“Science You Can See (and Hear)” Resources

The 31st Annual Faraday Lecture
Tuesday and Wednesday, November 13 and 14, 2018
Soldiers and Sailors Memorial Hall
Presented by Colin Gould and Gregg Gould

Below you will find more information on each of the demonstrations from this year’s Faraday Lecture. There are explanations and links to videos, products, building instructions, etc. Also, italics is used to call attention to specific vocabulary words associated with particular demonstrations. We hope you find this useful and we would be happy to field any questions you might have. Please reach out to us at the following:

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- Part 1 – Magnetism and Electromagnetism
  - Permanent magnets – used a variety of neodymium rare earth magnets which are exceptionally strong.
    - Used a volunteer to show the strength of a fishing magnet (400 lb lift strength) by lifting the volunteer using safety harness and winch. (Shop for “fishing magnets” on Amazon if you want to purchase one.)
      Once volunteer had been raised and then lowered, showed how difficult it was to remove the permanent magnet from the mating plate. Also showed that the magnet had no attraction to the aluminum in the ladder.
    - Talked about paramagnetic materials (anything with unpaired electrons) vs. diamagnetic materials (anything with no unpaired electrons). This is nicely detailed in a document available from Flinn scientific (https://www.flinnsci.com/api/library/Download/a3b9ed951e074396b322a060e05cb9a2)
      Also talked about how ferromagnetism occurs in certain materials where they preferentially magnetize along a particular axis forming magnetic microcrystalline grains. Permanent magnets are manufactured in a powerful magnetic field thus aligning the magnetic axes of all microcrystalline grains.
    - Demonstrated the diamagnetism of liquid nitrogen vs. the paramagnetism of liquid oxygen. This is shown nicely in this video: (https://www.youtube.com/watch?v=KcGEev8qulA)
    - Looked at a couple of mixtures containing black iron oxide powder which is ferromagnetic. One mixture was magnetic “therapy putty” (silicone putty with black iron oxide mixed in – a little more than 1 tablespoon of iron oxide per ounce of putty) https://www.instructables.com/id/magnetic-silly-putty/ .
      The other mixture was *ferrofluid* which is a mixture of black iron oxide powder, surfactants and solvent. The ferrofluid develops wild looking spikes when placed in a strong magnetic field. Ferrofluid can be purchased at Amazon. A 4 oz bottle costs about $35 and is plenty to show the spikes. (https://www.amazon.com/gp/product/B00126LYAG/ref=oh_aui_detailpage_o01_s00?ie=UTF8&psc=1

Here's a link to an entertaining video that shows the behavior of ferrofluid and also describes a recipe for homemade ferrofluid.
https://www.youtube.com/watch?v=L8cCvAITGWM
Note that black iron oxide is available at Amazon (https://www.amazon.com/Black-Iron-Oxide-Synthetic-Pounds/dp/B00IDD6Y06/ref=asc_df_B00IDD6Y06/?tag=hyprod-20&linkCode=df0&hvadid=167150018785&hvpos=1o1&hvnetw=g&hvrand=8076493762656584494&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9005959&hvtargid=pla-313195140140&psc=1). The synthetic black iron oxide is a finer and more uniform powder which is desirable for these applications.

- Electromagnetic induction
    - Stretched a thin insulated wire (about 28 gauge in thickness) lengthwise under some tension along a table. Positioned a neodymium magnet about 5 mm from the wire and then connected the wire to a D-Cell battery. The wire will either move toward the magnet or away from the magnet. Reverse the battery poles and the wire should move the other direction. This demonstrated *Faraday's Law* - moving charges generate (induce) a magnetic field.

    - Volunteers then made electromagnets using about 3 feet of insulated 28 gauge wire coiled around various metallic cores. Each electromagnetic was tested by powering it with a D-cell battery to see how many small washers it could pick up. The strength of the electromagnet depends on the number of turns of wire around the core as well as on the nature of the core. Iron is the only core that gives rise to noticeable magnetism. It's also interesting to see that the magnetism is turned on and off by turning on and off the power to the wire coil.

    - Extended this concept of coiling wires around an iron core using an electromagnet tug-of-war device. This consisted of an iron plate with an eye-bolt attached and an electromagnet powered by a D-cell battery, also with an eye-bolt on the end. A long rope was attached to the eye-bolts and two volunteers were unable to pull the metal plate off the electromagnet once the circuit was complete. When the circuit was broken, the two halves of the apparatus simply fell apart. The apparatus used here was quite old and the nearest thing currently available appears to be: https://www.amazon.com/Eisco-Labs-Iron-Clad-Electromagnet/dp/B00B5F4U96#feature-bullets-btf which is powered by 4 C-cell batteries.

    - Next demonstrated how a magnet dropped past wire coils connected to small LEDs would induce an electric current. This is another version of *Faraday's Law*. Not only does moving charge induce a magnetic field, but also, a moving magnetic field near an electrical conductor induces an electric current.

    - Used a small demonstration apparatus to show how a generator works. A hand crank was turned to move coils of wire past permanent magnets and an electric current resulted. The current was able to light a small lightbulb. One can notice that there is greater resistance to turning the crank when the circuit is complete compared when the circuit is open. This push back or resistance was further investigated in the next demonstration.

- Two sections of tubing of equal length and diameter, one a PVC (plastic) tube and the other a copper tube were contrasted. The tubes were held vertically, side by side a few feet apart and identical strong magnets were dropped simultaneously down the tubes. The magnets in the PVC tube drop straight through with no resistance. The magnets in the copper tube take several seconds to descend, clearly meeting with some resistance. This is explained by combining several of the principles revealed in earlier demonstrations. It was shown that a moving magnet creates an electric current in a conductor and it was also shown that a current induces a magnetic field. Thus, as the magnet drops down the copper tube, it induces a circular current around the tube. That circular current creates a magnetic field and that induced magnetic field opposes (repels) the permanent field of the moving magnet, thus slowing the magnet's descent. This induction of an opposing magnetic field is called *Lenz's Law*.

- Magnetic Braking was demonstrated by swinging a strong spherical magnet at a solid slab of copper. Lenz's Law applies here which means the induced magnetic field in the copper slab repels the permanent magnet, thus slowing it down. See other examples of this effect here: (https://www.youtube.com/watch?v=sENgdSF8ppA)

- The culminating demonstration for the first half of the show was the jumping ring apparatus (Elihu Thomson apparatus). This is apparatus had about 100 feet of 18-gauge insulated wire wrapped tightly around a core that is about 16" in length. The core is a bundle of some 300 straight sections of cheap, painted steel coat hangers. The ends of the wire coil are connected to 110 V through a Variac (variable transformer) which controls the amount of current running through the coil. When powered up the current in the coil induces a magnetic field in the iron core. The magnetic field in the iron core will induce an electric current in any completed, conducting loop placed over the core. The following things were shown:
  + a light bulb connected to a coil of about 10 loops of wire will light when placed over the iron core. The higher the power applied, the brighter the light, and the lower on the core the light is placed, the brighter it will light.
  + Copper and aluminum rings placed over the core will levitate with the appropriate applied power. This is because the current induced in the ring creates a magnetic field that opposes the magnetic field in the iron core of the device – Lenz's Law as described above in the tube race demo.
  + A copper or aluminum ring which has been cut so that it is no longer a complete loop will not levitate.
  + Using an abrupt pulse of the maximum power that will not overload the electrical circuit will cause the copper ring to be propelled about 4 feet in the air. The aluminum ring, due to its lower density (mass) will be propelled about 8 feet in the air by the same pulse.
  + An aluminum ring cooled in liquid nitrogen will be propelled nearly 20 feet in the air. This is because the conductivity of metals increases as temperature is decreased. The increased conductivity creates a stronger opposing magnetic field so a stronger repulsion occurs.
  Here's a link to a video which shows several of these effects:
  https://www.youtube.com/watch?v=T9PflsLZqY8
  There are lots and lots of these videos out there. Search "jumping ring apparatus" or "Elihu Thomson apparatus".

- Part 2 – Sound
  - Vibrations
    - Start by grasping a 3-foot metal bar and striking it with a bolt. A clank is heard and the person holding the bar feels the vibration. The audience members hear the clank but cannot feel the vibration in the bar.
      The vibration in the bar causes ripples (*sound waves*) in the air which propagate the sound to the audience member's ears.
      + If the bar is held with two fingers exactly in the center and struck, the sound produced is clearer and persists longer – the bar rings with the sound.
      + Bars of different lengths or different composition produce different *pitches*.
    - Next a tuning fork is struck and held up to a microphone to hear the sound. The fork is struck again and plunged quickly into a cup of water. The water splashes briefly, allowing one to see the vibrations of the tuning fork ends.
      + The tuning fork and the bar used earlier are compared - both vibrate but the rod vibrates only briefly unless held in the exact center. The tuning fork is designed to be held exactly in the center, so the tines of the fork are free to vibrate.
      + Next the tuning fork is bolted to a wooden box which allows the tuning fork to resonate. The vibrations in the tuning fork couple into the wooden box, creating a much louder sound. This is the phenomenon of resonance. The vibrating tuning fork creates a *standing wave* in the wooden box which amplifies the vibrations, creating a sound of higher volume.
      + The phenomenon is demonstrated with a coffee can moose call (https://www.youtube.com/watch?v=KabHOeRCwjA) and a vuvuzela. In each case vibrations are coupled into a resonance chamber to produce an amplified sound.
  - Standing Waves
    - Used a large scale standing wave generator to define *wavelength*, *frequency*, *amplitude*, & *nodes* in standing waves. Here's a link to a video of a smaller scale standing wave generator (https://www.youtube.com/watch?v=-gr7KmTOrx0)
    - The standing wave generator created *transverse* (sinusoidal) waves but sound travels via *compression waves*. A slinky on a horizontal pole is used to demonstrate compression waves. Introduced the words *compression* and *rarefaction* to describe compression waves.
      The first 3:30 of this video does a nice job explaining the fundamentals of waves and the difference between transverse waves and longitudinal (compression) waves: https://www.youtube.com/watch?v=TfYCnOvNnFU
    - The phenomenon of standing waves and resonance was shown using a singing pipe. A metal screen within a large piece of pipe held vertically is heated with a torch. When the torch is removed, the hot air around the screen rises through the tube to create vibrations that resonate within the tube. Here's a Steve Spangler video showing singing pipes, one of which is made from glass so you can see the metal screen. (https://www.youtube.com/watch?v=LCEvzU9sh4Y)
      + Resonance can be created in large diameter pipes (4" drain pipe of about 8' in length) by holding the pipe vertically over a large Bunsen burner (Fisher burner). The pitch of this singing pipe is quite low because of the large diameter and long length.

  - The final few demonstrations made use of audio speakers. This makes for a nice culmination of the demonstrations because audio speakers operate using the principles of electromagnetism to generate sound (a stream of compression waves).

An audio speaker consists of a permanent magnet which interacts with a wire coil (called a voice coil). Electric current of varying frequency is driven through the coil which induces a magnetic field that oscillates at the same frequency as the frequency of the electric current. The voice coil is connected to the speaker cone which is the cardboard that is most visible as you look at the front of a speaker. The oscillating magnetic field induced in the voice coil interacts with the permanent magnet in the speaker causing the voice coil and speaker cone to vibrate up and down. The moving speaker cone creates compression waves in the air that emerge from the speaker as sound waves. Here's a link to a video that explains this with some nice diagrams. https://www.youtube.com/watch?v=048tBZMt3eY

- Demonstrated the action a speaker using an automobile subwoofer and a frequency generator at a frequency of about 5 cycles per second. This is a subsonic frequency (below our ability to hear) but such a low frequency was useful here because you can clearly see the speaker cone pulsing in and out. As the frequency is slowly increased, sound emerges from the subwoofers as audible frequencies (about 20 Hertz and above) are reached.
  Here's a video showing a similar effect:
  https://www.youtube.com/watch?v=vESzcq25Ev8
- We had hoped to be able to have the subwoofer speakers pulse a pair of 5 gallon bucket smoke filled air cannons to demonstrate that the speaker cones move air as they vibrate. Unfortunately we could not get this to work as cleanly as we would have liked so instead of using the subwoofers we just filled the air cannons with smoke from a fog generator and generated smoke rings by hitting the rubber diaphragm on the 5-gallon bucket.
  Here's a link to a video showing how to build and operate a 5-gallon bucket air cannon: https://www.youtube.com/watch?v=hNjY9rZOnR4
- Two dimensional standing wave patterns were demonstrated using Chladni plates activated by an audio speaker connected to a frequency generator. Background information on Ernst Chladni who first created these plates and observed the phenomenon over 200 hundred years ago can be found here: https://en.wikipedia.org/wiki/Ernst_Chladni
  Here's a video showing a number of 2-D standing wave patterns on Chladni plates: https://www.youtube.com/watch?v=1yaqUI4b974
  Here's a video link that shows how to build a Chaldni plate with an audio speaker: https://www.youtube.com/watch?v=hKmPc0Q0kKg

- The grand finale was the Ruben's tube. This was a 10' long piece of 4" diameter metal electrical conduit into which a row of small (one-sixteenth inch) holes had been drilled every half-inch on top of the tube. One end of the tube was closed off with a solid barrier and the other end was closed off by clamping a stretched nitrile glove over it. An audio speaker is then fixed over the end with the nitrile glove so that sound waves from the speaker will make the stretched glove vibrate. Through a port in the bottom of the tube, propane gas is flowed from a gas grill propane tank. After a moment or two the gas has filled the tube and begins to emerge from the holes in the top. A flame held to the small holes will ignite them, creating a long straight row of candle-sized flames of approximately equal height.
  Here's a link to a video that describes a Ruben's Tube and shows standing wave patterns: https://www.youtube.com/watch?v=pWekXMZJ2zM
  + First, the frequency generator is used to pick resonant frequencies for the tube. When a resonant frequency is reached, the flames trace out a sine wave with a

wavelength corresponding to the resonant frequency wavelength. The sound waves within the tube are standing compression waves. At the points of compression, the gas pressure is higher and so the flame above this region is taller. At points of rarefaction, the pressure is lower and the flame height above these regions is lower. The net effect is a sinusoidal variation in flame height. Different resonant frequencies yield sine waves of varying wavelength in the flames.

+ To finish off the demonstration short samples of a playlist of songs are played through the tube. Since music consists of a mixture of many frequencies standing wave patterns are generally not visible but the flames respond strongly to bass beats and volume changes. Bass beats and increased volume cause high pressure throughout the tube and flame height increases dramatically. Sometimes, the pulse of high pressure is enough to extinguish the flames. Here's a link to a video of segments of various songs played through a Ruben's Tube: https://www.youtube.com/watch?v=gpCquUWqaYw