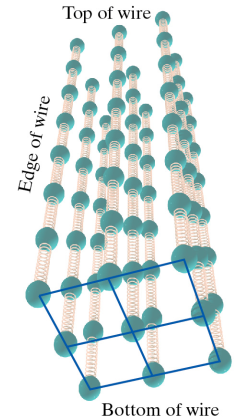
Dear Student,
It's 10 pm on a Friday night, and I'm sitting down to finally write this letter that I've been meaning to write for months now. So, as you read this and try to finish up those last few assignments or the entropy program (ahem), rest assured that we teachers procrastinate too.

A few years ago, I read a post about teacher who writes gorgeous parting letters to graduating seniors in his calculus class, and I said I'd really like to do that sometime for one of my classes when the time is right. I think it was way back in November when I realized the time was right—the past year teaching you and your classmates has been a true honor for me and one of the greatest joys of my now eighteen years of teaching. Like all procrastinators, I only wish I'd started a bit sooner.

I always write in my course descriptions, "Physics changes the way you see the world" and you might even remember that I often talk about "putting on your physics goggles." In this letter, I'd like to give you a gift of those metaphorical physics goggles. In my mind, I imagine they must stereotypically look something like this, but feel free to adjust them to fit you and your tastes.

You've earned these goggles—heck—you've crafted them with two challenging years of physics study. Now, it would be my honor to walk you through the owner's manual before you set off into the world. You probably know about the multitude of lenses in these goggles—with a flick, you can see the forces acting on tennis ball as you strike it with a racket, and the wonder of this brief interaction. Turning on a bit of slow-mo, you can see the strings in the racket exert a force 50 times greater than the weight of the ball, flattening it out like almost like a pancake and maybe you

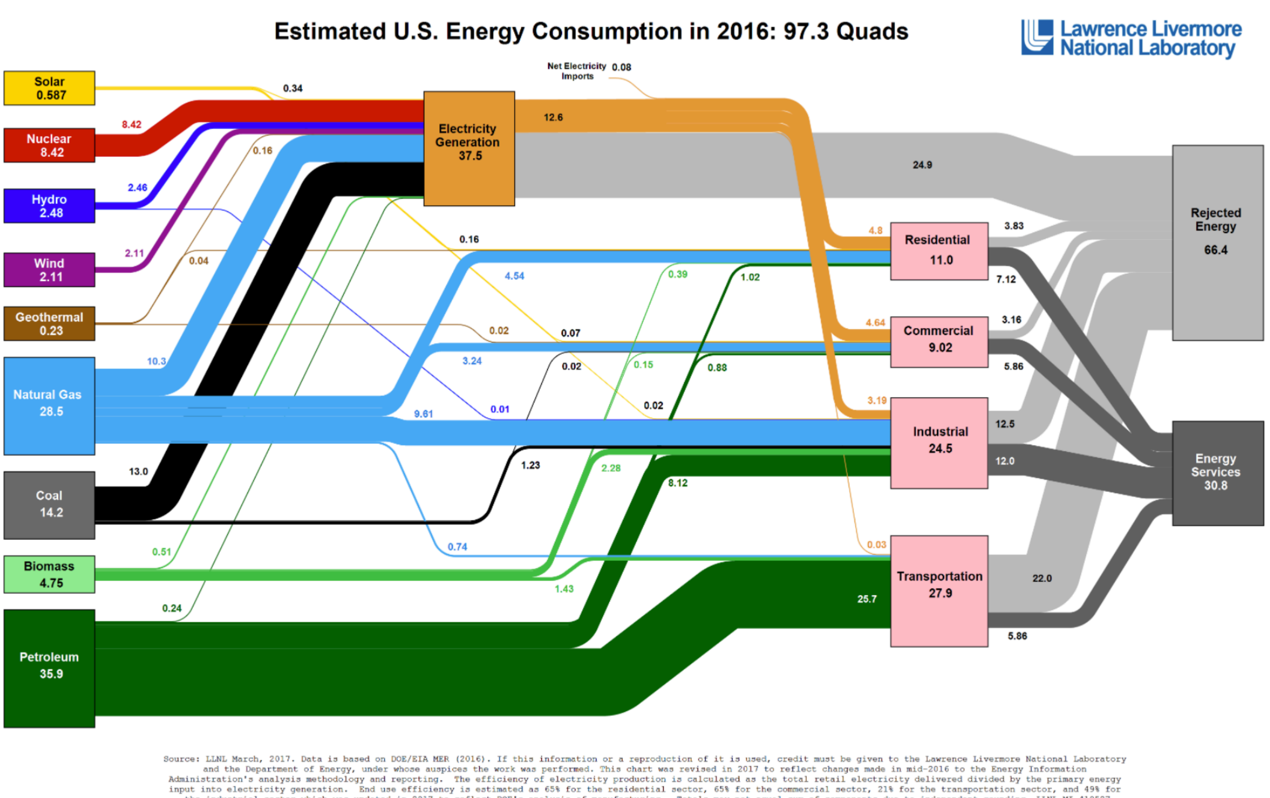
wonder just how much time the racket spends in contact with the ball. With your goggles, you can do that.



These goggles have the amazing ability to let you peer into worlds we will never be able to see with our eyes and come to amazing new discoveries. Hopefully, after our class, you'll never look at a simple cello or piano string in quite the same way again. As you turn that knob on the cello to tighten the tension, you can now imagine those little atomic springs stretching ever so slightly. And you might even wonder just how many springs there are in a cello string, or just how much each bond stretches when you give the tension peg half a twist. With your goggles you can do that, too.

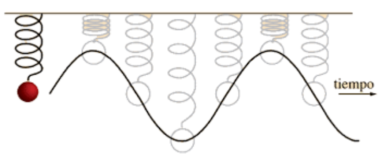
Your physics goggles are so advanced that they let you see things that don't actually exist at all, but that are among the most important and powerful ideas in our world. I'm talking about ideas like energy—a concept physicists invented almost 150 years ago and have been refining ever sense to make better and better predictions about the world around us. As you watch a pendulum swing back and forth and eventually come to rest, your goggles let you see the energy sloshing back and forth from kinetic to potential energy, with a small, steady trickle of energy leaking off to the random thermal energy caused the friction at the pivot and air. And if you wanted to predict when that pendulum would come to rest, your goggles can do that too.

Your goggles don't just work for tiny bits of energy in pendulums, they work for the enormous flows of energy that power our world. You can now see the ways in which energy flows throughout our civilization. You now see the 1.2 billion joules sitting in the gas tank of your car, and you can comprehend the 2.7×10^{19} Joules of petroleum it takes to power all the cars, trucks and the airplanes in the US each year. Your goggles let you see that 85% of the energy we use comes from fossil fuels, and with a bit of work, you can calculate that this this annually adds 3.8 billion tons of CO_2 (about 12 tons per person) to our atmosphere. So yes, your goggles have a handy feature that let you see what is likely the greatest challenge facing humanity. But wait—there's more—when you

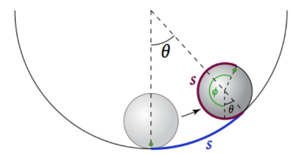


use your your goggles also let you see both the sadness and the opportunity that more than 68% of of the energy we used winds up as “rejected energy”, or E_{therm}, as we like to call it. Maybe your goggles will let you figure out how to develop a cheap and plentiful carbon free form of energy. Or maybe your goggles will let you extract a bit more useable energy and reduce that 68% wasted energy number—but your goggles should also tell you that we’ll never be able to get that number to zero, right?

Enough about big and complicated things; your goggles also have this powerful “simplify” mode—they let you see how the motion of a basketball free throw, the space shuttle orbiting the earth and a comet streaking around the sun are all essentially the same—the free fall motion of an object experiencing only the gravitational force. If you use your goggles enough, you’ll see this over and over—seemingly unrelated phenomenon turn out to be really just two different products of a simple ball and spring model, or two different solutions to a differential equation that looks like this:

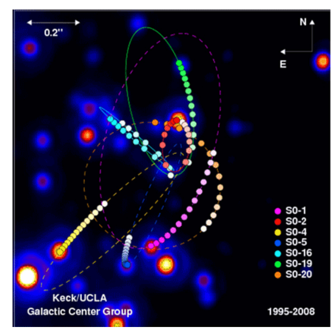


$$\frac{d^2x}{dx^2} = -\frac{k}{m}x$$



Many phenomena explained by a few ideas—I think you’ll find this motto inscribed on your goggles somewhere if you look closely enough.

This year, you upgraded your goggles with the computational engine that unlocked the “predict the future” powers. And yes, with a few lines of glowscript, and the momentum equation, you’ll find you can predict whether that soccer shot will go in the goal or the future position of the earth 10,000 years from now. Scientists before you have used these “predict the future power” even before the advent of computers to predict the return of comets, find the planet Uranus, and most recently, even discover the supermassive black hole (4 million solar masses) sitting at the center of our galaxy.



Most recently, you’ve discovered that these goggles have the power to let you contemplate truly vast things, like how many ways there are to store 10 Joules of energy in two 1 cm^3 blocks of iron touching one another, and why you’ll never, ever, ever, find anything other than 5 Joules of energy in each block. Answering this question lets you also understand why we’ll never see Humpy Dumpty jump reassemble and jump back up on that wall, or the room of a graduating senior spontaneously organize itself before graduating (even if we think of all the seniors for all time). Who knew that contemplating truly vast things like how you can arrange energy in a solid could give us insights into the nature of time?

At this point, you might begin to think your goggles are all-powerful. This is a common side effect of extended physics goggle use. A previous user once commented:

> *An intelligence which at a given instant knew all the forces in acting in nature and the position of every object in the universe–if endowed with a brain sufficiently vast to make the calculations–could describe with a* ***single formula*** *the motions of the largest astronomical bodies and the smallest atoms. To such an intelligence, nothing would be*

uncertain. The future, like the past, would be an open book.
—Pierre Simon Leplace (1749-1827)

Were he alive today, I think Leplace would certainly marvel at the "brain" within your iPhone as an intelligence beyond his imagination, still, our future predicting powers are woefully sad. That's because as you've also learned this year, our physics goggles do have some fundamental limitations—there are certain things, like the position and momentum of an electron, that we simply cannot know simultaneously with limitless precision. Knowing the location of an electron very precisely inherently increases our uncertainty about its momentum, and vice versa. And for many systems, like the turbulent flows of gases in our atmosphere small changes in the initial conditions quickly lead to big divergences means we'll likely never have a reliable 10 day weather forecast.

Still, the power of your goggles does require me to issue you a few warnings about their use. You likely don't need to be reminded that your goggles have been used by scientists before you to invent weapons of unimaginable horror. By converting just 1% of the rest energy of a few pounds of Uranium nuclei to kinetic and thermal energy, scientists created nuclear bombs capable of destroying entire cities.

A far more subtle way these goggles can cause harm is lulling scientists away from seeing the human story that is so essential to the process of science. They can blind into thinking that science exists outside of humanity, and cause us to ignore our own biases or to fail to appreciate the value of diversity and different perspectives. Dr. Prescod-Weinstein talked about this two years ago—there's a battle raging now in Hawaii between some astronomers who want to build a 30 meter telescope on Manua Kea, and the native Hawaiians who regard the mountain as a sacred space. We talked these same biases and blindness in our own unit on understanding why women are under-represented in physics. In very real ways, our goggles have served as blinders to seeing the ways in which the field of physics can often be indifferent to and sometimes even openly hostile indifferent to those who don't fall into the white male physicist stereotype, and this harms us all. I hope you'll keep working to add lenses to your goggles that help you be more aware of your own unconscious bias, and work to value diverse perspectives in whatever you choose to do.

Finally, the most wonderful thing about these goggles is not how powerful they are, but how incomplete they are. Richard Feynman, physicist extraordinaire, once said:

I was born not knowing, and have had only a little time to change that here and there.

There are so many things left to learn; you have a joyous time ahead of you as you customize these goggles to suit your purposes. Consider adding additional perspectives—humanities, political science, biology, music and art. Every field you learn has it's own set of goggles, and by combining them in new and interesting ways, you'll find inspiration all around you.

Take these goggles and use them often. I think you'll be surprised how often looking at the world through the eyes of a physicist can help you, and give you comfort that you can understand anything you put your mind to. When you computer fails to start up, or you find yourself struggling to figure out a complex project, it can be tremendously useful to break the problem down into smaller chunks, understand each of those chunks on its own, and then see how those chunks connect—this is what we've done all year long.

As your teacher, it's been my tremendous pleasure to see you try on these goggles and flourish as physicists this year—you have vastly exceeded my hopes for what we might do as a class, and helped me to improve my goggles as I've gained new insights into physics and more from your questions and ideas, and I thank you for your work, curiosity, patience, and kindness. Now, with bad google translated latin, I say "clelera reveles!"[1]

With very best wishes,

John Burk

ps. I can't leave without giving you one last question to think about—How might you estimate the atomic thickness of your signature? You might begin by assuming you write your name in pencil, creating a thin layer of graphite. The graphite in a pencil is a pure form of carbon consisting of many planar sheets of carbon atoms stacked atop one another. The carbon atoms have strong bonds within a planar sheet and weaker bonds between sheets and so one sheet can slide easily with respect to adjacent sheets, which explains why graphite is so useful as pencil lead. Can you devise an experiment to figure this out? (Physicists have measured the spacing between sheets of graphite layers to be 0.34 nanometers using X-rays).

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[1] I hope this translates to "make haste to discover or learn", but seriously doubt the power of Google Translate. Fun fact—the Latin word *celeritas (speed)* is why the speed of light is symbolized by *c*.