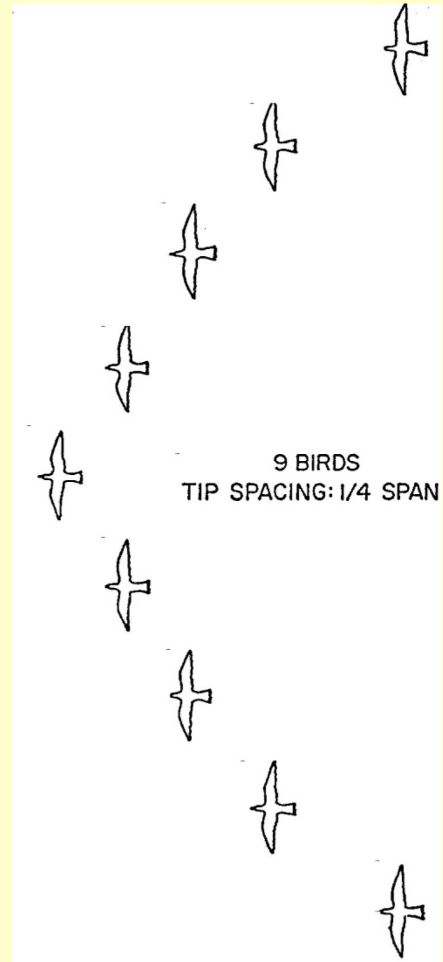
John Howard, USA, 1985: **152 mi/h**

Fred Rompelberg, NL, 1995: **167 mi/h**

(Rompelberg was 50 years old at the time.)

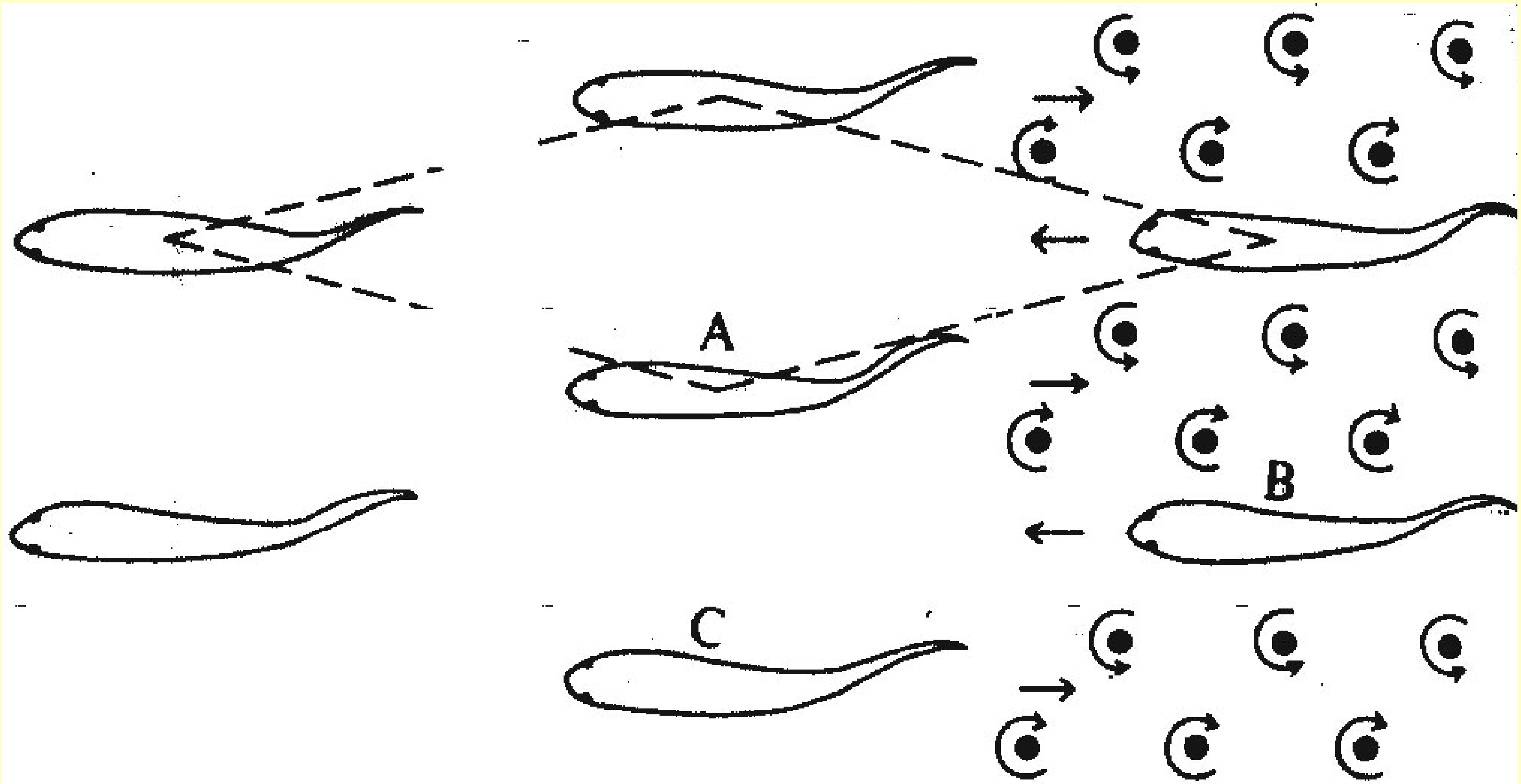
Bird Formations During Migration:





By taking advantage of **upward moving air** produced by their neighbors, **migrating birds traveling in "Vees" can travel 1.7 × as far as individual birds. (~40% energy savings/mile).**

Fish Schools

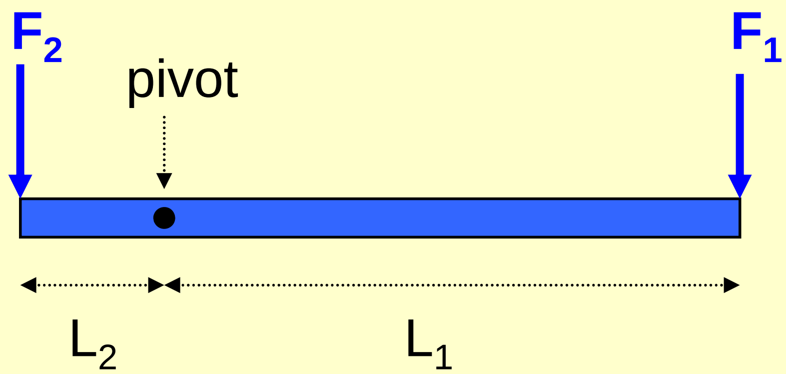


By **swimming in synchrony** in the correct formation, each fish can take advantage of **moving water created by the fish in front** to reduce drag.

Fish swimming in schools can swim 2 to 6 times as long as individual fish.

Summary

- Physics is interesting and powerful, but it’s also hard!
- Pay attention to emotional needs.
- Show them why physics is relevant to what they care about – themselves and their futures.
- Teach in a way that helps develop confidence and promotes future inquiry



For rotational equilibrium,

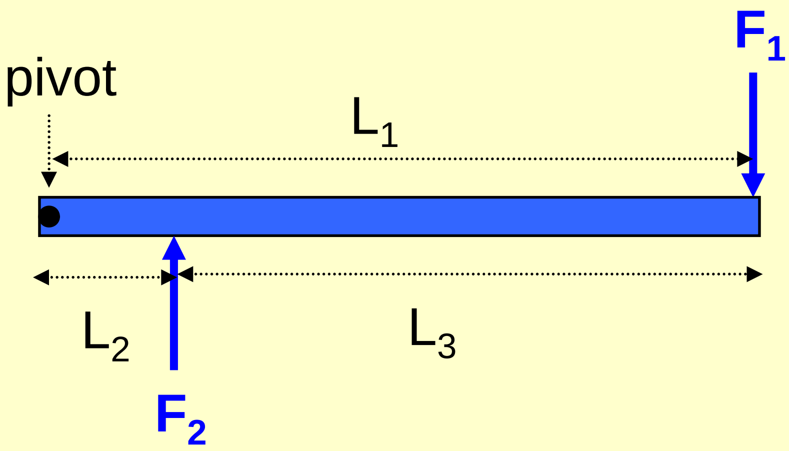
F_2/F_1 = ?

1. 1

2. -1

3. L_1/L_2

4. L_2/L_1



For rotational equilibrium,

F_2/F_1 = ?

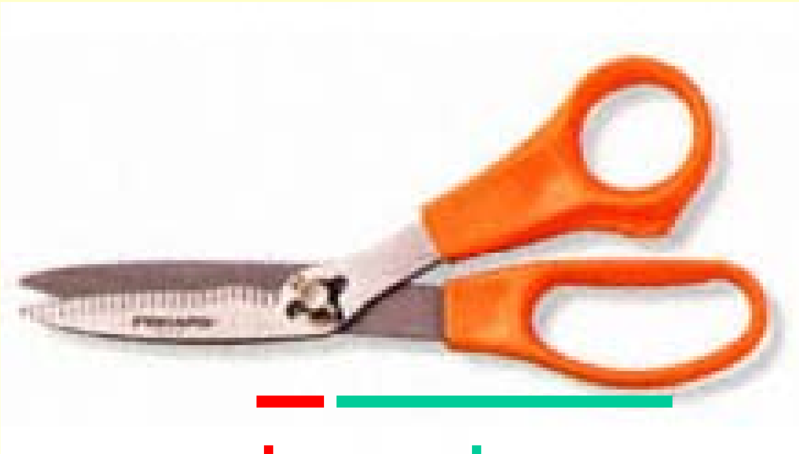
1. 1

2. -1

3. L_1/L_2

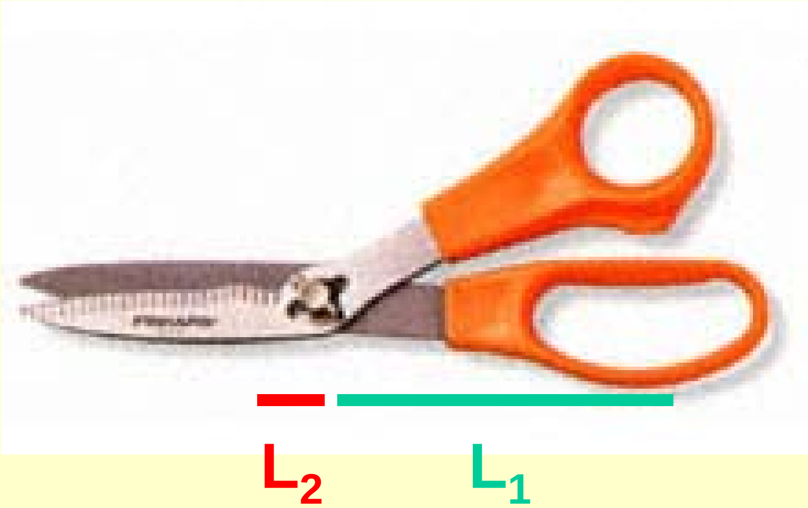
4. L_2/L_1

Levers in Kitchen Utensils:



L_1 L_2

Levers in Kitchen Utensils:



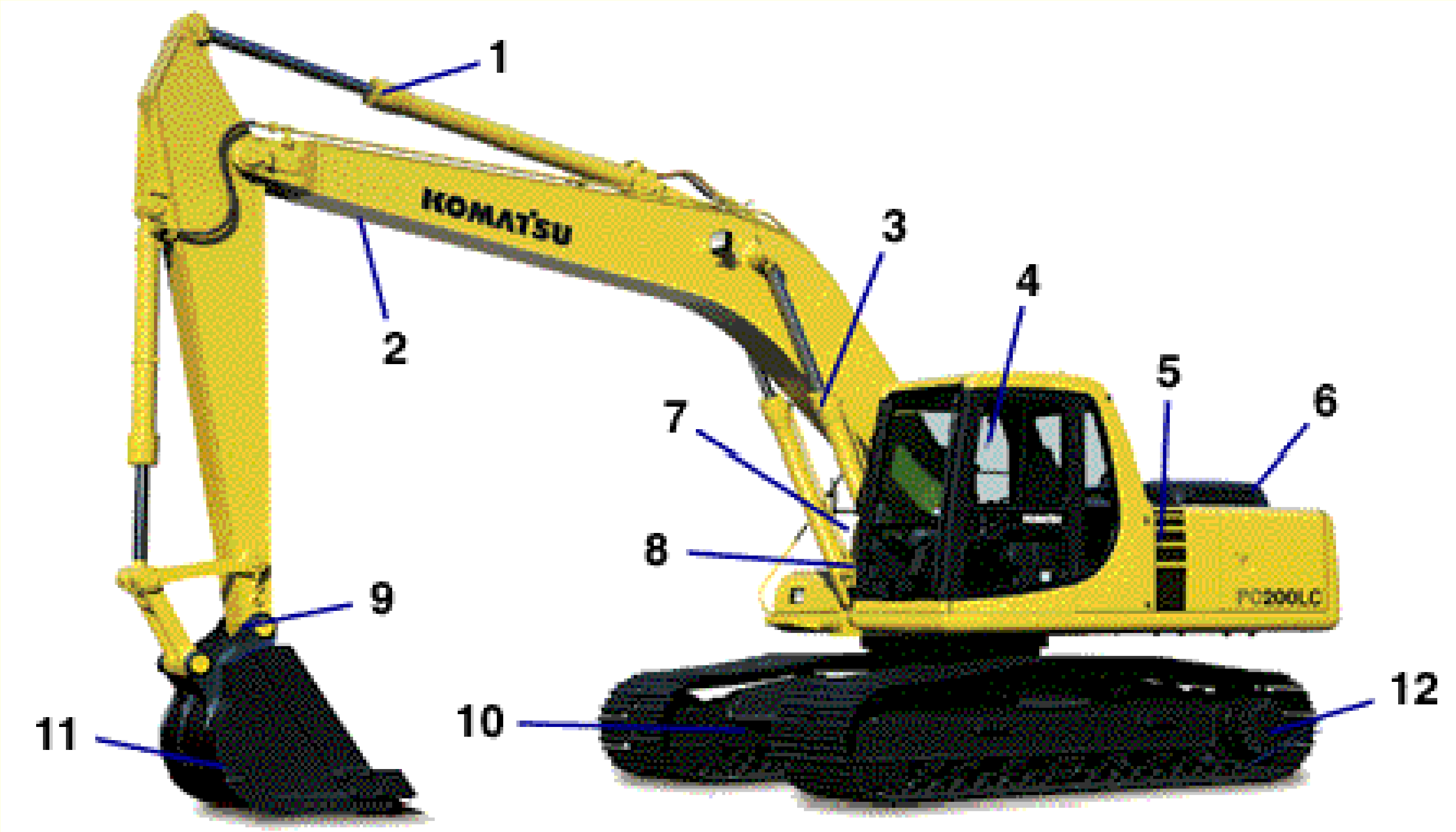
Typical mechanical advantage:

$F_2/F_1=L_1/L_2$: ~ 5

Maximum hand grip force: ~ 10 - 200 lb

Maximum utensil force: ~ 50 - 1000 lb

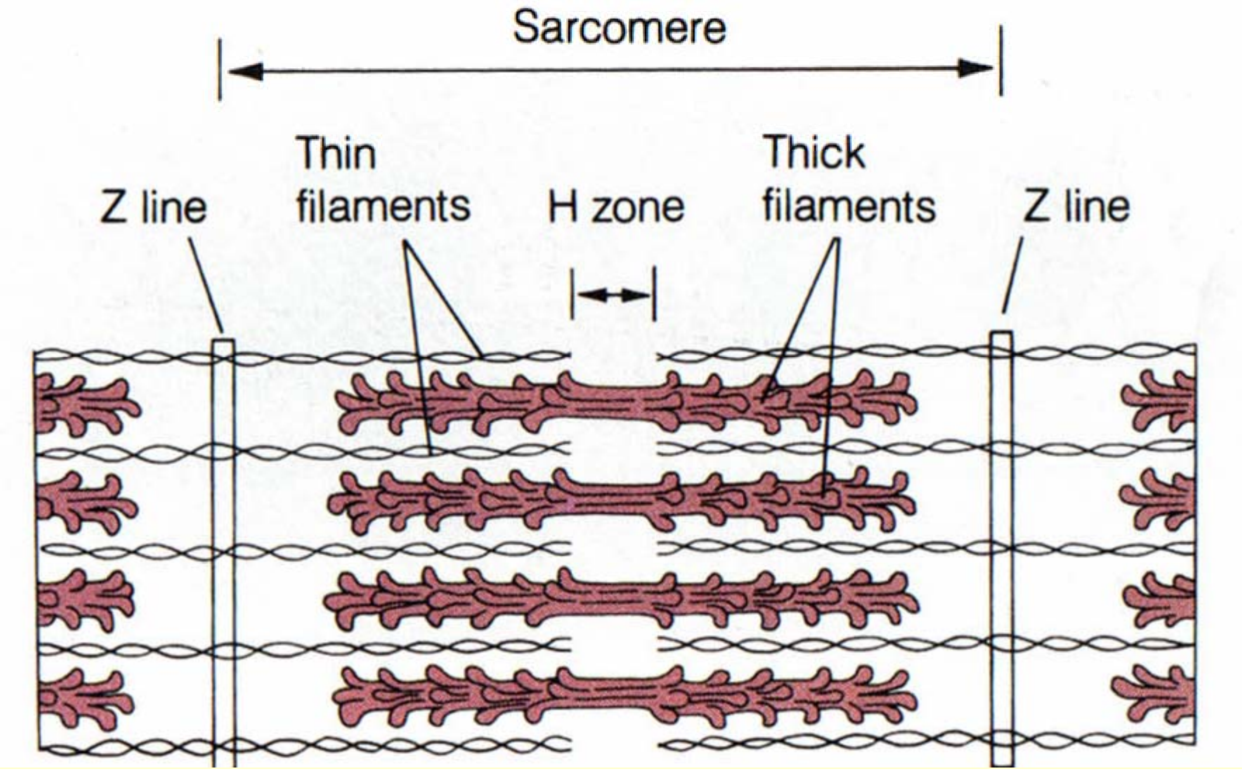
Levers in Hydraulic Machines:



How to throw a ball at 50 m/s using molecules that move at 10^{-5} m/s:

1. Start with **basic unit**: sarcomeres made of opposed actin filaments and myosin "motors" that pull filaments together.

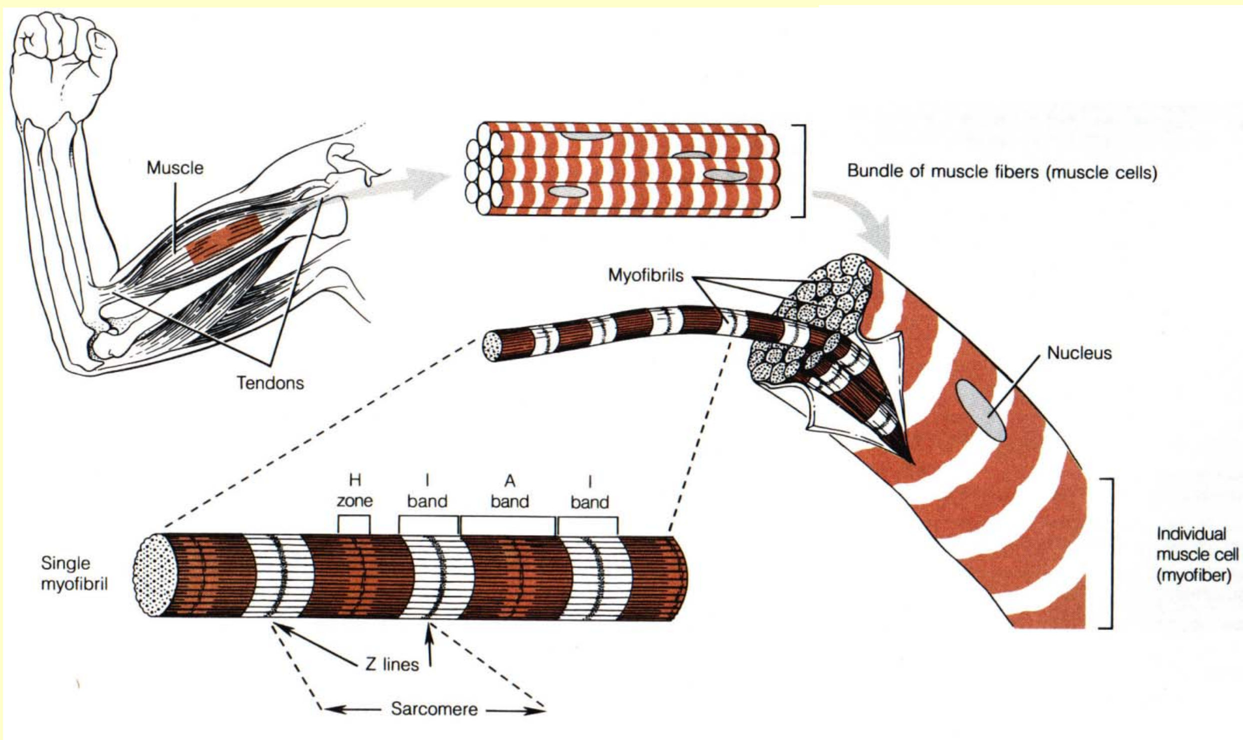
L~2.5 μm, **shortens by ΔL/L ~ 40% in ~0.1 s**



How to throw a ball at 50 m/s using molecules that move at 10^{-5} m/s:

2. Connect sarcomeres in **parallel** to get big force F (up to 10,000 N!)

Connect sarcomeres in **series** to get big L, ΔL (up to 0.1 m) $\Rightarrow$ **v_{max} (muscle) < 1 m/s**

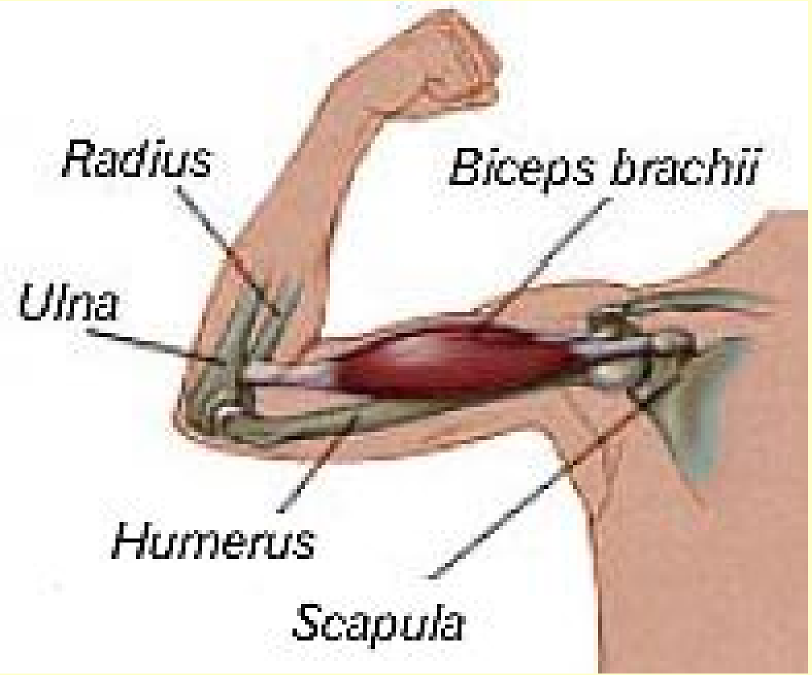


How to throw a ball at 50 m/s using molecules that move at 10^{-5} m/s:

3. Use tendons (with $d_{tendon} << d_{muscle}$) to **connect muscles close to pivot points of long bones**.

   Mechanical *disadvange* then produces **large limb displacements for given muscle ΔL**.

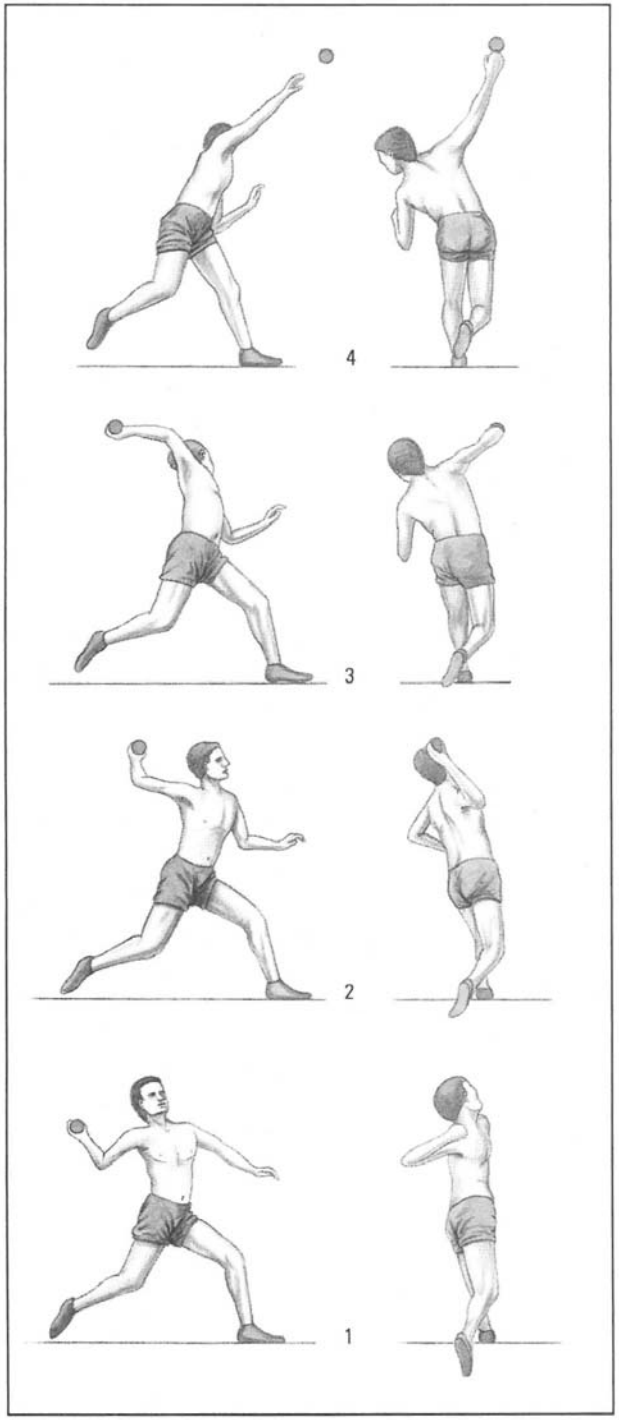
$\Rightarrow$ **$v_{rel,max}$ (limb) ~ 5-10 m/s**



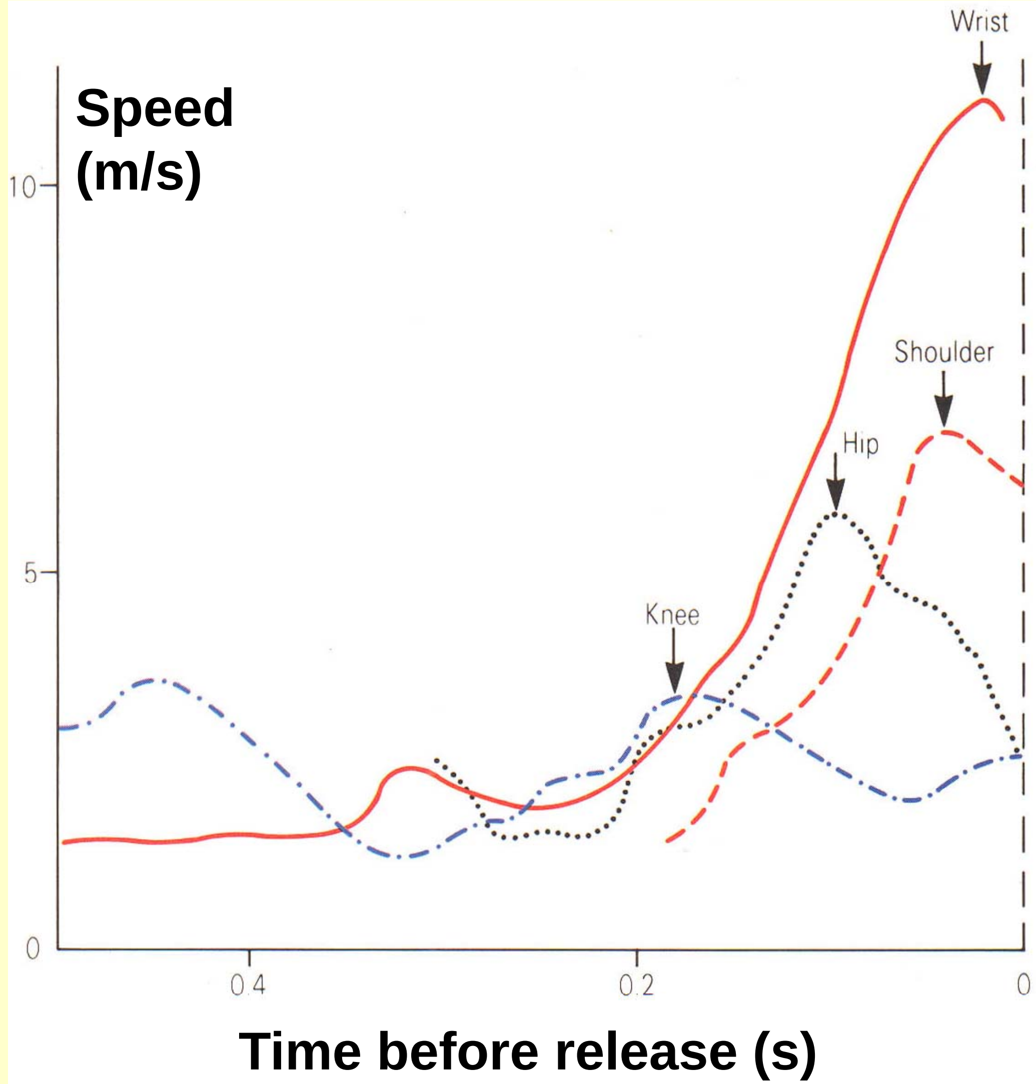
How to throw a ball at 50 m/s using molecules that move at 10^{-5} m/s:

4. **Use several mechanical "stages" that can rotate or move relative to each other**. (E.g., legs, hips, torso, arms, wrists, fingers).

5. Execute relative motion of each stage so that **relative velocities of each stage add**. "Whip-like" motion taking advange of elastic energy storage and release by tendons and ligaments maximizes impulse delivered to the ball.

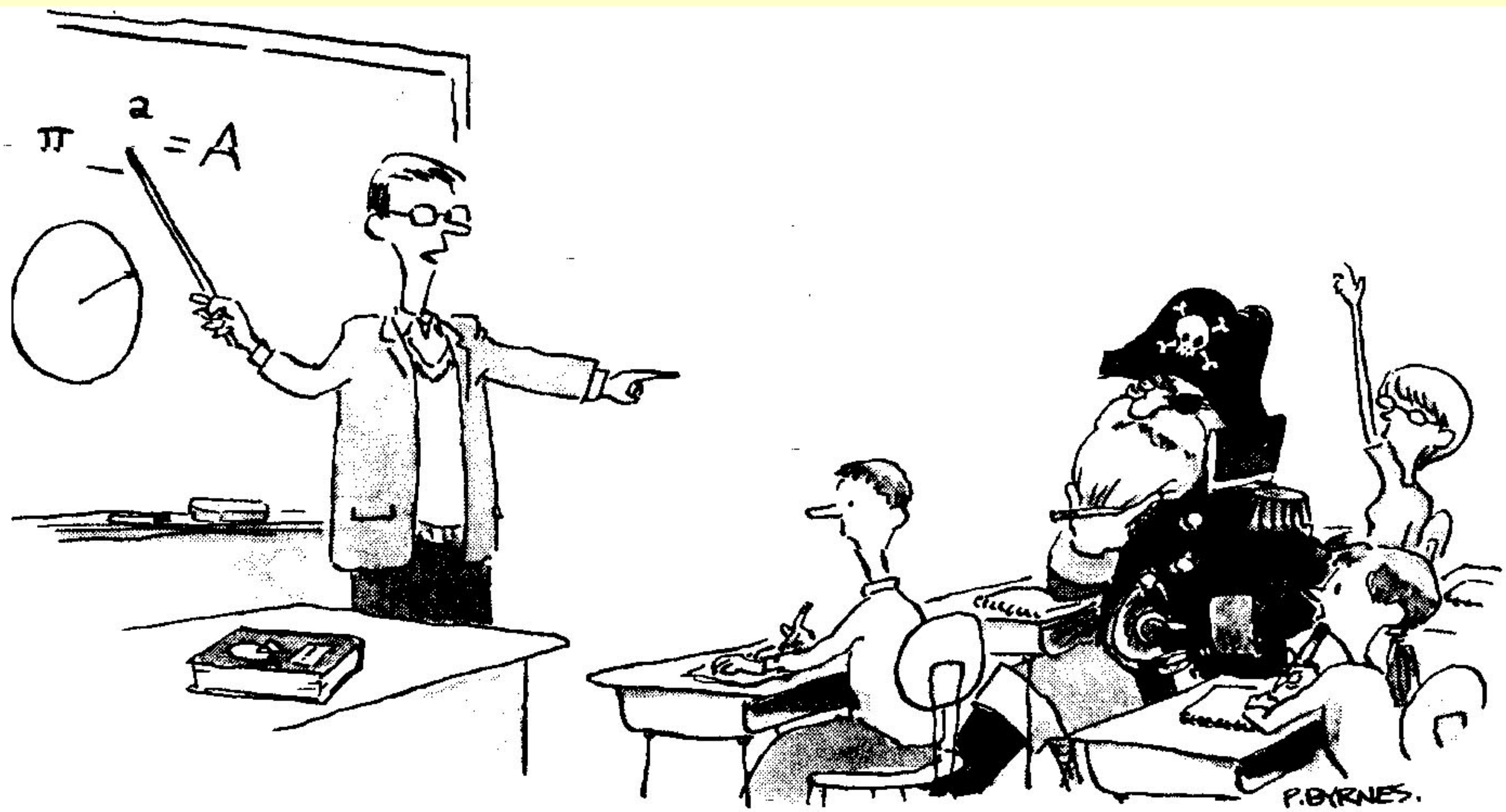


Speed of body parts relative to ground during a shot-put:



Summary

- Physics is interesting and powerful, but it's also hard!
- Pay attention to emotional needs.
- Show them why physics is relevant to what they care about – themselves and their futures.
- Teach in a way that helps develop confidence and promotes future inquiry



"Pi what squared? Long John, you should be able to get this."

Syllabus

- Describing motion along a line: *x*, *v*, *a* relations
- Motion in a plane; projectile motion
- Newton's laws and forces; free-body diagrams
- Circular motion; friction and fluid drag
- Energy; kinetic energy, potential energy; power
- Oscillations: free, driven, damped
- Momentum and impulse; collisions; center of mass
- Torques and static equilibrium; elasticity
- Heat; thermal expansion; heat capacity; heat transport
- Static fluids: pressure, buoyancy, surface tension
- Moving fluids: continuity, Bernoulli, viscous drag and flow
- Traveling and standing waves

If you miss work because of illness:

- **Get a note from your doctor** and give it to your TA.

- Make up missed lab work **the same week** in another lab. **Have the lab TA sign your yellow sheet.** If you cannot make up the lab that week, obtain data from another student and turn in your own analysis of the data. Indicate the source of your data.

- **Do missed homework, coop problems and turn them in, even if they are late.** You'll get partial credit even if you don't have a note, provided they're not too late.

Polling in Physics 207

Each week's questions are distributed in lecture at the start of the week, so students can work ahead.

Questions are presented and solved on transparencies.

Polling via a home built system (in use since 1972!)

Questions are interleaved with demonstrations and applications.

Powerpoint applications projected on a separate screen.

Polling in Physics 207

Emphasize transferable skills:

- graphical representations
- dimensional analysis
- proportional reasoning
- orders of magnitude and estimation
- approximate models

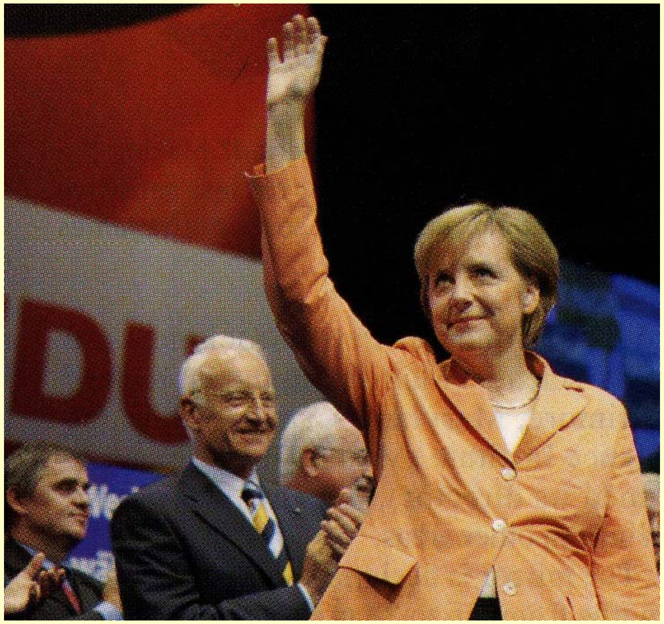
"Thank goodness you're here. I can't accomplish anything without a deadline."

Assignment 1 is due today.

International News:

Berlin - German opinion polls predict that the country will elect its **first chancellor trained in the natural sciences** later this month. A victory for the Christian Democratic Union on **September 18** over the ruling Social Democrats would mean a government led by **Angela Merkel**, **who holds a Ph.D. in physical chemistry**. She would also be the country’s first female chancellor.

International News:



The influential newspaper *Süeddeutsche Zeitung* wrote that Merkel had demonstrated both **meticulousness and tenacity** in her 1986 dissertation on the **calculation of rate constants in hydrocarbon decomposition reactions. Such qualities, the paper said, could be usefully applied to the equally complex problems facing Germany.**

Science, 2 Sept. 2005

Today's Trivia

To play some parts of an etude by Chopin, a pianist needs to be able to **read** and **play 3,950 notes** in two and a half minutes =**150 seconds**.

Average notes/second ~ **26**

Average time to play each note ~ 0.038 s

Speed of neural impulses down the arm ~ **80 m/s**

~ **180 mi/h**

Time to travel from brain to finger ~ 0.015 s

“He was expected to read a lecture on mathematics (broadly construed) each week during the academic term and deposit a copy in the university library. But he disregarded this obligation far more than the fulfilled it. When he did lecture, students were scarce. Sometimes he read to bare room or gave up and walked back to his chambers.”

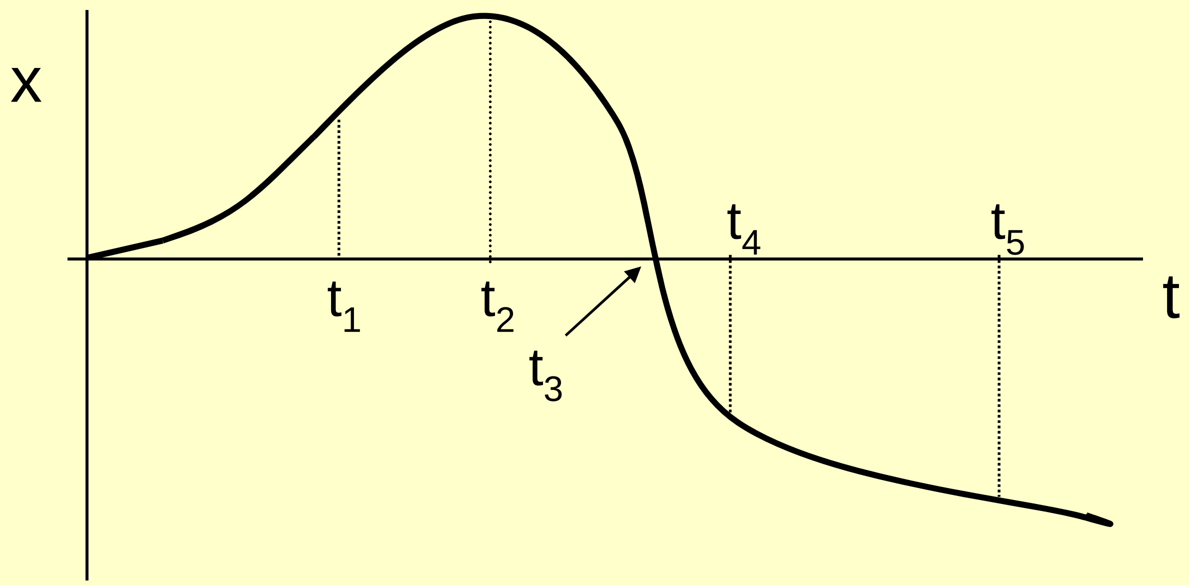
Isaac Newton by James Gleick

What role does thermal expansion play in forming the Taugannock Amphitheatre?

Pedagogy in Physics 207

- Pre-lecture PowerPoint shows containing
  announcements, physics news, trivia, humor
- Transparency notes mixed with **in-class multiple choice questions**
  (interactive learning / peer instruction)
- Demonstrations
- PowerPoint shows illustrating applications
- Cooperative learning sessions
- Labs tightly coupled with lecture

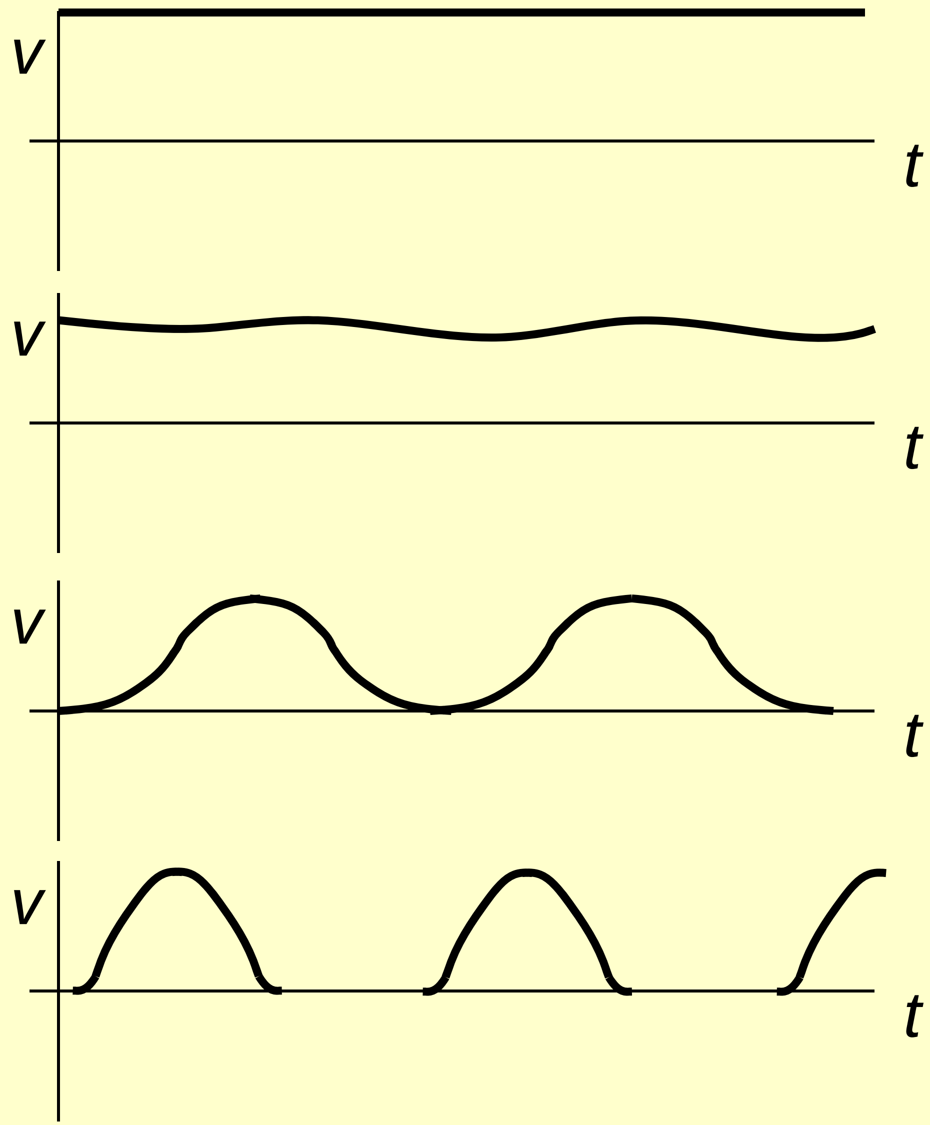
An object moves along the *x* axis as shown below.



At what time is v=0?

1. t_1
2. t_2
3. t_3
4. t_4
5. t_5

Which of the following *v*-*t* graphs best describes the horizontal motion of a foot relative to the ground during ordinary walking?



(1)

(2)

(3)

(4)

A car accelerates on a level road. What force **acting on the car** produces its acceleration?

1. The force of the engine on the wheels
2. The static friction force of the tires on the road
3. The static friction force of the road on the tires
4. The kinetic friction force of the tires on the road

A car of mass m traveling at a speed v is braked to a stop by a constant force F.

If the initial speed of the car is doubled, by what factor does its stopping distance d change?

$d(2v)/d(v) = ?$

1. 1/4
2. 1/2
3. 1
4. 2
5. 4

Pedagogy in Physics 207

- Pre-lecture PowerPoint shows
- Transparency notes mixed with in-class multiple choice questions
- Demonstrations
- **PowerPoint shows illustrating applications of physics**
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Making Physics Relevant

- Most students are not "true believers“ in physics, and take the course only because it is required.
- Many have little idea of why or how physics may be relevant to their future careers.
- Many students continue to view physics as irrelevant *even after taking high school and college physics courses*.

How can we introduce the applications of physics, in a way that motivates inquiry and promotes broader content knowledge?

- homework assignments

- demonstrations

- term papers / projects

- **in class via interactive “mini-lectures”**

Interactive “Mini-Lectures”

- Discuss applications of physics that are generally familiar in everyday life, or that are of particular interest to your students.
- Use a light touch, emphasizing basic ideas from class rather than detailed calculations.
- Use PowerPoint to provide a consistent “feel" and a smoother transfer of information.

Interactive "Mini-Lectures"

- Use applications to illustrate how the same concepts crop up in completely different contexts. Cover multiple applications per class.

- Try to give a sense of the **interconnected-ness of science**, of how phenomena and theory in distinct areas are interleaved into a complex, self-consistent tapestry.

- **Because of the central role of Physics, we are best positioned to give our students the “big picture”.**

Outcome:

	Lecture	Course
1991-1998	3.2	3.0
Fall 1999	3.5	3.3
Fall 2006	4.1	3.8

Class time is very limited, so stay "on message."

- Keep the students focused on physics.
- Begin class promptly, and avoid speaking in class about anything except the material being taught.
- Use handouts, course web pages/email lists and **pre-class Powerpoint shows** for announcements.

Demonstrations are an essential tool for illustrating concepts. <u>But</u> most students can't follow the physics of many "standard" demonstrations.

Select demos carefully. Perform those that are easy to understand, connect to everyday experience, and/or that are particularly illustrative of a fundamental concept.

Interactive “Mini-Lectures”

- Use applications to illustrate how the same concepts crop up in completely different contexts. Cover multiple applications per class.

- Try to give a sense of the **interconnected-ness of science**, of how phenomena and theory in distinct areas are interleaved into a complex, self-consistent tapestry.

- **Discuss real-world applications that are straightforward extensions of funda-mental ideas.**

- To allow more applications to be presented in a given time, emphasize concepts, not math, and use pre-prepared transparencies or powerpoint.

Math Skills for Intro Physics (Science!)

Sketching and properties of simple functions. E.g, x, x^2, x^3, $ax+bx^2+cx^3$, $1/x$, $1/x^2$, $1/(1-x)$, $1/(1-x^2)$.

Sines and cosines. E.g., $A \cos(\omega t + \phi)$. Graphing with arbitary A, ω, ϕ.

Units and dimensional analysis. Showing that equations have consistent dimensions. Using dimensions of variables to determine relations between variables.

Orders of magnitude. What is an "order of magnitude"? An "order of magnitude" estimate?

A feeling for the relative magnitudes of physical quantities (e.g., speeds of objects in m/s).

"Back of the envelope" calculations.

Exponentials exp(t/τ). Graphing. Meaning of the "time constant", relation to doubling time, half-life, decade time. What do "exponentially increasing" and "exponentially decreasing" mean? Does an exponential increase faster than x? x^2? x^3?

Proportions. Using proportions to make predictions based on measurements. E.g., if $y = A x^3$, by what multiplicative factor will y change by if x is doubled?

Algebra. General algebraic manipulations. Solving two equations in two unknowns.

Geometry. Slopes, tangents, relations between interior and exterior angles. Areas of rectangles, triangles, trapezoids and circles. Volumes of cubes, pyramids, spheres and cylinders. Surface to volume ratios; circumference to area ratios.

Logs. Basic relations and graphing. Numerical relation between a value and its log.

Semi-log plots. Generating them from a data set. Using semi-log plots to determine if a given data set has an exponential dependence; extracting the time constant.

Log-log plots. Using log-log plots to determine power-law relations between x and y, e.g., $y = A x^3$. Allometry and scaling.

Calculus. Basic notions of integrals and derivatives. Obtaining integrals and derivatives from data in tabular or graphical form; derivative = slope of curve at a point, integral = area under curve between two points. Numerical differentiation and integration. Derivatives and integrals of simple functions: x, x^2, $1/x$, $A \sin(\omega t + \phi)$, $A\exp(-t/\tau)$.

Solution (????):

Web-based math tutorial and evaluation tool.

1. A pre-test, whose completion is required for initial entry into the site. The student will be given their score and the "required" passing score.

2. Multiple choice or fill-in-the-blanks questions organized by topic, in the order they appear in the course. Include interactive questions.

3. Concise tutorial explanations (including motivation for why scientists require these skills and how they use them), which can be viewed directly or via links from questions.

4. Unit tests on each major topic.

5. A set of comprehensive post-tests comparable to the pretest, to allow evaluation of learning outcomes.

6. A set of more rigorous tests for students who want to achieve a greater level of mastery.

- Parallel and interlinked math and physics question tracks

Track 1: pure symbolic math

E.g. $y=ax^2$. If we double y, by what factor does x change?)

Track 2: Math with physical quantities, symbols and equations used in P207

E.g., the inward acceleration of an object moving in a circle is related to its speed and the radius of the circle by $a=v^2/r$. If we double v, by what factor does a change?

Pedagogy in Physics 207

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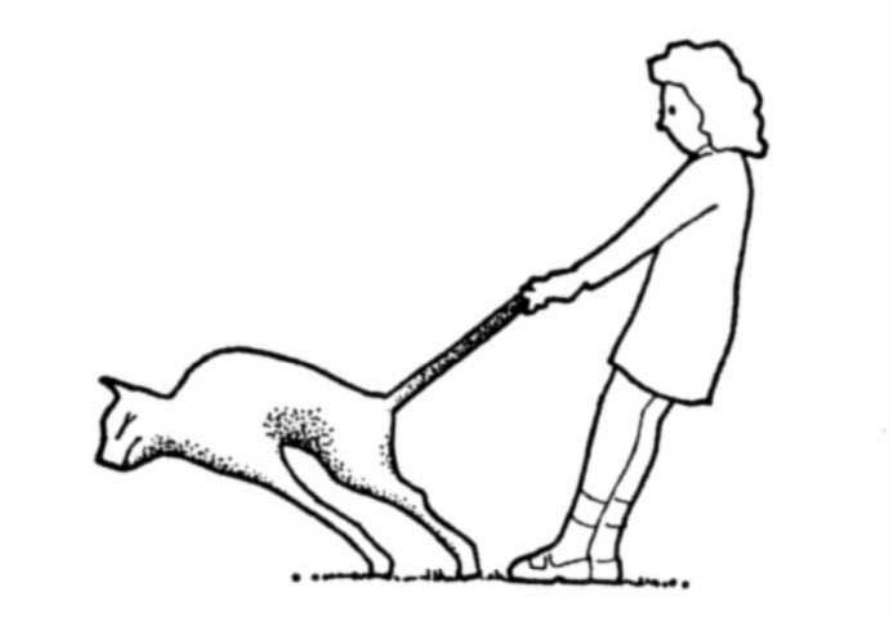
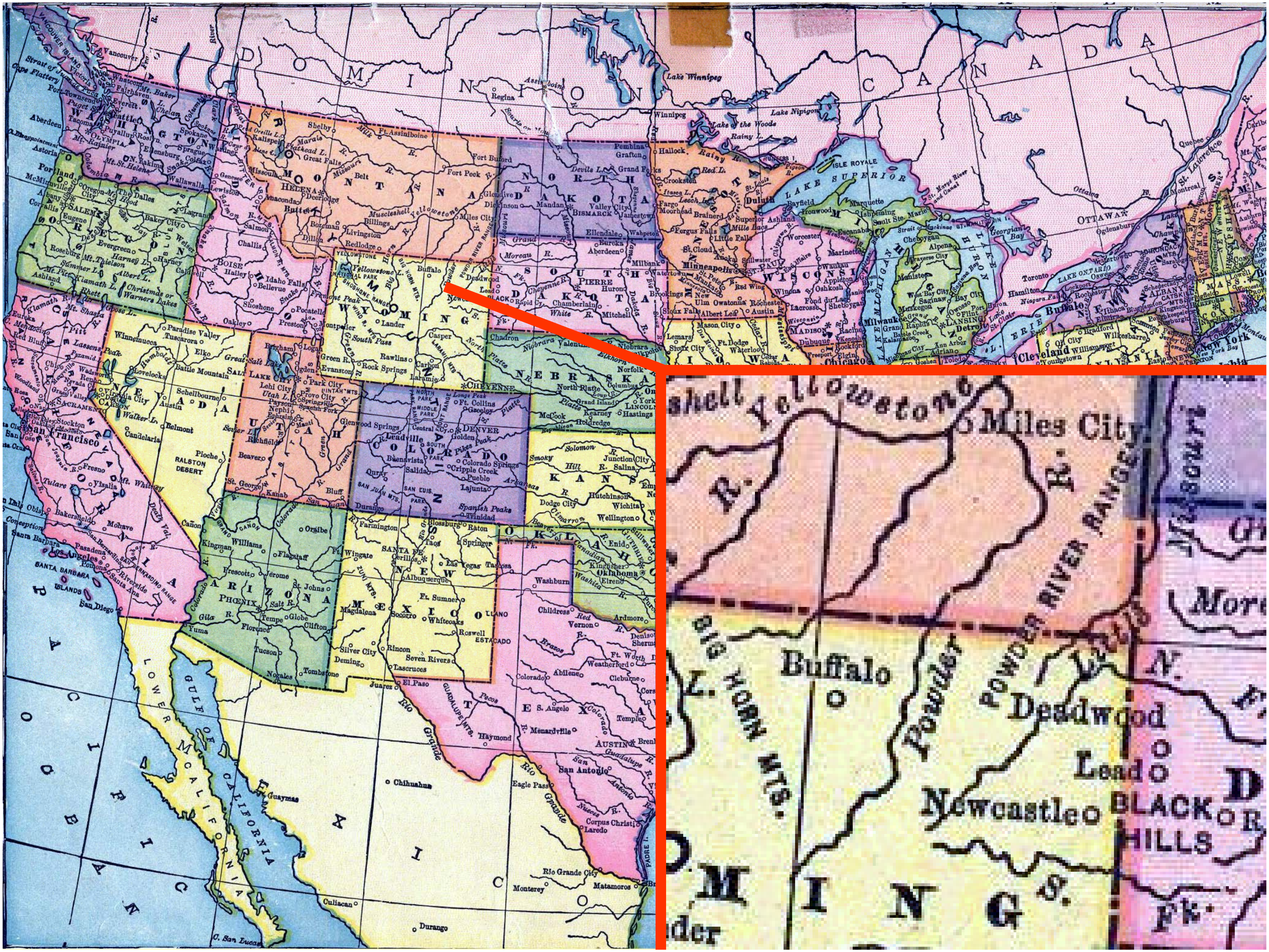


How does the force that Darling the daughter exerts on Kitty the cat compare with the force that Kitty exerts on Darling?

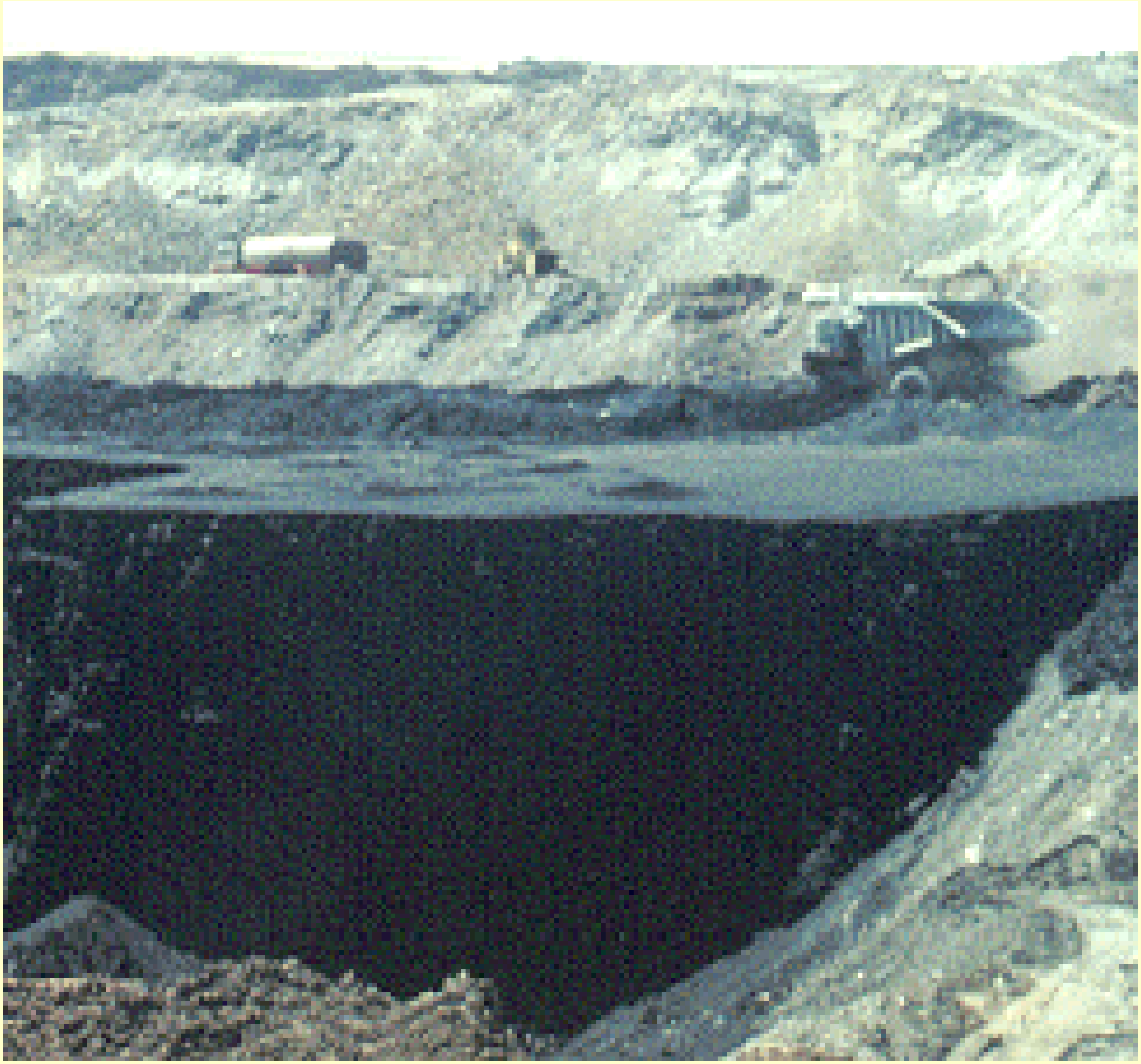
1. $F_{\text{Darling on Kitty}} > F_{\text{Kitty on Darling}}$

2. $F_{\text{Darling on Kitty}} = F_{\text{Kitty on Darling}}$

3. $F_{\text{Darling on Kitty}} < F_{\text{Kitty on Darling}}$



DOMINION OF CANADA
WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
WYOMING
UTAH
COLORADO
ARIZONA
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
TEXAS
MINNESOTA
WISCONSIN
MEXICO
PACIFIC OCEAN
GULF OF CALIFORNIA
LOWER CALIFORNIA
LAKE SUPERIOR
Lake Winnipeg
OTTAWA
Yellowstone
Miles City
R.
POWDER RIVER RANGE
Missouri
Moreau
BIG HORN MTS.
Buffalo
Powder
Deadwood
Lead
Newcastle
BLACK HILLS
Fk.



- The Powder River Basin is the world's largest coal producing region.
- **200 miles** of coal trains leave the Powder River Basin every day, 365 days a year, bound for electricity generating plants.
- Trains can be up to **2 miles long**, and weigh **23,000 tons**.

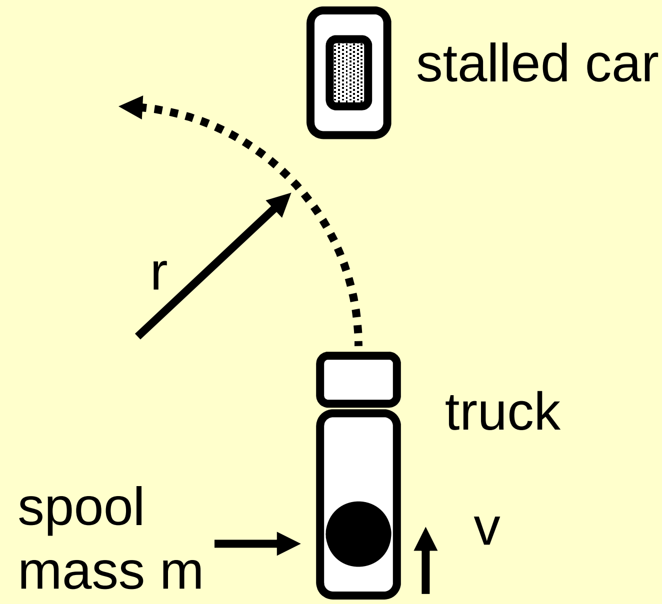
A flat-bed truck traveling at speed v carries a large spool of wire of mass m. The truck swerves to avoid hitting a stalled car directly ahead, and in so doing executes an arc of radius r. If the coefficient of friction between the spool and the truck bed is μ_s, what is the minimum radius r of the truck's turn for which the spool will not slip?

r_{min} = ?

(1) $m v^2 / g$

(2) $\mu_s g / v^2$

(3) $v^2 / \mu_s g$



Suppose that the mass m of the spool of wire is doubled. By what factor does the minimum turn radius change?

r_{min} (2m) / r_{min} (m) = ?

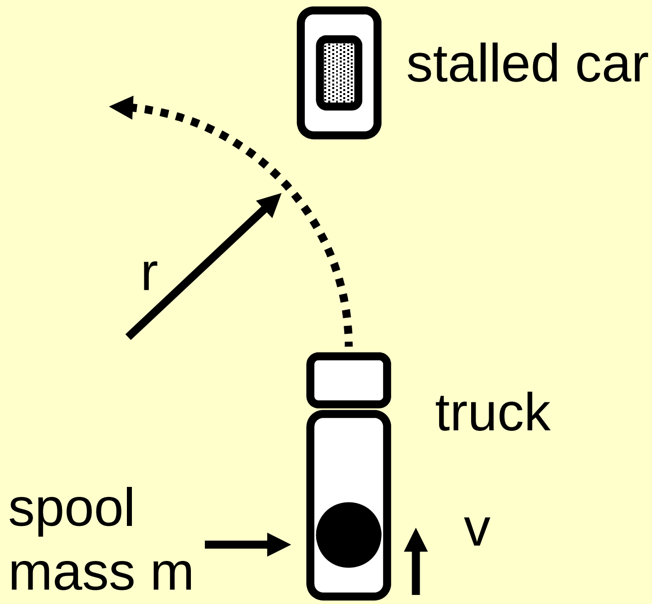
(1) 1/4

(2) 1/2

(3) 1

(4) 2

(5) 4



A car accelerates on a level road. What force **acting on the car** produces its acceleration?

1. The force of the engine on the wheels
2. The static friction force of the tires on the road
3. The static friction force of the road on the tires
4. The kinetic friction force of the tires on the road

Levers in Kitchen Utensils:

From a fortune cookie consumed at a local Chinese Restaurant: