NEWSLETTER

ONTARIO ASSOCIATION OF PHYSICS TEACHERS (An Affiliate of the A.A.P.T.. and a charitable organization) November 2006

High School Physics

Lies My Physics Text Told Me

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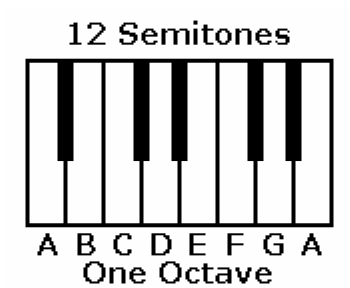
My grade 11 physics text told me that middle A on the piano is tuned to a frequency of 440 Hz. This is true. Four hundred and forty hertz is the international orchestral standard tuning for middle A. The text also told me that the next A above middle A makes an interval of one octave, that is, eight notes. The frequency doubles every time you go up an octave. This is also true.

What frequency would a piano tuner use for the A one octave above middle A? If you said 880 Hz, you would agree with my grade 11 physics text. You would also be quite wrong. If you tune a piano using a doubling of frequency for each octave, it is unplayable. How do I know this?



After signing the contract for my first paid position as a physics teacher, I decided to invest part of my salary in the purchase of a piano, a 1906 Mendelssohn upright grand. It was in poor condition, and I didn't have much cash, so I purchased some parts from a piano supply shop, and reconditioned the instrument, replacing the rather rusty strings, fixing broken hammers, and updating the old, yellowed ivory on the keys with bright, white imitation-ivory plastic.

When it came time to tune the piano, I smugly relied on my B. Sc. in physics to develop the procedure. I purchased a tuning hammer, borrowed a signal generator from my lab at the school, and used my Hewlett Packard scientific calculator to make up a table of frequencies using 440 Hz for middle A as a starting point. The scale used in western music is the equally-tempered scale. Each octave consists of twelve semi-tones, so the ratio of the frequencies for any two consecutive semitones is the twelfth root of two. I checked the middle few octaves with the table in my physics text, and the frequencies matched.

Forging ahead, I adjusted the signal generator for each key in turn, and tuned it to the calculated frequency.

Eighty-eight keys and three hours of careful tuning later, I sat down to try out my handiwork. Mouth watering, ears twitching, I poised fingers over the keyboard in a basic C chord pattern and played. The result was atrocious: atonal, sour, and thoroughly unpleasant. The piano was unplayable.

What had gone wrong? I swallowed my pride in my hard-won university degree, and slinked off to the local library, where I found a text on piano tuning. What I discovered amazed me: more lies from my physics text!

Let's return to the 440 Hz middle A. According to my physics text, the second harmonic is 880 Hz, the third is 1320 Hz, and so on. Lies! The second harmonic is more than 880 Hz, and furthermore, varies from one piano to another.

A vibrating string possesses a property called stiffness. One can see this in a plastic ruler. Take a 30 cm ruler, and it is fairly easy to bend. Cut it in half, and each half is much more difficult to bend. Cut a piece in half again, and it is almost impossible to bend. This property is called stiffness.

When a stretched string vibrates, the fundamental frequency, 440 Hz in this case, results from a standing wave with a single loop. The second harmonic arises from two loops in the standing wave. However, the stiffness of the half-string forming each loop is higher than the stiffness of the entire string. The frequency of the second harmonic is more than twice the fundamental.

When tuning a piano, the A above middle A must be tuned to the first harmonic of the A below it, not to twice the fundamental. Otherwise, it will cause a dissonant beat when the two notes are played simultaneously, as in a chord. This correction to the tuning is sometimes known to piano tuners as "octave stretch". Since it varies from piano to piano, each piano must be tuned in a custom manner. Old-fashioned piano tuners relied on a keen sense of hearing coupled with a number of rules of thumb regarding beat frequencies (continued on next page) to produce a pleasing compromise in the tuning of the strings.Younger piano tuners rely on electronic tuners as tuning aids. These electronic tuners can be programmed to employ different octave stretches for different makes and models of pianos.

Armed with these revelations, I retuned my piano using my ears rather than a signal generator. It sounded much better.

References for further information:
Piano Servicing, Tuning, and Rebuilding, Arthur A. Reblitz, The Vestal Press, Vestal, NY.
http://members.aol.com/chang8828/contents.htm, (an excellent online guide to the fundamentals of piano practice.)

The Demonstration Corner

Variable Tension in a Pendulum's String

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A very effective demonstration of a variable tension in a swinging pendulum can be performed using very simple equipment (Figure 1). Connect a large scale to a pendulum, pull it to the side and let go. As the pendulum swings the scale shows variable string tension values. The maximum tension will be observed at the bottom point of the swing (B). At this point, the mass will have its maximum speed and according to Newton's second law the string tension will exceed the pendulum's weight and will reach its maximum value: $T_B = mg + m\frac{v^2}{l}$. Notice that for all other points of pendulum's trajectory not only will the pendulum move slower, but also the tension and gravitational forces will not be aligned.

This demonstration can be turned into an interactive lecture experiment [1] using *Tracker: Open Source Physics Java Video Analysis Software* developed by Doug Brown at Cabrillo College [2] or using a video analysis feature of the Logger *Pro* software [3] and a video clip of the demonstration such as the one recorded by Doug Brown, the snapshot of which is shown on Figure 2.

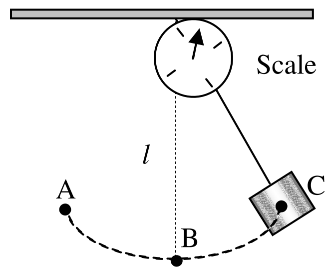

Figure 1: Demonstration – tension in the pendulum.

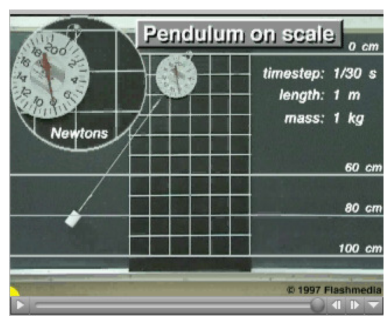

Figure 2: Video clip snapshot: tension in the pendulum.

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Submissions describing demonstrations will be gladly received by the column editor.

References:

1. Milner-Bolotin, M., A. Kotlicki, and G. Rieger, *Can Students Learn from Lecture Demonstrations: The Role and Place of Interactive Lecture Experiments in Large Introductory Science Courses.* Journal of College Science Teaching, 2007. **Accepted for publication**.
2. Brown, D., *Tracker: Open Source Physics Java Video Analysis*. 2006, Doug Brown: http://www.cabrillo.edu/~dbrown/tracker/.
3. Vernier Technology, *Logger Pro*. 2006, Vernier Technology: Portland Oregon.

Quantum Physics

Beyond the Two-Slit Experiment

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The usual vehicle for looking at wave-particle duality in high school is the two-slit experiment. However, there is another fabulous example sitting right smack in the middle of the grade-12 physics curriculum that is usually ignored. Polarization.

If unpolarized light is sent toward a polarizing filter - half of it will get through. This can be explained by referring to components of the electric field portion of the EM wave. Now, what happens if you send one unpolarized <u>photon</u> towards a polarizing filter?

I had never thought of this question until I attended the Einstein[+] workshop at the Perimeter Institute for Theoretical Physics in Waterloo*. The answer is that the photon either goes through or it doesn't - with a 50% chance for either possibility. There is no way to predict which of the two possibilities will occur - the process is intrinsically random in the same way that nuclear decay is random. Thus polarized light is a great example of the statistical nature of quantum events.

Now, so far, the polarized photon analysis doesn't seem terribly difficult or even all that interesting - but stick with me a bit longer. If light is sent towards two filters oriented at 90° to each other, we find that no light gets through. You can explain this by saying that the first filter stops the horizontally polarized photons and the second stops the 'vertical' photons. Or can you? If you put a third filter in between those first two and orient it at 45° to each of them, you find that light now gets through. You've added a third filter and the result is that <u>more</u> light gets through! How does quantum mechanics explain this? Suppose the first filter is vertically polarized. This vertical filter doesn't select vertically polarized photons - it causes some of them to become vertically polarized. This is an example of how measurements change the very thing we are measuring. This change is not due to sloppy experimental technique but is a core feature of quantum mechanics. Next the vertically polarized photons are sent toward a 45° polarizing filter and half photons of these photons pass through. Finally, these photons approach the horizontal filter. They aren't vertical photons anymore - they are 45 photons. Finally, these photons approach the horizontal filter.
Instead of all of these photons being blocked, half of them get through. In the end, ½ x ½ x ½ = 1/8, of the original photons pass through the three filters.

An examination of polarized photons can be used to deepen students' understanding of the fundamental ideas in quantum mechanics: intrinsic randomness, the connection between the observer and what is observed and wave-particle duality. It is also needed to understand quantum computing, teleportation and cryptography - three technologies that are in development now. Polarized photons are also needed to explain entanglement - considered by many physicists as being the <u>key</u> concept in quantum mechanics. If you want to learn more about these topics I highly recommend Jim Al-Khalil's book "Quantum: A Guide for the Perplexed". If you are going to STAO you should check out the talk by Damian Pope from the Perimeter Institute on " Teaching Quantum Physics via Hands on Games and very little Math" on Saturday Nov. 18, 2:30 –3:30.

I have been working on a game that allows students to explore entanglement. If anyone would like more information on this or if anyone else is working on introducing entanglement to their students, they can contact me at roberta@tevlin.ca. I'd love to exchange ideas.

* These are free weeklong workshops held at the beginning of the summer for teachers across Canada interested in bolstering their understanding of modern physics.

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Dave Doucettes PER Corner

An Introduction To P.E.R.

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Coming soon…to a Canada near you!

PER stands for 'physics education research', a PhD program amalgamating cognitive and educational psychology with physics education. This has become an option for M.Sc. (physics) graduates seeking a PhD path other than theoretical or applied physics. Researchers examine the ways in which physics is presented to students and compare pre and post test scores to determine conceptual gains. Primarily U.S. based, it is now poised to enter Canada – big time!

One of the pre-eminent supporters of this movement is Dr. Carl Weiman, 2001 physics Nobel prize winner. Dr.Weiman's passionate stance on the need for science education reform was poignantly presented to the U.S. House of Representatives Science Committee on March 15, 2006, where he began by stating flatly:

"*My main points are simple.*

1) Undergraduate science education is based on an obsolete model and is doing a poor job at providing the education that is needed today.

2) We now know how to fix it.

3) Until it is fixed, you can't fix K-12 science education."[1]

This committed and persuasive advocate for P.E.R. is coming to Canada, joining the University of British Columbia (UBC) faculty in January 2007. He was successfully lured by a $12 million dollar commitment to science education reform, his current primary research interest.

This unexpected coup may rattle some American physicists but it is a tremendous lift to those of us toiling to improve awareness of P.E.R. in Canada. It is easy to dismiss our impassioned pleas for change as naive enthusiasm but quite another to hear the compelling arguments of a Nobel laureate[2]. Thank you, UBC, for the boost to Canadian physics education and to Carl Weiman for adding his stature to PER reform.

In future articles, Dave will present examples of how P.E.R. plays out in his high school classroom. In the meantime, for a peek inside, see Dave at STAO session 2502 [Martial Arts can give you the H.O.T.S.] on Friday November 17. Yagottaloveit!

[1] http://www.house.gov/science/hearings/research06/march%2015/wieman.pdf

[2] For this and many other excerpts and broadcasts on Dr.Weiman, visit the following website: http://www.ubc.ca/announce/

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