**Physics 103, Elementary Physics I: lecture notes for Fall 2023**

These are Dan Styer’s lecture notes; they are not complete or polished, just notes.

**29 August; Assignments 1-4 posted**

**Friday, 1 September; Introduction**

Go over syllabus. Can you think of a more boring name for a course? All of football is subsumed within physics! Hence physics teachers should be paid more than football stars!! What if you could kick a football high enough that it would reach the International Space Station?

Don’t memorize equations.

**Monday, 4 September (no class, Labor Day)**

**Wednesday, 6 September; Problem solving**

How to solve the “training for a footrace” problem. Ask students to confer for 5 minutes.

Solve three ways: (1) numbers in a spreadsheet; (2) sum of series … forward and backward (if = training mileage, = race mileage, ); (3) diagram and triangles.

Problem solving tips.

Read textbook on “Units”, and on “Significant Figures”.

**Friday, 8 September; Motion in one dimension**

Motion (“Kinematics”) in one dimension.

Displacement = change in position (signed)

Distance = magnitude of displacement (positive)

Velocity, speed

Acceleration

You can ask about change in acceleration with time, etc., etc.

Motion at constant velocity

Motion at constant acceleration , ,

If = 16 m, = 6.0 m/s, = -2.0 m/s2 then: (1) when does it turn around? (2) how fast does it pass the origin?

An equation is not an inert jumble of symbols awaiting numbers to “plug in and chug through”. An equation is a troubadour singing songs about nature. The songs are interesting only if you listen for them.

**Monday, 11 September; Falling**

Demo: coin and feather tube; ball; book and coin.

Coin and feather: The vacuum needs about 30 seconds to evacuate the tube. Open the valve on the end of the tube before turning on the pump and close it before turning off the pump. Keep the feather away from the valve end so it won’t get sucked up.

Start with diagram of “up = positive”; three big equations

g = 9.81 m/s2 approx. 20 mph/sec approx. 40 (km/h)/sec

Ball falling from rest; ball with initial positive (upward) velocity

Diagram showing ball going up, stopping at an instant, going down; but “falling” throughout

Discuss among yourselves: what does ball with initial velocity look like from a glass-encased elevator rising at the speed of initial velocity?

Falling means a different thing in physics and in everyday speech; ascending/descending, rising/falling; as with speed/velocity; this won’t be the last time.

Ball with initial velocity; how high does it go?; don’t do it by splitting into upward motion and downward motion

How high does it go? (1) check dimensions; (2) increase or decrease ; (3) ; (4) increase or decrease g; (5) g = 0.

**Wednesday, 13 September; Vectors**

Work the “Yosemite Half Dome rockfall” problem.

We’ve had great fun with motion in one dimension, but ultimately we have to think about three dimensions. The powerful mathematical tool for this: the vector.

Vector: like an arrow. Scalar: a number. Examples of vectors: position (meters), or velocity of a ball (meters/second), or wind velocity (meters/second), or human migration rate (number of people/year), or migration of money (dollars/year). A vector is not a journey.

Represent a vector with an arrow atop; book does it with boldface.

Adding vectors, multiplying by a scalar. Graphical.

Vector components: a vector in three dimensions can be represented by a triplet of numbers. Sometimes said that a vector IS a triplet of three numbers, but the triplet (height of Empire State Building, price of coffee in Brazil, date of my wedding) is NOT a vector. There’s nothing here “like an arrow”.

(Does anyone want to bring a skateboard for Friday?)

**Friday, 15 September; Tossing**

Walk/skateboard with uniform speed and drop a ball straight down, or toss a ball straight up. Demo. Run/skateboard and toss a ball straight left into a trash can.

Vector and scalar equations for motion when air friction is negligible. Write time equations only.

Problem 4-34 from Walker: Two snowballs are thrown at speed 13 m/s from a roof 7.0 m above the ground. One is thrown straight downward, one is thrown at 25 degrees above the horizontal. Which ball lands with higher speed?

Guess / Diagram (understand the problem) / Use variables not numbers (solve both problems at once, less writing) / Strategy: find ground-striking time , then velocity, then speed / Execute / Wow at end! Good thing we did it for general angle theta!

Does “faster” mean “less time”? Not in physics! Drive to the IGA at 20 miles per hour, requires 3 minutes, everyday meaning words “quick, fast”; drive to Nashville at 60 miles per hour, requires 8 hours, everyday meaning words “slow and boring”; despite the fact that the drive to Nashville had higher speed (i.e. faster), in the physics sense of the word!

We’ve been talking about motion. But what causes motion, what changes motion? Force.

**Monday, 18 September; What is force?**

Class outlined in document on web page: “What is force? What does force do?”

Demos: brick, pillow, cart, rubber band, model car, Galileo’s “Dialogue Concerning the Two Chief World Systems” pages 216-218.

**Wednesday, 20 September; Newton’s laws**

Force is a push or pull; causes change of motion, not motion

 (constant of proportionality is 1 when F in newtons, mass in kg, a in m/s2). This is why I give you practice in vector addition.

Sources of force: gravity, contact (touching: strings, springs, rubber bands) also E&M, nuclear forces, deal with in Physics 104.

Newton’s Laws: (1) If , then hence = constant

(2)

(3) Two objects, A and B,

Third law: Often called “action – reaction”, poor names. Confused with “cause and effect”, even worse.

The word “law”: in common speech, law is how you *ought to* behave but you can do otherwise (no law against jumping 30,000 feet high), in physics, law is how nature *does* behave.

Falling brick: double wide fat arrow for force, double headed arrow for acceleration; where is the third law opposite force?

Brick on pillow: lifelike diagram, free-body diagram – third law pairs act on different objects, are of same type (gravity, contact) (“normal” force, in sense of perpendicular)

Person pushing car: lifelike diagram, free-body diagram

The word “force”: in the Oxford English Dictionary, there are 53 meanings of the noun “force” … and it's a verb, too! Military force (“military strength or power”) vs. physics force. The intuition you developed about military force probably doesn’t apply to physics force.

**Friday, 22 September; Exam prep**

Significant figures: If number rounded off is 0-4, round down. If 6-9, round up. If 5, “round to even”. I don’t care, round up or down. The “even/odd” rule gives the impression that for any scientific problem there is a single correct answer and a single correct way to find it. That science doesn’t involve creativity or ingenuity.

**Monday, 25 September (no class, Yom Kippur)**

**Wednesday, 27 September; Exam**

**Friday, 29 September; Working with forces I**

Exam debrief:

* Conference session hours, tutors, drop in.
* Science involves many different styles of thinking: numbers, equations, graphs, diagrams, equipment.
* Explain; write down equation before plugging in numbers.
* Use symbols, not numbers: is one character, 9.807 m/s2 is nine characters.
* Dropping time: Use arbitrary height , not 10 m; shows result is independent of , of (same result on Earth, Moon, Jupiter!); remember the surprise we got by doing the “speed at bottom of cliff” problem with arbitrary angle θ.
* Symbols: means “3.24 m/s”; the units are inside the , don’t write “ m/s”.
* Pep talk: I failed my first linear algebra exam (23%), went on to solve problems that my professor couldn’t solve.

We started with position. How to explain position? Velocity. How to explain velocity? Acceleration. How to explain acceleration? Force. How to explain force? Gravity – which is really a description not an explanation. (We know how gravity works with extraordinary precision. We can aim the Cassini spacecraft to fly by Venus (twice), Earth, asteroid 2685 Masursky, and Jupiter, and end up at the expected place between two rings of Saturn.) Contact forces – similarly. So we really can’t explain forces, but we *can* work with them. (Just as I can’t explain why a tree is called “tree” rather than “baum”, but I can work with the words.)

Science is limited … ultimately it seeks to describe, not explain. Theology tries to explain, and (in my opinion) fails. Science learns from theology and tries not to fall into that trap.

Example: Canoes in contact, then pushed apart (Walker example problem 5-6). Note that only one person gets tired and sweaty (“exertion”), but force exerted by 1 on 2 is same magnitude as force exerted by 2 on 1. Play with results: What if ? What if is 25000 kg?

Third law force pairs are of the *same type* (gravity and gravity, contact and contact), and they *act on different objects*.

**Monday, 2 October; Working with forces II**

Bring: bike wheel, paper

I always found Newton’s third law counterintuitive. For example: Harry and David are engaged in a barroom brawl. Harry punches David in the face. Later, David sues Harry for damages. Harry argues that the force by David’s face on Harry’s fist was the same as the force by Harry’s fist on David’s face, so he should get off scot-free. That’s true, but equal force doesn’t mean equal damage, or equal moral culpability. (I haven’t yet mentioned the word “strength” in this course.) It wasn’t until I made up the following argument that Newton’s third law made any intuitive sense to me.

Two boxes slide without friction on a horizontal surface. Force from the left. Apply to the system, to the left box, to the right box. Newton’s third law follows.

Set up and strategize for Urone and Hinrichs problem 4.16, “the brave rugby player”. There’s a tendency to think of friction as an annoyance “wouldn’t things be better if friction didn’t get in the way”, “friction opposes motion” … no “friction opposed slippage”. When we start walking, the force that makes us accelerate is friction.

Take a step – attempt to drag foot north, force of friction to south, so I accelerate south. Yes, there is a force on the knee by the ankle, but that’s cancelled by the force on the ankle by the knee.

Parallel with bike wheel. To see direction of slippage, place sheet of paper on table, lower spinning wheel to table.

“When a car speeds up, what force makes it accelerate?” Discuss for five minutes.

Friction propels the car forward. When I was young I thought that friction was always the enemy, that it could never be harnessed for doing what I wanted. Dead false. Friction does not “oppose motion”, when you step, it originates motion.

Video of car on slick ice. Wheels spin but car stays stationary, no acceleration.

Set up and strategize for Urone and Hinrichs problem 4.22, “baby in a basket”.

**Wednesday, 4 October; Friction; Falling**

Bring: brick or book, ball, penny, computer to show video.

Two objects in contact on a plane. The perpendicular part of the contact force is called “normal force”, the parallel part is called “friction”. Friction doesn’t oppose motion, it opposes slippage. Brick on table. (Force of hand to south, force of friction to north.) Coefficient of kinetic and static friction.

The fact of static friction means that when you push an object resting on a table, it remains stationary for a gentle push. This gives rise to a misconception that you always require some force, and that force is needed to “overcome inertia”. Absurd, wrong dimensions. But that’s what my sons were taught in middle school.

Video demo: “A Million to One” with flea circus.

https://www.youtube.com/watch?v=rYN1DyxkISI

How does a spring scale work? Three pounds of bananas. Strings and scale has negligible mass. “Tension.” Scale doesn’t read vector sum of forces … zero. Scale doesn’t read scalar sum of forces … 6 pounds. It is set to read the one force, tension.

Falling elevator: After 1 second, 20 mph. After 4 seconds, 80 mph. You’re going to hit the floor! My Dad says: jump up just before you hit the floor. I spent a decade as a physicist getting rid of the misconceptions my father instilled.

Hang bananas in elevator. No acceleration (force of gravity, “weight”, and force of spring, tension). Accelerate upward. Feel it in your legs, pillow with brick compresses. Accelerate downward. Normal force is . Free fall when . “Weightless.” You don’t need to be in outer space. (Even *Magic School Bus* got this wrong.)

Why do all objects fall at same rate? The book has more gravitational force, but also more inertia, and (surprise!) they exactly cancel out.

Throw ball into orbit: speed needed depends on and . Think about it: should increase with and with (because horizon is farther away). Dimensional analysis . Derivation .

That’s physics! All the way from bananas to orbits.

**Friday, 6 October; Various – last class on force**

**(1)** “Can you kick a football into orbit?”  Look again at orbits.  Turn time backwards.  You could kick it as high as the International Space Station, but then it would fall back to earth.  It needs two kicks to get into orbit.

Circular motion (U&H book section 6.2). Uniform speed, velocity perpendicular to radial position, acceleration antiparallel to radial position (hard to derive, easy to remember, dimensions, limit as r goes to infinity).

**(2)** Centripetal acceleration vs. centrifugal force.

Problem:  A suitcase of mass sits on a merry go round a distance from the center.  Coefficient of static friction is .  At how many revolutions per second will it slip? At

 Discuss: dimensions, limits.

**(3)** A year ago I looked up at the nearly full moon, near the bright Jupiter.  Stunning, poetic, romantic sight.  Indeed, my wife Linda insisted on a long kiss, and who am I to argue?  But it’s not just beautiful.  Understand that a bright Jupiter will be near a full moon.  To my mind, the understanding deepens the beauty.  Others see poetic light.  I see poetic light but also a story demonstrating that the universe is a rational system capable of being understood, not simply “the slings and arrows of outrageous fortune.”

From “Two Ways of Seeing a River” in *Life on the Mississippi* by Mark Twain:  Once he understood the Mississippi river, “All the grace, the beauty, the poetry had gone out of the majestic river!”

From *The Sense of Wonder* by Rachel Carson:  “Those who dwell, as scientists or laymen, among the beauties and mysteries of the earth are never alone or weary of life. Whatever the vexation or concerns of their personal lives, their thoughts can find paths that lead to inner contentment and to renewed excitement in living. Those who contemplate the beauty of the earth find reserves of strength that will endure as long as life lasts.”

I hope that in this course you will see the beauty, but also see what it tells us about the structure of the universe.

**Monday, 9 October; The Measure of Effectiveness of a Force: Work**

Bring: box, ball, brick or book, cardboard box top.

Push on a wall. There’s force, but it doesn’t get anything done. Can I develop a measure of “what a force accomplished”?

I push a box to the right with force . It moves a distance to the right (we called this “displacement”). I have done work This is not the same as the everyday understanding of the word “work”.

Unit: newton times meter = joule

Suppose that instead of pushing, I pull at an angle. The component of the force parallel to the displacement does work, but the component perpendicular is as ineffective as when I push on a wall. It does no work. .

What if force and displacement are in opposite directions? Superman stopping a truck.

Dot product … . You can talk about the “part of the force parallel to the displacement” or the “part of the displacement parallel to the force”.

Can gravity do work? Positive going down, negative going up. When it goes up at an angle? Work done by gravity near Earth’s surface:

Can friction do work? At first it seems to be always negative: static, kinetic. But! Drag brick within cardboard box top. Work done by friction on system “brick plus box top” is negative. Work done by friction on brick is positive. False: “friction opposes motion”. True: “friction opposes slippage”.

The poet says “Man is the measure of all things”. Maybe, maybe not. While I was driving to work this morning, I saw two bald eagles flying in tandem – beautiful and powerful at the same time. They probably think that “Eagles are the measure of all things”. What is true is that “Work is the measure of all force”.

**Wednesday, 11 October; The payoff of work**

Bring: box, ball, brick or book, cardboard box top.

What is the result of work? If we work (in the colloquial sense) we expect a paycheck. What is the payoff for work in the physics sense? The payoff of force is acceleration. What is the payoff of work?

Work left-overs: Variable force: push box soft (50 N) for 3.0 meters, then hard (80 N) for 2.0 meters. Draw graph of force vs. distance, area under curve.

Spring force: Extend spring with hand. Positive direction to right, zero at relaxed length of spring. For small displacements, Force exerted by hand . (Large displacements break the spring.) Graph force v. distance. Work done by hand . Work done by spring .

Back to constant force: work =

Does total force have to be parallel to displacement? Discuss. No. Circular motion, tossed ball.

Orient -axis in direction of displacement, hence direction of the force that has an effect. Start with equation and derive the payoff of work. Name “oomph” or “vis viva” (“liveliness”). Define “kinetic energy”. (Differs from “Colin has a lot of energy.”)

May need to split into small bits, just as we did with earlier with “work left-overs”.

Conclusion is that

.

Remarkable in that left-hand side depends on the details of force at every moment between initial and final, right-hand side depends only on initial and final.

It’s as if a book depended only on the last and first pages. Have we ever seen such a thing? Yes, with gravity!

So

Kinetic Energy, Potential Energy

**Friday, 13 October: What else depends only on initial and final?**

Write down work-KE theorem. Show that the signs are correct for pushing package, for circular motion, for superman stopping a train.

Move gravitational work from left to right.

Think of the “snowball toss from top of cliff” problem from class 6. Easy to solve now! This won’t tell you “how far from the base of the cliff does it land”, but it does tell you “at what speed does it land” and it does so much easier than the force equations do.

The process of moving work terms from the left to the right can be continued. For example, a spring of spring constant , stretched a length ℓ from equilibrium:

For example, “energy is conserved if there’s no friction”. But fact is that all forms of work yet discovered can be moved over to the right … thermal energy (What do you think motivated Joule? Was he a pure scientist? An engineer interested in minimizing friction? A brewer.), electrical energy, chemical energy, sound energy, light energy. If you burn a carrot, you get so much thermal energy (“bomb calorimeter”). If you eat a carrot, do you get the same energy? YES! I’m not giving you all the details.

Example: “A mountain climber eats a snickers bar and then climbs a mountain. If all of the chemical energy were converted into gravitational potential energy, how high could she climb?”

Energy in a snickers bar: . Find

.

Makes sense: increase , decrease , decrease ; check units.

Numbers: a snickers bar contains 280 calories. Approximate amount of energy needed to raise 1 gram of water by one degree Celsius is called a “calorie”. 1 kg of water, a “kcal”. 1 kcal = 4184 J. Except that the food industry calls the kcal a calorie. Shrug.

So S = J.

Use my mass when I’m healthy: 195 lbs = 88.4 kg.

Result: 1.35 km = 4430 feet = higher than El Capitan in Yosemite

Body is not perfectly efficient, work done against friction, etc.

Story about humming birds.

“How fast would she go if this person converted all the energy in a snickers bar into kinetic energy?”

Using our numbers results in 163 m/s or about 300 mph. (Can the snickers company use this in an advertisement?)

Advice for fall break: relax and come back refreshed.

**Fall Break**

**Monday, 23 October: Energy of many kinds**

Where were we?

We're interested in where things are: positions. We understand positions through velocities, we understand velocities through accelerations.

Misconception about velocity: I was driving with my wife on a highway over fall break. We had been driving at 63 mph behind a red car for several miles. My wife remarked that the car in front of us must be traveling at 65 or 66 mph. She thought that it had to be going faster because it was in front of us.

We understand accelerations through forces: acceleration is proportional to net force.

“Force” is a push or pull. It doesn’t have exactly the same meaning as the colloquial word force. For example: I get involved in a barroom brawl and punch Paul in the face. Paul recovers and sues me for damages. I argue that Paul’s face exerted the same magnitude force on my fist as my fist exerted on Paul’s face. This is correct physics, but it doesn't hold up in court: the same magnitude force does not imply the same magnitude of damage, nor the same amount of moral culpability.

“The effect of a force”; Work.

We’ve seen the process of moving work terms from the left to the right.

The fact that total energy is conserved suggests there ought to be a picture: something like indestructible marbles of energy or “energy flows”. I would like a picture not just an equation. As far as I can see, no such picture exists.

As far as tugging our heartstrings, a picture is worth a thousand words, many feel that a word is worth a thousand equations. For energy I have only an equation.

A problem assigned: “(a) Calculate the force needed to bring a 950-kg car to rest from a speed of 90.0 km/h in a distance of 120 m (a fairly typical distance for a non-panic stop). (b) Suppose instead the car hits a concrete abutment at full speed and is brought to a stop in 2.00 m. Calculate the force exerted on the car and compare it with the force found in part (a).”

If distance to stop is , force required is .

**Wednesday, 25 October: Another measure of force**

Suppose you exert a force for a long time but don’t move anything. For example, Dutch boy holds back the North Sea by putting his finger in a dike. You did no work, but at the same time it’s not right to say you were ineffective.

Another measure of effectiveness:

Unlike work, impulse is a vector. No special name for the unit of impulse: newton second.

Uniform total force 🡪 uniform acceleration 🡪

Call it “momentum”: unit: kilogram meter/second = newton second

Non-uniform force: still true.

If no force, momentum is conserved. Not always true for mechanical energy!

A bunch of particles: e.g. my hand is a bunch of atoms. Internal impulse is zero, but internal work is not! E.g. fist to extended hand. Knuckles don’t move, fingertips do move.

Hopewell Furnace National Historic Site in Pennsylvania. Blast furnace door latch has broken open, molten iron is pouring out. Throw mud at it or throw stones of same mass at it? Let’s do this thinking before we have the accident, so that we can be sure to have a source of mud/stones around when the emergency comes. Your life, and the lives of your coworkers, depends upon your choice! Discuss among yourselves.

Begin with situation, find a model, solve the model, what does solution tell us about situation?

**Friday, 27 October: Using momentum**

computer to show image “golf-ball-impact-compression”

**(1)** Measure of “oomph”: Shoot a bullet into a sand dune, retarding force constant once bullet enters the sand. Work-kinetic energy says distance required to stop is

Impulse-momentum says time required to stop is

If you double initial speed, you double the time required to stop, but quadruple the distance. Similarly, throw a ball into a china shop. Compare “Colin has a lot of energy.”

Work-energy tells us a lot about distance but usually doesn’t say anything about time.

Impulse-momentum tells us a lot about time but usually doesn’t say anything about distance.

**(2)** Golf ball struck with massive club. Club speed 40 mph, ball exits at 80 mph. How can it be bigger? Ball compresses. Bulldozer and beachball.

**(3)** Center of mass, total momentum.

“Natalie and Ben went for a canoe trip on a lake. They rented a 65 pound canoe and set off with Ben in the stern and Natalie 9.4 feet forward, near the center. They paddled to a secluded spot near the far shore of the lake, where they stopped to watch the full moon rise over the glass-smooth surface of the lake. After a few minutes they exchanged seats. Ben noticed that, during this exchange, the bow of the canoe moved 1.2 feet further from the shore. Then they turned the canoe around and paddled back to the dock. Ben knows that he weighs 180 pounds, and now he knows how much Natalie weighs, too. Do you? Comment on any assumptions you (and Ben) must make.” (130 pounds)

**Monday, 30 October: Rotation I**

Lots of things rotate: footballs thrown with a “spiral”. But we start with wheels. A dot on a bike wheel takes which path? Ask for possibilities. Place chalk-dusted finger on bike wheel and trace the path. If wheel rolls right, no point on wheel ever goes left.

Before, we talked about position, velocity, acceleration.

With rotation, we talk about angle, angular velocity, angular acceleration.

Before, we started with setting a unit of distance, an origin, and a positive direction.

Same here: unit to use for angle, degree (ancient Babylonian calendar had 360 days in a year hence 360 degrees in a circle) radian. Use , works only if angle is measured in radians. Note dimensionless. By convention origin horizontal, positive is counterclockwise.

Angular velocity, conventionally . , speed of rim . Check dimensions. If you call omega, “w”, it won’t bother me but others will snicker at you behind your back.

Angular acceleration, conventionally .

The same equations have the same solutions. Write down three equations for motion with constant angular acceleration. One way in which this analogy breaks down is that with constant acceleration gets bigger and bigger and bigger. Whereas comes back to itself after one rotation.

What is the analog of force that changes rotational velocity? Can’t press down on bike wheel and expect it to start rotating. Only the portion of the force perpendicular to the radius counts.

Furthermore, it counts more the further away from the axis it is … demo with door.

Analog to force is (distance from axis) times (part of force perpendicular to that distance) … call it torque.

Analog to acceleration is angular acceleration.

What is the analog to mass? I would call it “rotational inertia” but official name is “moment of inertia” where “moment = importance” NOT “moment = instant”.

**Wednesday, 1 November: Problem solving**

Reminder about significant figures: The figures you write down are significant. For example, suppose you calculate a length and your result has three significant figures.

Result from your calculator:

1.7432987

Correct result:

1.74 m

Result from your calculator:

1.7032987

Correct result:

1.70 m (1.7 m is wrong)

Result from your calculator:

1743.2987

Correct result:

1.74× m or 1.74 km (1740 m is wrong)

Result from your calculator:

1.7032987

Correct result:

1.70× m or 1.70 km (1700 m is wrong)

Problem solving:

Here’s a problem I assigned: “A 78-kg skateboarder grinds down a hubba ledge 2.5 meters long and inclined 19 degrees below the horizontal. Half of her potential energy change is dissipated to sound or thermal energy through kinetic friction. What is the coefficient of kinetic friction between her skateboard and the ledge surface?”

My first impression: there’s not enough information, because initial and final velocities are not given.

(1) Draw diagram.

(2) Work with symbols , , and . (Fewer penstrokes, more general, and benefit to be seen later.) Label diagram.

(3) Select strategy: First use Work-Energy to find dissipation and friction force. Second use a free body diagram and to find coefficient of kinetic friction.

Show that . The mass and length (and planet!) are irrelevant.

Instead of giving us too little information, the problem statement gave us too much!

Charles Darwin: “I have deeply regretted that I did not proceed far enough at least to understand something of the great leading principles of mathematics; for men thus endowed seem to have an extra sense.”

Value of high school algebra is not that most people will use algebra in their jobs or their out-of-job lives. The value is getting people to think abstractly. For example, regardless of whether represents a length of 3.0 feet, a mass of 1.7 kg, a force of 9.34 N, $156 of money, or $1239 of debt. What represents is irrelevant.

Value of abstract thinking: Compare “Obama tramples on the constitution” because he issues executive orders later overturned by courts. When Trump does the same thing, well that’s judicial overreach. But the name of the president is irrelevant.

My opinion: The goal of science is not to produce numbers or to build inventions to make life easier or to cure diseases and make life longer. Numbers and inventions are intermediates. The goal of science is to understand nature. We do this by getting our numbers or equations and then seeing what stories they tell about nature.

“Dover Beach” by Matthew Arnold.

One of the goals of this course is to extend your ability to think abstractly.

Another goal (not listed on the syllabus) is to convince you that our universe is “far more various, far more beautiful, far more new, than anyone ever could have imagined”.

**Friday, 3 November; Rotation II**

With translation, we did kinematics, then force, then mass (inertia), then work, then KE, then impulse, then momentum.

Torque = (distance from axis) times (component of force perpendicular to that distance)

Torque

where angle is defined properly: set vectors tail to tail, angle from to , check sign.

With rotation, we did kinematics, then torque, and we got sort of stuck on how to define “rotational inertia” or “moment of inertia”. It had the dimensions of mass × [length]2.

Do it by analogy to kinetic energy.

KE of bike wheel. where .

Given this . (You can make this a vector equation, but we don’t need to in this course.)

Text page 397 has lots of expressions for I:

For a disk, . For a sphere, .

For a rod of length rotating about one end,.

Examples: Walker page 341, conceptual example 11-5 (discuss among yourselves); example 11-6 (represent gravity acting along arm through an odd number of small arrows, demo!)

**Monday, 6 November; Exam prep**

Exam topics: force and Newton’s laws; work; kinetic and potential energy; impulse and momentum; collisions; centripetal acceleration; projectile motion.

The following question was posted on “Yahoo Answers”:

“A truck weighing 2.8 tonnes is stationary when hit head on by another truck travelling at 3.0 m/s weighing 3.3 tonnes. No brakes were applied. What is the speed of the wreckage immediately after the collision?”

The answer proposed was:

“Zero.

It might have escaped your attention that trucks are NOT point masses; in a collision they tend to deform rather a lot which means that a LOT of the energy is dissipated and also means that it takes a little while to actually start the wreckage moving (place, essentially).

The very term WRECKAGE is rather telling in that sense.”

Why is the proposed answer not only wrong, but also self-inconsistent? Other conclusion: You can’t believe everything you read on the Internet.

“You throw a glove straight upward to celebrate a victory. Its initial kinetic energy is and it reaches maximum height . What is its kinetic energy half way up?”

How about one-third of the way up?

**Wednesday, 8 November; Exam**

**Friday, 10 November; Rotation III**

Exam debrief:

* Use significant figures.
* In problem 3, *Firecracker*, was mathematically the easiest problem on the exam. It’s obvious that KE is not conserved during the explosion. I gave it last year and only three students realized that momentum would be conserved. All semester I’ve been teaching to make sure that you do better. And it worked! 19 students recognized that momentum would be conserved, 11 got it right in all respects.
* I was hoping that you’d see the connection between the Tarzan *Rescue* problem and the lab with the heavy lead ball. At least one student did.
* Tarzan *Rescue*: Almost everyone recognized energy conservation for Tarzan’s swing. Fewer recognized momentum conservation for Tarzan’s snatch. Several students recognized momentum conservation in the firecracker but not in the Tarzan snatch.

Stand up on a bike to avoid falling over: increase torque, but more increase in moment of inertia about axis on the ground, so decrease in angular acceleration.

Rotating bike wheel. How to tip it.

**Monday, 13 November; Gravity**

Bring: basketball and pen, for symmetry argument with spherical object; tennis ball.

Newton’s law of gravity (1687), N m2/kg2: magnitude of force diminishes with distance … mathematically, never goes to zero; physically, becomes so small that it can’t be measured. When I give you a problem on dropping an eraser, I don’t need to tell you where the Andromeda Galaxy is.

Two sources, superposition.

Spherical source: superposition argument, symmetry argument. Point at center.

Acceleration of gravity in terms of gravitational constant . When Henry Cavendish made the first accurate measurement of in 1798, he called it “Experiments to determine the density of the earth”.

Orbits: . Find expression for . “Kepler’s third law” (1619).

Tides: Due to Moon’s gravitational pull on water. But then one hump of water, rotate beneath, one high tide per day?? Think of two bodies, say Oberlin and Japan, with Oberlin closer to the Moon. To have same angular speed they need more force on Oberlin and less force on Japan, tie them together with a rope, rope will stretch and provide the needed forces, stretching gives rise to two humps of water and hence two high tides per day.

**Wednesday, 15 November; Fluid Statics**

Demo: tennis racket, paper plate

Fluid: material that can flow, although it might not be doing so right now. (Fluid statics.)

We live in a fluid. Hold out hand palm up. How can I hold up that huge column of air?

Pressure: “cut plane” is not imaginary.

Because of symmetry: (a) force is perpendicular; (b) pressure same regardless of orientation. (There are situations where orientation matters, like a flowing stream.) Hold up paper plate representing cut plane and rotate it to illustrate perpendicularity. Resolution of hand problem is same pressure above as below.

Density : mass/volume. Incompressible fluid model.

Variation of pressure with height: cut plane rectangular solid within cylinder, within flask, within writhing tube.

Buoyancy, Archimedes’ principle; iceberg (my wife Linda thought the 90% rule was just a metaphor for “you can’t see all aspects of a problem”).

Global warming denier: “All the ice floating in the Arctic Ocean could melt and it wouldn’t increase sea level!” True and irrelevant.

**Friday, 17 November; Fluid Flow**

Demos: tennis racket, sheet of paper.

Official demos: Hanging Light Bulbs, Bernoulli Tubes, Ball in Funnel, (sheet of paper), Velocity of Efflux

Steady, incompressible, frictionless flow. (Also irrotational.)

State Bernoulli’s principle:

Demo by blowing over a sheet of paper; one source of airplane lift; source of name “plane”.

**Monday, 20 November; Oscillation**

Demos: SHM on Air Track; Wilberforce Pendulum

The world is full of things that move. We’ve been concentrating on moving out a long distance: constant velocity, or constant acceleration, or constant force. But some things, like pendulum, come back where they started (swing your arm).

Example: cart on air track. If at equilibrium point, . “Hooke’s Law”, an approximation. Robert Hooke, of cell and gravity fame. Meaning (“stiff spring” versus “soft spring”) and units of spring constant .

Equation, in absence of friction: . Graph. If you started clock at a different point in the journey, you’d get some different sinusoidal pattern. Amplitude and period on graph. Show .

Dimensional analysis: Period could depend upon amplitude (longer path takes more time), spring constant , mass It is , sensible dependence on and , but independent of . Huh? Demo: larger amplitudes have faster speeds, two effects exactly cancel out. Miraculous.

What do you call it when frequency (tone) is independent of amplitude (loudness)? Harmony. Add to title “simple harmonic oscillation”.

On graph, sketch out , .

There are more complicated oscillations, demo with Wilberforce Pendulum. (*AJP* this month!)

Be thankful that our universe is both diverse and comprehensible.

**Wednesday, 22 November; Cancel – day before Thanksgiving**

**Monday, 27 November; Introduction to waves**

Demos: rope, lead-weighted rubber tubing; vertical slinky hanging from stand;

computer and film loop on “Nonrecurrent Wave Fronts”

Write: “Introduction to”; a week ago we talked about oscillations of one item in time; but we might have many items oscillating at different places; demo with rope and tubing and slinky; write in “Waves”.

Kinds of waves; film loop

Waves that don’t change shape; sine waves, wavelength and period, power delivered .

Big positive circle moving right, little positive circle moving left;

Big positive circle moving right, little negative circle moving left;

Big positive circle moving right, big negative circle moving left.

Superposition: total wave = sum of component waves

Next class: bring your musical instruments if you wish.

**Wednesday, 29 November; Superposition and standing waves**

Demos: lead-weighted rubber tubing attached to wall ring for jump rope; Chladni plates;

 standing waves on rubber tubing; assorted musical instruments

 (just a few horns, violin [202-06-C], stretched wire, organ pipes)

Superposition videos. (Usually not worthwhile.)

What if waves moving right and left are

 and ?

This doesn’t “speak to me” in the way that or or does.

Use and .

Graph. “Nodes”. Yes, but is this just math? Show demo.

Two dimensions: Chladni plate, circular then square.

What about three dimensions?

All musical instruments – violins, organs, drums, even the voice box – work by setting up standing waves and then letting some of that standing wave leak out of instrument so that listeners can hear it.

The richness of musical instruments –

the sweetness of the violin,

the brightness of the oboe,

the mellowness of the bassoon,

the throatiness of the clarinet,

the ethereal eloquence of the Native American flute, and

even the expansive range of expression of the human voice

 – all reflect the richness of standing wave patterns in three dimensions.

**Friday, 1 December; Two source superposition**

Demos: Interference of sound waves;

 red and green lasers and CAL sheet, projected onto left screen [105-01-D1]

Instead of looking at superposition of incoming and reflected waves, look at two sources.

For example sound. One source, all directions, two sources. Demo. Will superpose with “add up” or “cancel out” or “in between”. Word “interference”. Formula for far away (“Fraunhofer limit”). Can find wavelength not by direct measurement, but by looking at interference maxima and minima.

Light?? Do the demo!

**Monday, 4 December; Interference topics**

Demos: red laser and CAL sheet and grating, projected onto left screen [202-21-E5];

 sodium lamp; diffraction gratings for giving out

Sound rolling around Finney Chapel. NOT decay with distance, you can hear it all the way across Tappan Square.

Interference for length measurements.

From 1960 to 1983, the meter was defined 1,650,763.73 of the reddish-orange light emitted by krypton-86.

Gratings.

Babinet’s principle.

**Wednesday, 6 December; Interference from thin films**

Demos: soap film interference: with sodium light and with white light

**Friday, 8 December; Single-slit diffraction, end of waves**

Demos: sodium lamp, red laser and CAL sheet, projected onto left screen

 Poisson (Fresnel) bright spot

(1) Single slit diffraction (lakeport Cleveland)

(2) Poisson (Fresnel, Arago) bright spot

(3) Poisson bright spot for neutrons and molecules

**Monday, 11 December; Review**

A surprising conclusion from the train-car-latching problem: Energy dissipation fraction upon latching depends on mass ratio only, independent of initial velocity. Who would have guessed?

Problem with two speakers a distance apart: (a) let the problem speak to you, don’t look up an equation and force the problem into the equation; (b) use variables not numbers.

Error propagation: can be done simplistically.

Let the problem speak to you, don’t force it into a procrustean bed.