Science-1A Lab: Week-8, Friday, March 5, 2021

On Wednesday, you saw the "Our Friend the Atom" program which included an introduction to nuclear physics. Our main study of nuclear physics will continue during the last few weeks of the course. That show was also a good start for the chemistry part of our course. For now, however, I'll toss out some physics things I skipped.

Boy Breaks Wine Glass with Voice
https://www.youtube.com/watch?v=sH7XSX10QkM

This is a great example of a kid on the way to becoming a scientist. The straw is there to visually indicate when the resonant frequency is found. Once the voice is at the resonant frequency, the glass will vibrate with increasing amplitude until it breaks.

I hope you see the analogy to how a child pumps up the amplitude of a swing.

How to make a singing glass. Experiment
https://www.youtube.com/watch?v=yPsCcrwvZ3o

I do this each semester in class. When I offer it to students to do, half are able to get it to work, but others are too embarrassed to keep trying long enough. It takes a very light touch and steady circular motion, and works better with a damp finger. It usually takes a while to get a hang of it, but once mastered, becomes pretty easy.

It takes a quality glass with a very uniform thickness in order for it to have what is called a high quality factor Q for ringing. If you gently tap the edge of the glass and it rings for a few seconds it has a high Q. A poor quality glass will not ring well and is likely to not work well for this demonstration.

The rim of the glass is like a bell and will ring at its resonant frequency. How does a steady motion of a finger pump the glass rim at its resonant frequency? Children pumping a swing do so by intentionally synchronizing their pumping with the swing's frequency, but the person controlling the finger doesn't sense the motion of the rim well enough to synchronize with it.

The finger, however, imperceptibly sticks and breaks loose repeatedly in response to the slight motion of the rim. When the vibrating rim moves in the same direction as the finger, the finger briefly sticks to the glass and adds a slight amount of energy into the vibration. The glass then breaks loose from the finger when it does its return motion. That causes the sticking and breaking loose to become synchronized with the vibrations.

The screeching of tires on a road or finger nails on a blackboard both involve a similar repeated sticking and releasing action.

Let me know if you try this and get it to work.

I often stress how learning the physics of one situation, like a child pumping a swing, helps in understanding a bunch of other related things. Think about how a violin bow is able to drive a violin string to resonance, blowing past the end of a bottle can drive an acoustic resonance in the bottle, and how the Tesla coil spark gap sparks drove the electrical resonance of its high-voltage coil.

The more physics you know, the easier it is to learn more.

What is Quantum Tunneling, Exactly? 10 min 5 s
https://www.youtube.com/watch?v=WPZLRtyvEqo

I spent 20 years doing experiments using a (quantum) tunnel diode semiconductor device to power electrical resonators that could be configured to measure exceedingly small (0.001 ppm) changes physical quantities.

Colleagues of mine made superconductor-thin insulator-superconductor sandwiches known as Josephson Junctions that used quantum tunneling to replace batteries as the national voltage standard. Those devices obey the formula $f=\frac{2e}{h}V$ that convert a voltage *V* to a frequency *f*. This depends on Plank's constant *h* and the charge of an electron *e* having values known with an accuracy of about 0.01 ppm.

The emission of subatomic particles called alpha particles also depends on quantum tunneling.

The Strange, Frictionless World of Superfluids 7 min 10 s
https://www.youtube.com/watch?v=zJblFBwqjPo

This is a good summary about liquid helium. For 25 years, I used liquid helium to cool my experiments. Numerous times when using the required liquid nitrogen-cooled double-walled glass containers called Dewars, I would watch the frantic bubbling of the liquid helium abruptly cease as it cooled below 2.172 K and became a superfluid. My Ph.D. dissertation was about measurements on the properties of liquid helium down to 0.3 K. It is absolutely amazing stuff.

The Physics of superconductors 8 min 47 s
https://www.youtube.com/watch?v=h6FYs_AUCsQ

This is a pretty good short introduction to the very weird behavior of superconductors. When Kamerlingh Onnes first saw a metal become superconductive as he cooled it, he was sure that the experiment had a short circuit. After repeated tests, he had to conclude that the metal had truly lost its electrical resistance. This happens to lead and tin, but not to metals that are the best conductors at room temperature – copper, silver, and gold. The lattice vibrations the make lead and tin poor conductors at room temperature help them become superconductors at 7.19 K and 3.72 K, respectively.

When studying another very strange quantum phenomenon called the Quantum Hall Effect, I used superconducting magnets with fields as strong as 18 tesla, 36000 times stronger than the Earth's magnetic field. We had to make sure that no visitors had heart pacemakers that could be disrupted by our magnet when it was on.

How a Laser Works 4 min 52 s
https://www.youtube.com/watch?v=oUEbMjtWc-A

This is the most appropriate explanation I could find for Science-1A. It leaves out lots of practical details, but conveys the basic idea.

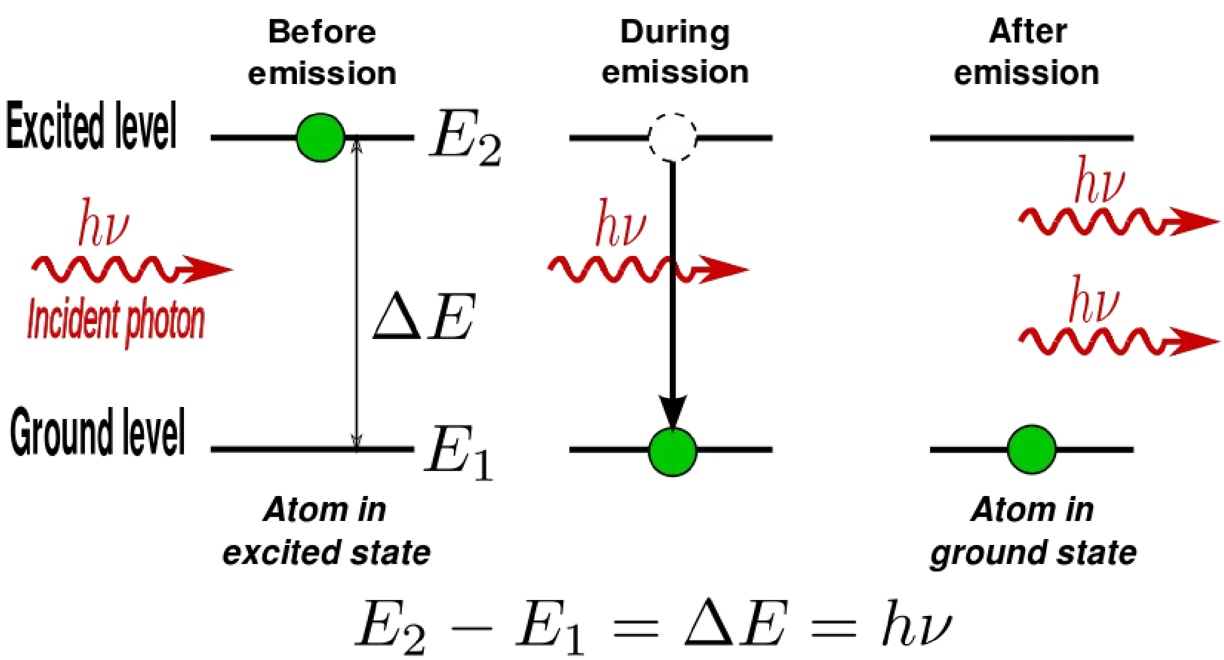
I'd like to add a bit more. Consider the following facts:

1. The electrons in atoms have discrete energy levels.
2. If its electrons are at the lowest possible level E_1 , called its ground state, the atom remains unchanged.

3. If the next higher energy level at an energy E_2, is empty (has no electrons), a light photon with an energy $E_{photon} = \Delta E = E_2 - E_1$ striking the atom can kick an electron from E_1 up to E_2. This is called **light absorption**. The atom now has the photon energy.
4. Normally, an electron at energy E_2, will spontaneously fall back down to E_1 and emit a photon with an energy identical to that of the photon that was absorbed. This is called **spontaneous emission** of light.

The next part is the magic the makes lasers possible.
It was proposed by Einstein in 1917, but not demonstrated until 1953.

5. If spontaneous emission of light is delayed, and the atom is struck by a photon with precisely the energy $E_{photon} = \Delta E = E_2 - E_1$, that photon will **stimulate** the atom to immediately emit its photon so that there are then two identical photons. Both photons will have the same frequency, phase, polarization, and direction. This is called **stimulated emission of light**. The drawing below shows this process with the E_{photon} represented by a more traditional expression $h\nu$:



If there are many atoms ready to emit, this will cause a chain reaction with all of them producing identical photons at once – a laser beam.

The word laser is an acronym for

Light **A**mplification by **S**timulated **E**mission of **R**adiation

You may need to remember this acronym during a future quiz or test.