Apparatus Competition

2023 Summer Meeting of the
American Association of Physics Teachers

AAPT PHYSICS EDUCATION® **2023** SUMMER MEETING
July 15–19, Sacramento, CA

Sponsored by the
AAPT Committee on Apparatus

Prizes are generously provided by

PASCO®

Apparatus descriptions also available at:
http://www.aapt.org/Programs/contests/apparatus.cfm

Table of Contents

Apparatus Competition Entry Form
2023 AAPT Summer Meeting
Sacramento, CA

Name: Sean Albiston

Institution: UofMN School of Physics and Astronomy

Address: 116 Church St. S.E.

Minneapolis, MN 55455

Phone: 612-625-3598

Fax:

E-mail: albis001@umn.edu

Support required for apparatus:

Can this apparatus be constructed for under \$100?   yes ■ ***   no ☐

***If yes, you must also provide a materials list with your apparatus description including prices and vendors of each item. Your apparatus will then be considered for both the unlimited cost and the low cost categories of the competition. Please see additional rules for the low cost category.

Approximate size (width and depth of table and/or floor space) .7m x .7m of table space

Does this apparatus require Electrical Power?   yes ☐   no ■

Will you be present to set up your apparatus?   yes ☐   no ■

 If no, who will be setting up the apparatus? Paul Noel (thanks for your help!)

 (It is possible for the apparatus to be shipped to the meeting and then setup by the competition director. But be sure to make prior arrangements with the competition director before doing so.)

When do you plan to set up your apparatus (on Sunday July 15)?

 12-3 PM ☐   I need to arrange a different time (contact the competition director). ☐

What day do you plan to take down your apparatus? It is preferred that all apparatus be displayed until Wednesday, July 19. Wednesday, noonish
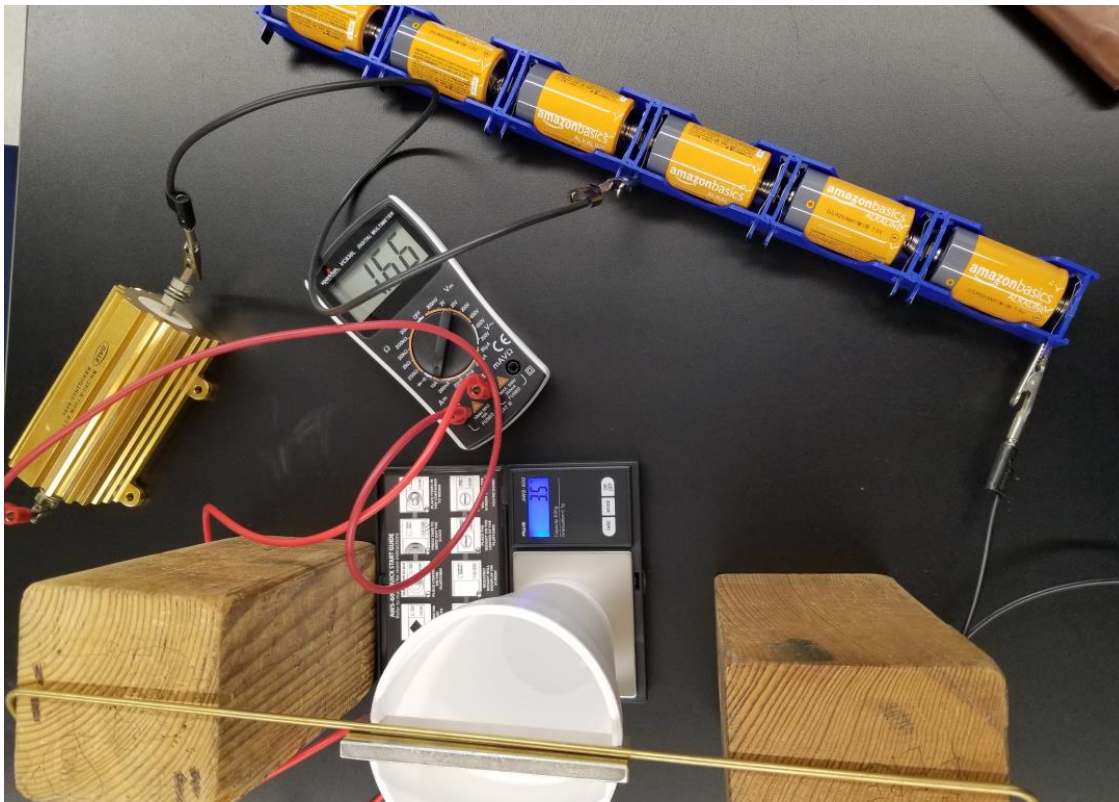
Other support needed for the proper operation of this apparatus:

LOW COST Magnetic Force on a Current setup:

- CMS Magnetics SKU:NB047-45N Block Magnet N45 4x1x1/4" Block Neodymium Magnet **$11.76**
- Weigh Gram Scale 600g x 0.1g Amazon **$9.99**
- Sparkfun DMM TOL-12966 Mouser Part #474-TOL-12966 **$14.95**
- 5 x Sparkfun banana cables CAB-00507 Mouser Part # 474-CAB-00507 4.95x5 **$24.75**
- LEIFIDE 8 Pieces D Cell Battery Holder Series or Parallel Storage D Size Battery Case Physical Science Plastic D Battery Holder Box Container, Blue Amazon **$10.99**
- 6 x Mueller Test clips Alligator BU-60 Mouser Part # 548-60 .50x6 **$3.00**
- 2ohm 45 watt resistor HS50 2R J Digi-Key Part # HS502RJ-ND **$4.12**
- Brass Rod – McMaster-Carr 300 mm Lg. 3.5 mm Dia #88605K49 **$6.01**
- 2 x 7" 4x4 Wood blocks out of 4 in. x 4 in. x 8 ft. Untreated Douglas Fir Dimensional Lumber Home Depot $12.48 *The spare foam cups from the 25pack listed below could also be used stacked appropriately. Less than $1.50 per 7" length **$3.00**
- 20 Oz Disposable Foam Cups (25 Pack), White Foam Cup Insulates Hot & Cold Beverages Amazon $16.99 per 25 or 16.99\25 **$0.68**

Total listed is $89.25

Note: The power resistor shown is 120W, included is a 50W 2ohm version (to keep the battery holders from smelling up the AAPT conference).
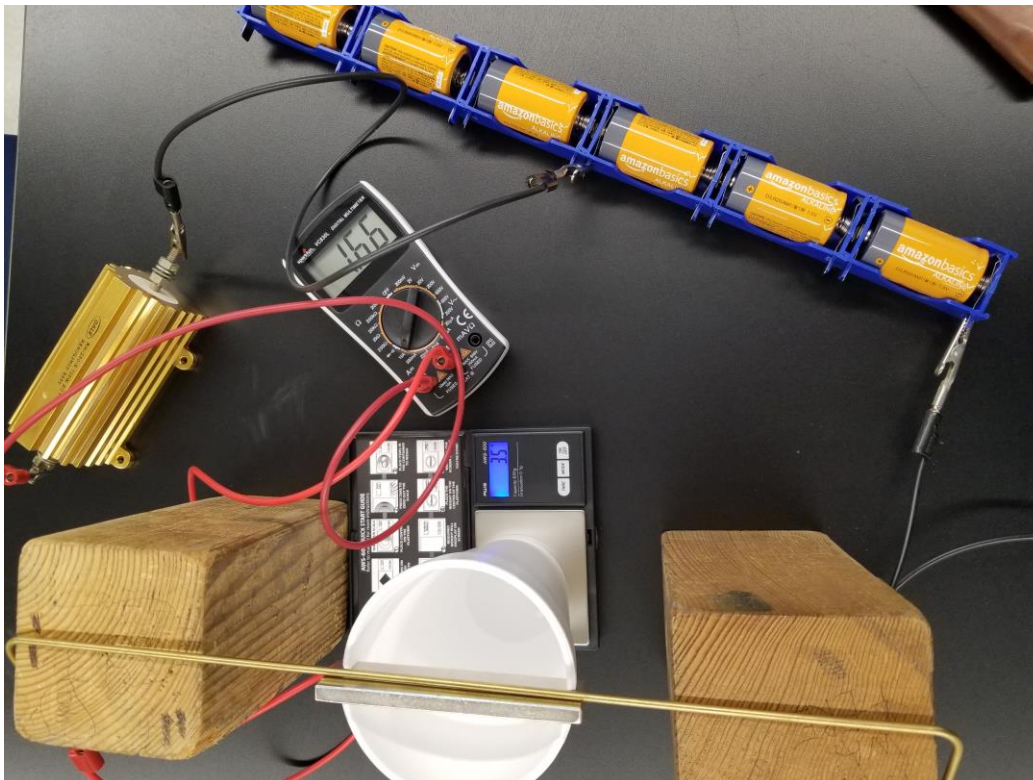
LOW COST Magnetic Force on a Current setup:

- CMS Magnetics SKU:NB047-45N Block Magnet N45 4x1x1/4" Block Neodymium Magnet **$11.76**
- Weigh Gram Scale 600g x 0.1g Amazon **$9.99**
- Sparkfun DMM TOL-12966 Mouser Part #474-TOL-12966 **$14.95**
- 5 x Sparkfun banana cables CAB-00507 Mouser Part # 474-CAB-00507 4.95x5 **$24.75**
- LEIFIDE 8 Pieces D Cell Battery Holder Series or Parallel Storage D Size Battery Case Physical Science Plastic D Battery Holder Box Container, Blue Amazon **$10.99**
- 6 x Mueller Test clips Alligator BU-60 Mouser Part # 548-60 .50x6 **$3.00**
- 2ohm 45 watt resistor HS50 2R J Digi-Key Part # HS502RJ-ND **$4.12**
- Brass Rod – McMaster-Carr 300 mm Lg. 3.5 mm Dia #88605K49 **$6.01**
- 2 x 7" 4x4 Wood blocks out of 4 in. x 4 in. x 8 ft. Untreated Douglas Fir Dimensional Lumber Home Depot $12.48 *The spare foam cups from the 25pack listed below could also be used stacked appropriately. Less than $1.50 per 7" length **$3.00**
- 20 Oz Disposable Foam Cups (25 Pack), White Foam Cup Insulates Hot & Cold Beverages Amazon $16.99 per 25 or 16.99\25 **$0.68**

Total listed is $89.25

Note: The power resistor shown is 120W, included is a 50W 2ohm version (to keep the battery holders from smelling up the AAPT conference).

Use of Apparatus:

Exploration

Zero the scale and connect the batteries to complete the circuit by clipping to the selected tab/voltage along the series of batteries. Adjust the current through the rod by clipping to the battery holder tabs in sequence. Do you see the reading on the scale change? According to this change, what is the direction of the force on the magnet? Hence, what is the direction of the force on the current-carrying brass rod? Note the direction of the current through the rod. Knowing the direction of the force on the rod, what must be the direction of the magnetic field of the magnet at the location of the rod, and, thus, is this side of the magnet a south or north pole? Switch the current leads at the battery supply. Are the scale readings what you expect? Finally, vary the distance between the magnet and the brass rod (anywhere from nearly touching the rod to up to a centimeter away). How does this affect the force measurements?

Measurement

Based on your exploration, pick a distance of the magnet from the brass rod and measure the scale readings for enough currents so that you can determine the trend between current and magnetic force. Repeat these measurements when you reverse the current by switching the leads at the battery supply. Repeat this for a couple more distances (which you should record) between the magnet and the brass rod.

Analysis

Convert your scale readings to force measurement and graph the force on the current-carrying rod as a function of current for each magnet-rod distance. Fit lines to these plots manually (varying the slope of the line) so that you can determine the uncertainty in the slope of these lines. What does the slope correspond to?

Extract the magnetic field (and its uncertainty), knowing how the magnetic force on a current depends on the current, for the different magnetic-rod distances. (Here, you need to estimate the length of the current-carrying rod that lies in the magnetic field of the magnet.) Finally, plot the magnetic field of the magnet as a function of the distance from the magnet. Do you see a trend in the magnetic field strength of the magnet as a function of the distance from the magnet? Can you quantify this, e.g., is the field proportional to some power of the distance from the magnet that the field is measured? (Note, far from magnetic dipoles, the field is inversely proportional to the cube of the distance from the dipole, as you'll explore in a later lab. But this may not be the case near a dipole.)

Introduction: Magnetic Force on a Current

Magnetic forces can act on electric charges moving through a magnetic field. Hence, magnetic fields are often used in applications in which moving charges are deflected (e.g., in electron microscopes and particle accelerators). Since an electric current comprises moving charges, magnetic forces also act on electric current in magnetic fields, and are used in applications such as electric motors, where magnetic forces cause coils carrying electric currents to spin.

In this lab, we will investigate how the magnetic force on a current carrying wire depends on the current amplitude in the wire, the strength of the magnetic field, and the length of the current carrying wire.

You have a dc power supply, cables, a brass rod to carry the current, a digital scale, wood blocks, a strong magnet, and a 20oz Styrofoam cup to place on the scale and on which the magnet can be set into.

Before you start

Read: Halliday & Resnick Fundamentals of Physics Chapter ?.

Use of Apparatus:

Exploration

Zero the scale and connect the batteries to complete the circuit by clipping to the selected tab/voltage along the series of batteries. Adjust the current through the rod by clipping to the battery holder tabs in sequence. Do you see the reading on the scale change? According to this change, what is the direction of the force on the magnet? Hence, what is the direction of the force on the current-carrying brass rod? Note the direction of the current through the rod. Knowing the direction of the force on the rod, what must be the direction of the magnetic field of the magnet at the location of the rod, and, thus, is this side of the magnet a south or north pole? Switch the current leads at the battery supply. Are the scale readings what you expect? Finally, vary the distance between the magnet and the brass rod (anywhere from nearly touching the rod to up to a centimeter away). How does this affect the force measurements?

Measurement

Based on your exploration, pick a distance of the magnet from the brass rod and measure the scale readings for enough currents so that you can determine the trend between current and magnetic force. Repeat these measurements when you reverse the current by switching the leads at the battery supply. Repeat this for a couple more distances (which you should record) between the magnet and the brass rod.

Analysis

Convert your scale readings to force measurement and graph the force on the current-carrying rod as a function of current for each magnet-rod distance. Fit lines to these plots manually (varying the slope of the line) so that you can determine the uncertainty in the slope of these lines. What does the slope correspond to?

Extract the magnetic field (and its uncertainty), knowing how the magnetic force on a current depends on the current, for the different magnetic-rod distances. (Here, you need to estimate the length of the current-carrying rod that lies in the magnetic field of the magnet.) Finally, plot the magnetic field of the magnet as a function of the distance from the magnet. Do you see a trend in the magnetic field strength of the magnet as a function of the distance from the magnet? Can you quantify this, e.g., is the field proportional to some power of the distance from the magnet that the field is measured? (Note, far from magnetic dipoles, the field is inversely proportional to the cube of the distance from the dipole, as you'll explore in a later lab. But this may not be the case near a dipole.)

In the experimental setup shown below, with the cables connecting the power supply to the wire with the polarity shown and the magnetic field of the magnet pointing into the page (so we are viewing the south pole face of the magnet), what direction would the magnetic force act on the wire?
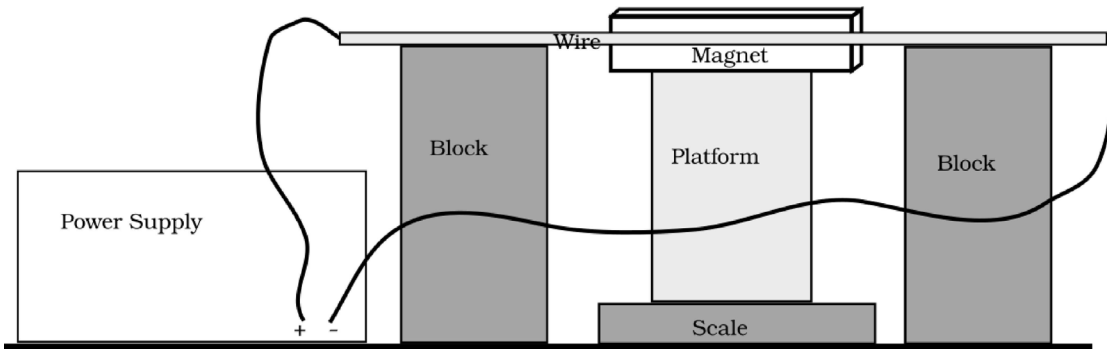
Considering Newton's 3rd law, if the magnetic force of the magnet on the wire happens to be downward, as this magnetic force increases (e.g., by changing the current running through the wire), the reading on the scale supporting the platform and magnet would _____.

Apparatus Competition Entry Form
2023 AAPT Summer Meeting
Sacramento, CA

Name: Claudio Oliveira Egalon

Institution: Los Angeles Harbor College

Address: Rua João Café Filho no. 400, apto. 103

Bairro Dom Bosco, Volta Redonda, RJ

27286-090, Brazil

Phone: 1-310-963-6106

Fax:

E-mail: coegalon@aol.com

Support required for apparatus:

Can this apparatus be constructed for under $100?   yes ■ ***   no ☐

***If yes, you must also provide a materials list with your apparatus description including prices and vendors of each item. Your apparatus will then be considered for both the unlimited cost and the low cost categories of the competition. Please see additional rules for the low cost category.

Approximate size (width and depth of table and/or floor space) 20 cm x 10 cm x 6 cm

Does this apparatus require Electrical Power?   yes ■   no ☐
Will you be present to set up your apparatus?   yes ☐   no ■

If no, who will be setting up the apparatus? The competition director

(It is possible for the apparatus to be shipped to the meeting and then setup by the competition director. But be sure to make prior arrangements with the competition director before doing so.)

When do you plan to set up your apparatus (on Sunday July 15)?

12-3 PM ☐   I need to arrange a different time (contact the competition director). ☐

What day do you plan to take down your apparatus? It is preferred that all apparatus be displayed until Wednesday, July 19. Wednesday, noonish

Other support needed for the proper operation of this apparatus:

The apparatus is self contained

Planck's Constant Determination Using a Side Illuminated Fiber Optics (SIFO™)

Introduction: Side Illuminated Fiber Optics, SIFO™

A Side Illuminated Fiber Optics, SIFO™, is a very convenient way to make multiple measurements from multiple sources and samples using a single detector Figure 1: this detector being either inexpensive photodiodes or more expensive spectrometers. [1-3]
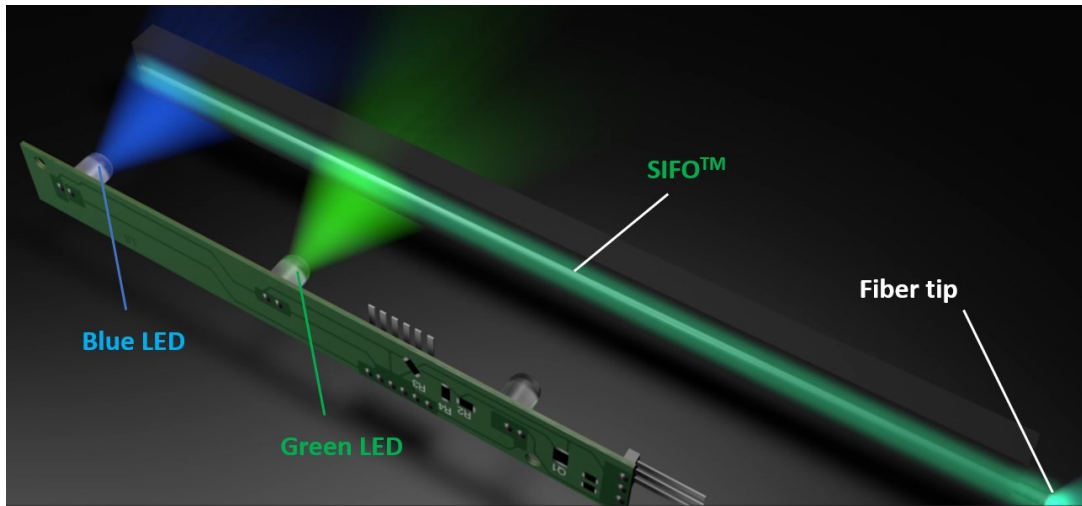

Figure 1. Fiber being side illuminated by multiple LEDs.

Using a SIFO™ and multiple LEDs of different colors, we built a prototype to determine the Planck's constant. This prototype has external connectors to conveniently measure the light intensity carried by the fiber, the current flowing through each LED and their voltage (Figure 2). By measuring the minimum voltage required to power the LED, or the knee voltage, we can find the Planck's constant using the inverse photo-electric effect (see Figures 3a and 3b).

Figure 2. The set of plugs shown in the above figure are used to measure voltage across each LED, the current they are subjected to and the light intensity (frequency measurement) at the fiber tip .

Historical Background: The Photoelectric Effect

The photo-electric effect was first observed in 1887 by Heinrich Hertz while he conducted a series of historical experiments that proved, conclusively, the existence of electromagnetic waves.[4] Unfortunately for Hertz, he did not believe his experiments had any practical importance. For this reason, it was up to Guglielmo Marconi [5] and, to a certain extent, Nikola Tesla,[6] to put this discovery into practice with the invention of the radio. This invention earned Marconi a Nobel Prize award and a dispute with Tesla that was resolved to Tesla's favor after his death.[6]

While performing his experiments on electromagnetic waves, Hertz discovered that electrodes illuminated by ultraviolet light created a more intense electric spark:[7] these electric sparks were associated with the ejection of electrons from the surface of the metal that was being used. Because these electrons are ejected by light, they were called photoelectrons. This phenomenon received the name of photoelectric effect and was later explained by Albert Einstein in 1905.[8] According to Einstein, light behaves as particles that undergo collisions with the electrons in a material: the higher their frequency the higher their likelihood to eject electrons from metallic surfaces (Figure 2a). In other words, light incident on a material could make electrons move and, depending on the wavelength, these electrons could be ejected from a metal: the source of the more intense spark observed by Hertz.
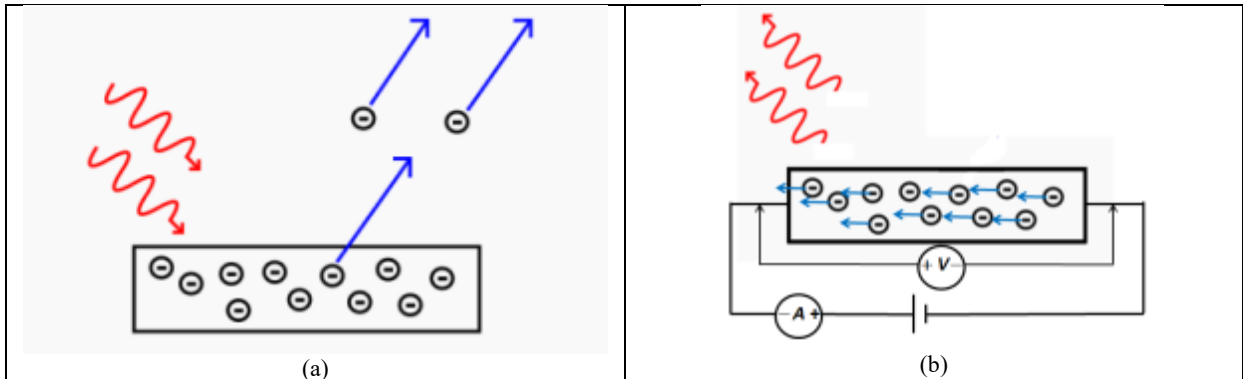

Figure 3. (a) The photoelectric effect: light with a given wavelength can be used to provide energy for electrons to scape the surface of a metal. (b) The inverse photoelectric effect: a current above a certain level generates light in a Light Emitting Diode, LED. The minimum voltage required to generate light is related to the Work function of the material.

The Inverse Photoelectric Effect [9]
The inverse process, to generate light through the motion of electrons, is also possible using the circuit of Figure 3b and an LED. This experiment requires the measurement of a minimum, or knee voltage, capable of producing light: the shorter the wavelength of the light the higher the knee voltage. There are at least five different ways of measuring the knee voltage, either with our SIFO configuration or without it:

1. By determining, with the naked eye, the point where the LED is on the verge of emitting light.
2. By determining, with an ammeter, the point where the current through the LED is on the verge of becoming different of zero.
3. By replacing the eyes in item 1 with a photodiode.
4. By performing the measurement in item 1 with a side illuminated fiber and a photo detector.
5. By adding an ammeter to the configuration in item 4 to confirm there is no light reaching the photo detector.

Performing the experiment with the eyes is not recommended because the LED light comes from a very small point on the surface of the LED and may damage the retina in the long run. In all the above cases, a voltmeter must be used to measure the threshold voltage of the LED. For items 1, 3 and 4 an ammeter is not required.

The Photoelectric Effect Theory and Planck's Constant Determination
Theoretically, the lowest frequency of light required to emit a photoelectron, f_{min}, can be written as:

$$hf_{min} = W_f$$

… where h is the Planck's constant and W_f is the work function of the material from which a photo electron is emitted. Since, for *many* metals, this frequency is in the ultraviolet region of the spectrum (see Table 1), it is understandable why Hertz reported the production of photo electrons in the UV.

But the work function can also be written in terms of the knee voltage or:

$$hf_{min} = eV_{knee}$$

… where e is the fundamental charge and V_{knee} is the minimum voltage required to generate light by the LED in Figure 3b. Rewriting this equation, we have:

$$f_{min} = \frac{e}{h}V_{knee}$$

Table 1. Work function of some metals and the wavelength of light required to create a photoelectron. Values of the Work functions were obtained from Wikipedia [https://en.wikipedia.org/wiki/Work_function, accessed on 07/07/2018].

metal	W_{fmin}	W_{fmax}	W_{fmin}	W_{fmax}	f_{min}	f_{max}	λ_{max}	λ_{min}
Ag	4.26	4.74	6.82E-19	7.59E-19	1.03E+15	1.15E+15	291	262
Au	5.10	5.47	8.17E-19	8.76E-19	1.23E+15	1.32E+15	243	227
Fe	4.67	4.81	7.48E-19	7.71E-19	1.13E+15	1.16E+15	265	258
Al	4.06	4.26	6.50E-19	6.82E-19	9.82E+14	1.03E+15	305	291
Cu	4.53	5.10	7.26E-19	8.17E-19	1.10E+15	1.23E+15	274	243
Cs	1.95	1.95	3.12E-19	3.12E-19	4.72E+14	4.72E+14	636	636
Units	*eV*	*eV*	*J*	*J*	*Hz*	*Hz*	*nm*	*nm*

Accordingly, if we measure the LED's peak wavelength (obtained with a spectrometer or directly from the LED's datasheet) and measure the V_{knee}, we can plot the frequency of the light against V_{knee} (the inverse also works). This plot should provide us with a straight line and a slope that is compared with $|e|/h$.
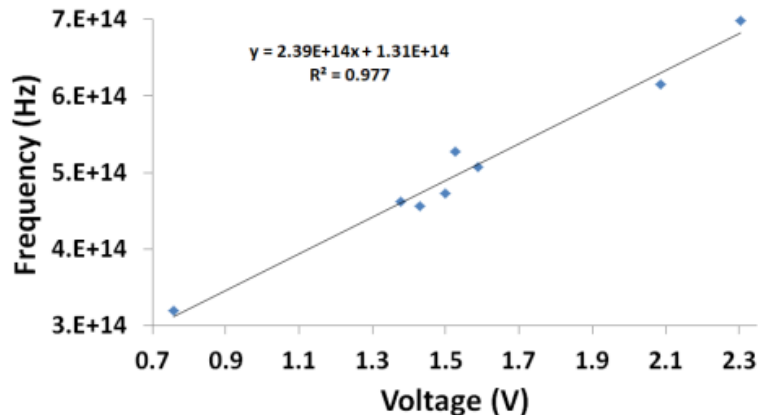

Figure 4. Experimental determination of the *e*/*h* ratio using our colorimeter.

Experimental Procedure and Results
Using our prototype and eight LEDs of different wavelengths (430; 488; 570; 592; 635; 650; 659 and 940 nm, from the blue to the infrared), we performed the experiment illustrated in Figure 3b. The

experimental result is shown in Figure 4. Notice that the slope obtained is 2.39 x 10^{14} *Hz/V* whereas the expected experimental value is 2.41 x 10^{14} *Hz/V*: a 1% difference. Ideally, the intercept should be zero, however the result obtained corresponds to a frequency in the near infrared region of the spectrum at 2.3 microns. Since *n*=8 and R^2=0.977, this result corresponds to an alpha value, α, of 3.84 x10^{-6} and a Confidence Level, *CL*=1−α, of 99.9996%. The CL is a measure of how close the curve fitting is to the experimental data.

Conclusions
Our SIFO[TM] prototype is a very convenient way of making multiple measurements with a single photodetector. Using this technique, we measured the knee voltage of eight LEDs and determined the Planck's constant. Other types of convenient measurements are also possible with our SIFO[TM] configuration. [1-3]

Clarification
The description below corresponds to a much simpler version of the prototype used and described above. This version can be built from readily available and inexpensive mass-produced components.

Materials
In the list below, the components' dimensions, wavelengths, characteristics, and quantity can be modified.

1. A 2 mm diameter by 15 cm long plastic optical fiber from Mitsubishi.
2. Eight 5 mm diameter LEDs of different colors and known peak wavelengths at 430; 488; 570; 592; 635; 650; 659 and 940 nm. Different peak wavelengths can also be used.
3. Acrylic bar 10 mm x 10 mm x 100 mm.
4. One intensity to frequency converter photodiode.
5. A protoboard.
6. Six channel LED driver to power each LED separately.
7. Multimeter with a frequency measurement.
8. Potentiometer to adjust the LED current.
9. Black cloth.

Preparation
1. LED and fiber support:
   a. Drill six holes in the acrylic bar for each of the 5 mm diameter LED.
   b. Drill a 1.5 mm diameter channel along the LED bar: this channel should pass through the 5 mm holes of the LEDs.
   c. Install the LEDs in their corresponding holes.
   d. Tape the optical fiber over the channel on the acrylic bar.
   e. Glue the intensity to frequency converter at the tip of the fiber.
2. Electronic connections.
   a. Connect all six LEDs in parallel using the protoboard.
   b. Connect the LED driver to each LED through the protoboard.
   c. Connect the multimeter to the photodiode.

Step by Step Procedure
1. Using an Excel spreadsheet, make a table with three columns:
   a. First column: the knee voltage of the LED, V_{knee}.
   b. Second column: the LED peak wavelength (obtained from the LED datasheet). and
   c. Third column: the LED frequency, $f=c/\lambda$, calculated using Excel's formulas.

2. Cover the LED and fiber support with the black cloth: it is important the whole set remains in the dark to ensure no outside light affects the measurement.
3. Experimental check out: turn on the first LED and read the intensity read by the photodiode with the multimeter set to measure frequency. As you increase the current applied, the LED intensity and the reading from the photodiode should increase. This step is performed to ensure the setup is working properly.
4. Adjust the LED driver to determine the point where the LED is on the verge of turning on. At this point the frequency, or LED intensity, read by the multimeter should be zero. Leave the setting of the driver at this point.
5. Set the multimeter to read current and confirm that the current through the LED is on the verge of becoming different of zero.
6. With the multimeter set to read voltage, determine the voltage across the leads of the LED: this is the knee voltage, V_{knee}, or minimum voltage to active the LED. Log this value in the first column of the table.
7. Repeat steps 2 through 6 for the remaining LEDs.
8. Determining the Planck's constant.
   a. Plot f, the frequency of the peak wavelength of the LEDs, along the y-axis and the knee voltage, V_{knee}, of the LEDs along the x-axis: you should obtain a straight line.
   b. Determine the Regression equation of this plot.
   c. The slope of this line is the ratio, $|e|/h$, between the fundamental charge, e, and the Planck's constant, h.
   d. Using the value of the fundamental charge and the slope of the graph, determine the Planck's constant.

References

1. Claudio Oliveira Egalon, "Reversible, Low Cost, Distributed Optical Fiber Sensor with High Spatial Resolution", US Patent number 10,876,960, Priority date: Jan. 31, 2009, Patent Date: Dec. 29, 2020.
2. Claudio Oliveira Egalon et al., "Side Illuminated Optical Fiber as a Multiplexing Element for Spectroscopic Systems", Photonic Fiber and Crystal Devices: Advances in Materials and Innovations in Device Applications VII, edited by Shizhuo Yinh, Ruyan Guo, Proc. of SPIE Vol. 8847, 2013.
3. Science & Sensors Technologies, www.SciSensorsTec.com, accessed 6/18/2023.
4. Jed Z. Buchwald, The Creation of Scientific Effects - Heinrich Hertz and Electric Waves, University of Chicago Press, 2011, pages 77-91.
5. Wikipedia, https://en.wikipedia.org/wiki/Heinrich_Hertz#cite_note-UnivOfJerusalem-24, access 6/18/2023.
6. PBS, "Who Invented Radio?", https://www.pbs.org/tesla/ll/ll_whoradio.html, access 6/18/2023.
7. Hertz, Heinrich (1887). "Ueber einen Einfluss des ultravioletten Lichtes auf die electrische Entladung". Annalen der Physik. 267 (8): 983-1000. Bibcode: 1887AnP…267..983H. doi:10.1002/andp.18872670827.
8. The Nobel Prize Foundation, https://www.nobelprize.org/prizes/physics/1921/summary/, access 6/18/2023.
9. The WikiLectures, https://www.wikilectures.eu/w/Photoelectric_effect, access 6/18/2023.

Apparatus Competition Entry Form
2023 AAPT Summer Meeting
Sacramento, CA

Name: Alan DeWeerd & Eric Hill

Institution: University of Redlands

Address: 1200 E Colton Ave

Redlands, CA 92373

Phone: 909-748-8658

Fax:

E-mail: alan_deweerd@redlands.ec

Support required for apparatus:

Can this apparatus be constructed for under $100?   yes ☐ ***   no ■

***If yes, you must also provide a materials list with your apparatus description including prices and vendors of each item. Your apparatus will then be considered for both the unlimited cost and the low cost categories of the competition. Please see additional rules for the low cost category.

Approximate size (width and depth of table and/or floor space) 60 cm x 60 cm

Does this apparatus require Electrical Power?   yes ☐   no ■

Will you be present to set up your apparatus?   yes ■   no ☐

If no, who will be setting up the apparatus?

(It is possible for the apparatus to be shipped to the meeting and then setup by the competition director. But be sure to make prior arrangements with the competition director before doing so.)

When do you plan to set up your apparatus (on Sunday July 15)?

12-3 PM ■   I need to arrange a different time (contact the competition director). ☐

What day do you plan to take down your apparatus? It is preferred that all apparatus be displayed until Wednesday, July 19. Wednesday, noonish   Wednesday morning

Other support needed for the proper operation of this apparatus:

None

Apparatus Title: Two Conservation of Angular Momentum Experiments with 3D-Printed Parts

Names: Alan DeWeerd & Eric Hill

Address: University of Redlands
1200 E Colton Ave
Redlands, CA 92373

Phone: 909-748-8658

e-mail: alan_deweerd@redlands.edu

Abstract: We designed two modifications, based on 3D-printed parts, to Pasco's Rotating Platform (ME-8951) that allow additional conservation of angular momentum experiments to be performed with it.

Construction of Apparatus: The figures below show the two 3D-printed parts (STL files available at https://www.thingiverse.com/thing:5426789 and https://www.thingiverse.com/thing:5793730). The sliders on the left have thumb screws to attach a string, and each holds a 100-g mass from Pasco's Mass and Hanger Set (ME-8979). The launcher on the right has a partially thread post and spring attached horizontally, bolts to attach it to the beam, and thumb screws to attach a string which holds the ball to be launched in place.
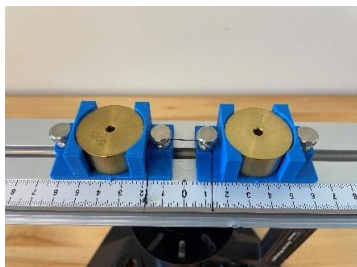
Use of Apparatus: The two conservation of angular momentum experiments are designed to be done after measuring the moment of inertia of the "beam" (really the beam and the shaft), I_{beam}, as described in the manual for Pasco's Rotating Platform. For both experiments, a Pasco Photogate (ME-9498A) is used to measure the angle using the spoked pulley attached to the shaft.

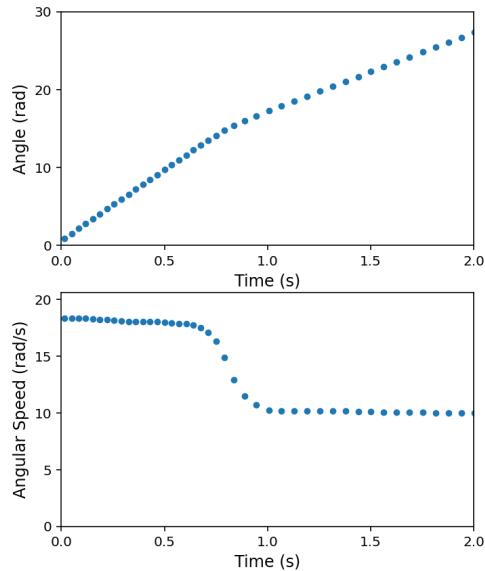(1) Conservation of Angular momentum with changing moment of inertia:

The figure below shows the complete set up for the first experiment where the angular momentum changes.[1] Note that holes are added near the ends of the beam so that the bolts that act as stops pass through them. The shorter bolts that come with the apparatus rely on friction and are not secure enough. Initially, the sliders are held near the central shaft by a thread connecting them. The system is set spinning by hand, then the thread is burned allowing the masses to slide outward to the stops. Since the moment of inertia increases, the angular speed decreases.

Video of the experiment: https://www.youtube.com/watch?v=PU7LaC895fc
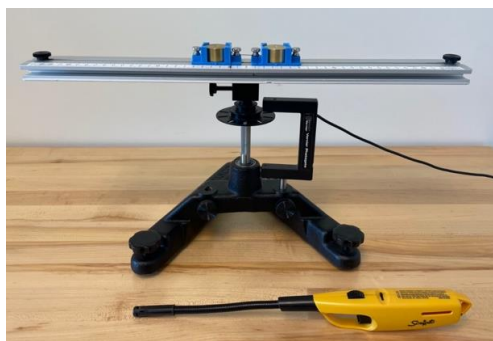
Sample data is shown below. Note that the change in each of the angular speed vs. time graphs is less sharp because the software used (Vernier's Logger Pro) approximates derivatives using seven data points.

Students test if the angular momentum

$$L = I\omega,$$ (1)

is conserved. The initial and final moments of inertia is calculated using

$$I \approx I_{beam} + 2m_{slider}r_{slider}^2 + 2m_{stop}r_{stop}^2,$$ (2)

where r_{slide} and r_{stop} are the radial distances to the centers of the sliding masses and stops, respectively.

(2) Conservation of Angular momentum with a launched ball:

The figure below shows the complete set up for the second experiment where a ball is launched from the beam.[2] After the ball is loaded by compressing the spring, the string holding it in place is burned to launch the ball with everything initially at rest.

Video of the experiment: https://www.youtube.com/watch?v=BULQYNCaUj8
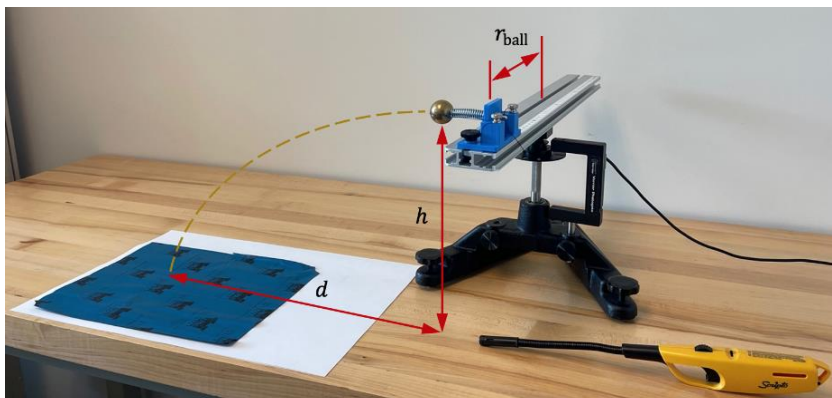
Sample data for the angle vs. time is shown below. A quadratic fit is made to the data, and the linear term gives the angular speed just after the ball is launched, while the quadratic term accounts for friction.

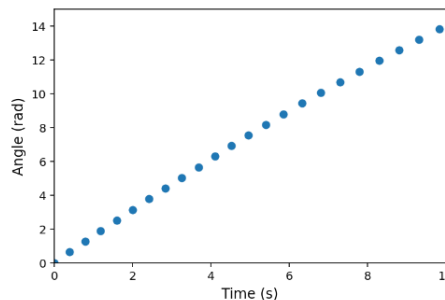Students test if the angular momentum of the ball is the same size (but in the opposite direction) as that of the beam and the launcher. The moment of inertia after the ball is fired is calculated using

$$I \approx I_{\text{beam}} + m_{\text{launcher}}r_{\text{launcher}}^2, \tag{3}$$

where m_{launcher} and r_{launcher} are the launcher's mass and the radial position of its center, respectively.

The angular momentum associated with the rotation of the beam and launcher is

$$L_{rot} = I\omega. \tag{4}$$

The speed of the ball is determined by measuring the intial height h of the ball and the distance d that it travels horizontally, which is found using a mark left by the impact on carbon paper placed faced down on a sheet of white paper. Since the ball is initially moving horizontally, its initial speed is

$$v = d\sqrt{g/2h}. \tag{5}$$

The ball is lauched perpendicular to the beam, so its angular momentum about the axis is

$$L_{\text{ball}} = m_{\text{ball}}r_{\text{ball}}v, \tag{6}$$

where m_{ball} and r_{ball} are the ball's mass and the radius from which it launches, respectively. (For our apparatus, $r_{\text{ball}} = r_{\text{launcher}}$ because the ball is centered on the launcher.)

1. Robert Carr, Harold Cohen, and Terry Ragsdale, "Demonstrating Angular Momentum Conservation," *Phys. Teach.* **48** (3), 169-171 (1999).
2. R. Ö. Akyüz, "Angular momentum conservation (a freshman experiment)," *Am. J. Phys.* **64** (4), 446-448 (1996).

Apparatus Competition Entry Form
2023 AAPT Summer Meeting
Sacramento, CA

Name: Nancy Donaldson, Ph.D.

Institution: Rockhurst University

Address: 2439 SE 6th Terrace

Lee's Summit, MO 64063

Phone: 8165060765

Fax:

E-mail: nancy.donaldson@rockhurs

Support required for apparatus:

Can this apparatus be constructed for under $100?   yes■***   no☐

***If yes, you must also provide a materials list with your apparatus description including prices and vendors of each item. Your apparatus will then be considered for both the unlimited cost and the low cost categories of the competition. Please see additional rules for the low cost category.

Approximate size (width and depth of table and/or floor space) 2 feet x 2 feet (plus poster s

Does this apparatus require Electrical Power?   yes■   no☐

Will you be present to set up your apparatus?   yes■   no☐

If no, who will be setting up the apparatus?

(It is possible for the apparatus to be shipped to the meeting and then setup by the competition director. But be sure to make prior arrangements with the competition director before doing so.)

When do you plan to set up your apparatus (on Sunday July 15)?

12-3 PM■   I need to arrange a different time (contact the competition director).☐

What day do you plan to take down your apparatus? It is preferred that all apparatus be displayed until Wednesday, July 19. Wednesday, noonish   Tuesday, 9 PM, July 18

Other support needed for the proper operation of this apparatus:

Additional supplies needed (3D printer - plans included), Power Source, Data Interface (Pasco or Vernier) and Differential Voltmeter

Schematic Neuron Internode Model (AAPT 2023 Apparatus Competition)

Abstract: The Schematic Neuron Model is a hands-on 3D printed model of an internode (myelinated segment) of an axon that is incorporated into an Electricity in the Body Neurophysiology Curriculum Module designed for Physics of Medicine students. Students will experiment with different values of resistors and capacitors to investigate passive and active transport and nerve signal conduction velocity in myelinated and diseased neurons.

Construction of Apparatus: The Schematic Neuron model was constructed to integrate physics with the physiology of Nerve Signal Transfer. The goal was to make the physics electric circuit principles "visible" to students within the context of nerve physiology. Pictures (copied below) illustrate that breadboards with circuitry modeling passive transport are encased in a 3D printed model to visibly represent an internode of an axon. Complete construction instructions for the Schematic Neuron Model are included in the curriculum to be submitted to the Living Portal for use and adaptation by physics educators.

Use of Apparatus: The Schematic Neuron Model is incorporated in a larger Electricity in the Body Neurophysiology Module designed for physics students intending to enter clinical graduate programs (Medical School, etc.) or Biomedical Engineering Graduate Programs. The curriculum written for this model is written with an active learning, inquiry based pedagogy. Previous laboratory curriculum has been published using breadboards and circuit boards to model the circuitry of passive transport of nerve signals. The impetus for designing this Schematic Neuron Model was to improve the integration of physiology with physics and reduce challenges that occur when using breadboards in an inquiry based classroom setting. The Schematic Neuron Model makes physiology "visible" with the goal of students using electricity principles to model both "healthy" and "diseased" axon conditions thereby increasing their understanding of both physics and physiology. Incorporating the circuitry inside of the 3D Neuron Model allows students to easily change circuitry components to investigate changes in resistance and capacitance within the context of how changes in the length constant and nerve signal conduction velocity affect the neuron's ability to activate another neuron or muscle.

(Please see pictures on the pages 2 and 3)
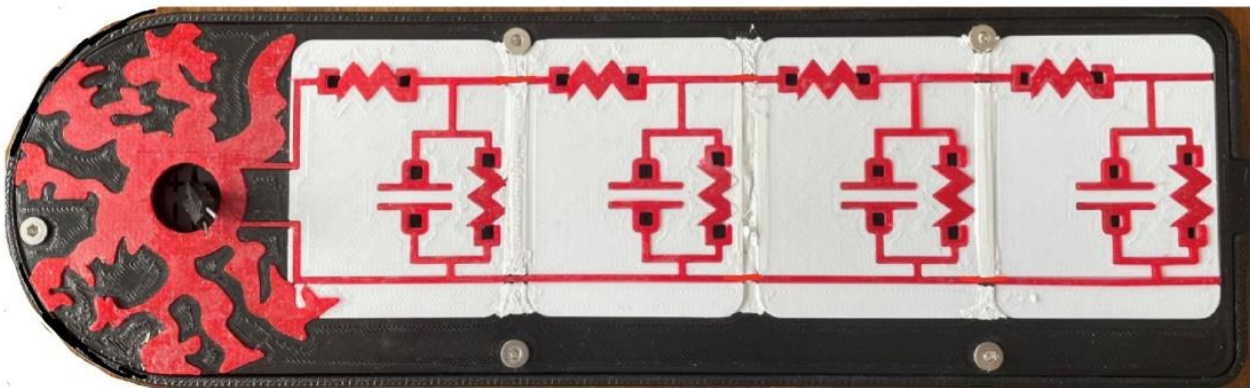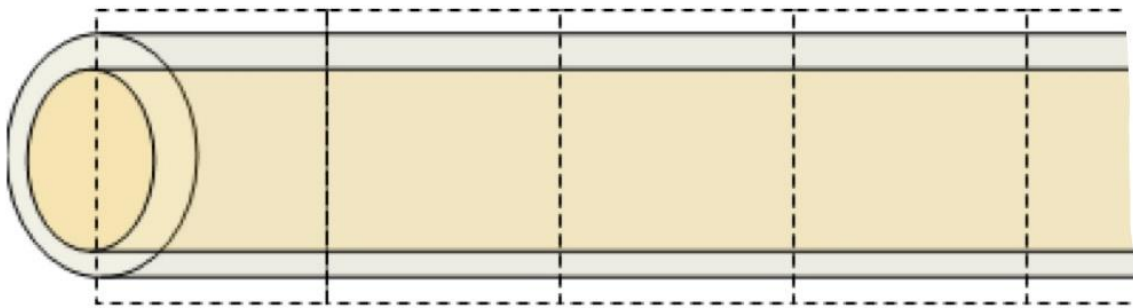
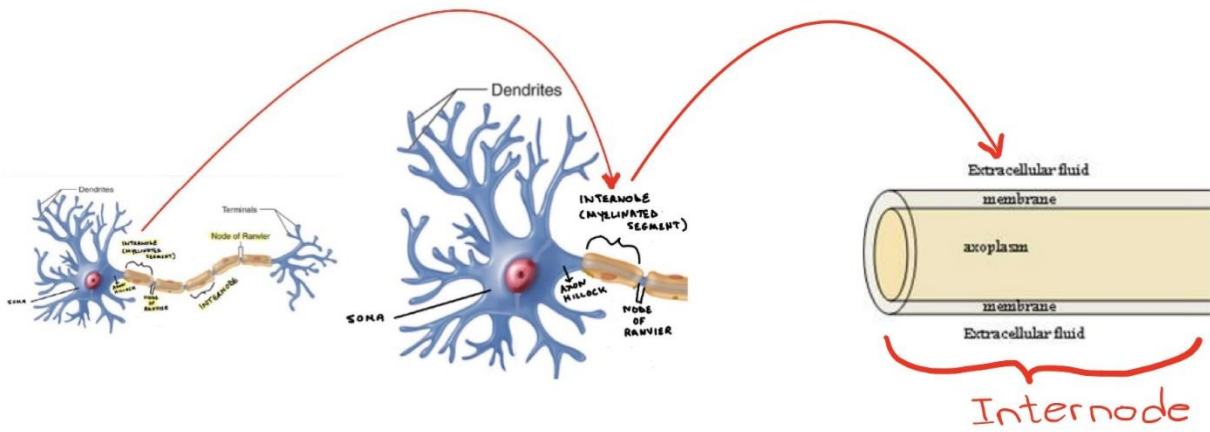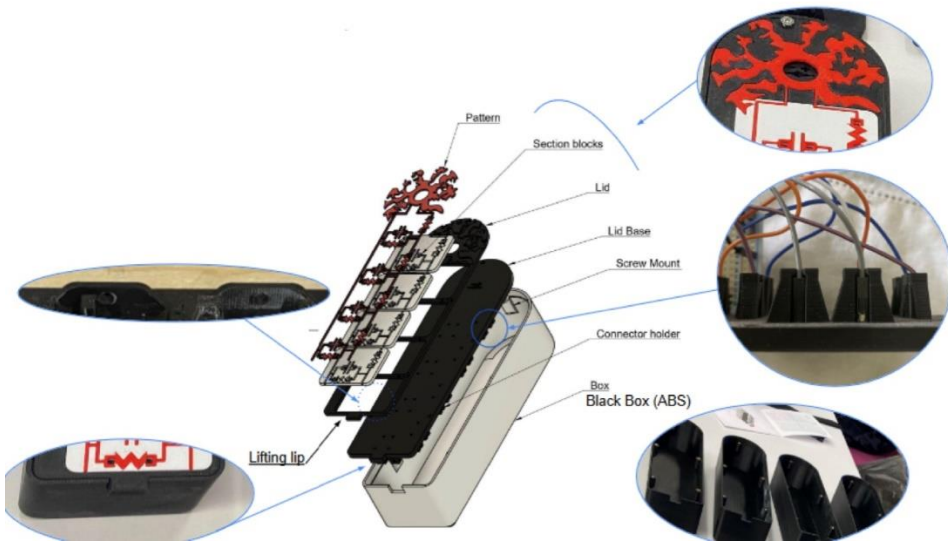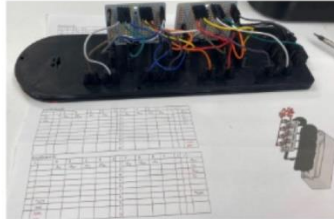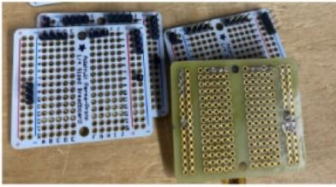Figure: Anatomical Drawing, Axon Cable Drawing and Schematic Neuron Physical Model of one Internode. Dotted Lines and Circuit connections represent ion channels in the Internode.

Assembly

Pattern
Section blocks
Lid
Lid Base
Screw Mount
Connector holder
Box
Black Box (ABS)
Lifting lip

Apparatus Competition Entry Form
2023 AAPT Summer Meeting
Sacramento, CA

Name: J. Reid Mumford

Institution: Johns Hopkins University

Address: 3701 San Martin Drive

Bloomberg 366

Baltimore, MD 21212

Phone: 410-516-5183

Fax:

E-mail: reid.mumford@jhu.edu

Support required for apparatus:

Can this apparatus be constructed for under $100?   yes■*** no☐

***If yes, you must also provide a materials list with your apparatus description including prices and vendors of each item. Your apparatus will then be considered for both the unlimited cost and the low cost categories of the competition. Please see additional rules for the low cost category.

Approximate size (width and depth of table and/or floor space)

Does this apparatus require Electrical Power?   yes☐   no■

Will you be present to set up your apparatus?   yes■   no☐

    If no, who will be setting up the apparatus?

    (It is possible for the apparatus to be shipped to the meeting and then setup by the competition director. But be sure to make prior arrangements with the competition director before doing so.)

When do you plan to set up your apparatus (on Sunday July 15)?

      12-3 PM■   I need to arrange a different time (contact the competition director).☐

What day do you plan to take down your apparatus? It is preferred that all apparatus be displayed until Wednesday, July 19. Wednesday, noonish

Other support needed for the proper operation of this apparatus:

Car on Circular Track

Name: J. Reid Mumford
Address: 3701 San Martin Dr, Bloomberg 366, Baltimore, MD 21212
Phone: (410) 516-5183
e-mail: reid.mumford@jhu.edu

Abstract

The conservation of angular momentum is a fundamental law of physics that states that in the absence of external torque, the total angular momentum of an isolated system remains constant. Students are often confused on what constitutes an isolated system and internal and external torque.

This apparatus uses a remote control car on a turntable that is free to rotate to demonstrate the conservation of angular momentum. When the car moves, it has angular momentum. The turntable rotates in the opposite direction so that the total momentum of the system remains constant.

Construction of Apparatus

Parts List

- Kidzlane Remote Control Cars (two cars for $23.74 on Amazon.com)

- Plastic ruler (twenty pack for $9.99 on Amazon.com)

- Foam Core Board (Gatorfoam Pack of 5, 32"x40" sheets $28 on Uline.com)

- Rotary Motion Sensor (RMV-BTD, $189 from Vernier). Other suitable bearings certainly exist. Something as simple and inexpensive as a fidget spinner could also be modified to work.

- Short lab stand for display.

Figure 1: The assembled angular momentum apparatus.

A large circle, with a radius of approximately 40cm, was cut from a sheet of strong foam core. A small hole was punched in the center. The foam core disk is attached to a rotary motion sensor so that it is free to spin around its center forming a turntable. The sensor is only used for its low-friction bearing and because it was available. Other devices, such as raw bearings, fidget spinners, or commercial turntables could also be used. To add rigidity, a second, smaller circle could be mounted below the larger one. In this version, a custom 3D printed part was used.

A smooth rod, with threads on one end, is used to attach the foam core disk to the sensor. The rod protrudes above the surface of the disk.

The remote control car is attached to one end of the plastic ruler (with tape or short wood screws). A hole in the opposite end of the ruler fits loosely over the vertical rod at the center of the turntable. Because the car will be turning in very tight circles, performance is enhanced by removing the rubber tires from the inside wheels. The steering trim on the toy car can also be adjusted to help the cars steer towards the center of the circle.

Mount the sensor to a short lab stand and attach to a table with clamps or a heavy base so that it won't tip over. The surface of the turntable can be painted or marked so that its rotation can be observed.

Figure 2: The underside of the turntable. A 3D printed part provides some additional support to the foam core turntable. An additional smaller disk of foam core could also be used.

Use of Apparatus

The apparatus can be used to show the conservation of angular momentum, $\vec{L}$, of the system[1]:

$$\vec{L}_{\text{total}} = \vec{L}_{\text{car}} + \vec{L}_{\text{disk}}$$

Angular momentum is also equal to the moment of inertia I times the angular velocity ω:

$$\vec{L} = I\vec{\omega}$$

This apparatus exemplifies the results of internal forces/torques on a system. The Newton's third-law force pairs (force of the car on the turntable and force of the turntable on the car) cannot change the total angular momentum of the system:

---

[1] PIRA bibliography 1Q40.40

Figure 3: The car is constrained to rotate in a circle by the ruler. The inside tires are removed so that the car drives more uniformly in the tight circular trajectory – the toy car is not equipped with a rear wheel differential.

To accelerate the disk and car system, an external torque (for example a hand pushing the disk) must be applied. In the absence of such a torque, the system will not have any angular acceleration.

$$\vec{\tau}_{\text{net,ext}} = \frac{d\vec{L}}{dt} = I_{\text{total}}\vec{\alpha}$$

If the system (disk and car) starts at rest, the angular momentum is zero. When the car accelerates to an angular velocity ω,the disk will accelerate in the opposite direction so that the angular momentum is equal in magnitude and in the opposite direction of the angular momentum of the car:

$$\vec{L}_{\text{total}} = 0 = I_{\text{car}}\vec{\omega}_{\text{car}} + I_{\text{disk}}\vec{\omega}_{\text{disk}}$$

$$I_{\text{car}}\vec{\omega}_{\text{car}} = -I_{\text{disk}}\vec{\omega}_{\text{disk}}$$

When the car comes to a stop, the disk also stops rotating and the stationary system still has a total angular momentum of zero.

The apparatus can also be used to compare the moments of inertia. The moment of inertia of the disk is given by:

$$I_{\text{disk}} = \frac{1}{2}m_{\text{disk}}r_{\text{disk}}^2 \sim \frac{1}{2}(0.575kg)(0.36m)^2 = 0.037kgm^2$$

$$I_{\text{car}} = m_{\text{car}}r_{\text{car}}^2 \sim (0.200kg)(0.3m)^2 = 0.018kgm^2$$

More mass could be added to the car to make the moments of inertia more similar. As it is currently constructed, one can observe that the angular velocity of the disk is approximately one half of the angular velocity of the rotating car.

Apparatus Competition Entry Form
2023 AAPT Summer Meeting
Sacramento, CA

Name: Paul Nord

Institution: Valparaiso University

Address: 1610 Campus Drive

Valparaiso, IN 46383

Phone: 219-508-7874

Fax:

E-mail: Paul.Nord@valpo.edu

Support required for apparatus:

Can this apparatus be constructed for under $100?   yes■*** no☐

***If yes, you must also provide a materials list with your apparatus description including prices and vendors of each item. Your apparatus will then be considered for both the unlimited cost and the low cost categories of the competition. Please see additional rules for the low cost category.

Approximate size (width and depth of table and/or floor space) 24"x24" table space

Does this apparatus require Electrical Power?   yes☐   no■

Will you be present to set up your apparatus?   yes■   no☐

    If no, who will be setting up the apparatus?

    (It is possible for the apparatus to be shipped to the meeting and then setup by the competition director. But be sure to make prior arrangements with the competition director before doing so.)

When do you plan to set up your apparatus (on Sunday July 15)?

       12-3 PM■   I need to arrange a different time (contact the competition director).☐

What day do you plan to take down your apparatus? It is preferred that all apparatus be displayed until Wednesday, July 19. Wednesday, noonish   Wednesday, noonish

Other support needed for the proper operation of this apparatus:

Apparatus Competition

2023 AAPT Summer Meeting

Sacramento, CA

Apparatus Title : Superhydrophobic Surface Display

Name: Paul Nord

Address: 1610 Campus Drive
Valparaiso, IN 46385

Phone: 219-508-7874

e-mail: Paul.Nord@valpo.edu

Abstract (50-75 words): This hallway display features a mirror partially coated with NeverWet paint, showing the exceptional properties of superhydrophobic surfaces and the adhesion of water to glass.

Construction of Apparatus: 12" Frameless Mirror Deco-Tiles (6 pack) $15.99
Rust-Oleum NeverWet Coating $17.50
Food Coloring $4.94

Use of Apparatus: Visitors interacting with the display should note how the water is strongly repelled from the coated surfaces and how it is attracted to the glass surface. At the interface, the water can stand almost half a centimeter high. A superhydrophibic surface will have a contact angle with a water droplet of greater than 150 degrees.

[Your description of the apparatus should explain how to construct and use the apparatus along with the educational value or use of the apparatus. Figures, pictures, sample lab write-ups, etc. may be included as appropriate. This description (made anonymous) will be available to the judges of the apparatus. This description will also be posted on the apparatus competition web page.]

Apparatus Competition

2023 AAPT Summer Meeting
Sacramento, CA

Apparatus Title: Bubble in Viscous Liquid and Color Addition *(Improved Version)*

Name: Said Shakerin

Address: Department of Mechanical Engineering
University of the Pacific
Stockton, CA 95211

Phone: 209-946-2377

e-mail: sshakerin@pacific.edu

Abstract:

A low-cost flow visualization device demonstrates bubble motion in glycerin in a double-layer enclosure. Each layer contains air and differently colored glycerin. In each layer there is a central partition with small gaps to regulate the flow of glycerin. A number of physics of fluids topics such as bubbles, drops and other interfacial phenomena are exhibited. Furthermore, color addition can be seen when the colored glycerin in the two layers overlap.

Construction of Apparatus:

To make the demonstration device portable and self-contained, I chose a simple design of sealed enclosure, which is made of acrylic stock and measures 8in x 10in with a spacing of 1/8in between the front and back in each layer. Instruction to fabricate a simple enclosure is available.[1] A horizontal partition with two ¼ inch gaps divide each layer into two chambers. *The addition of the partition is an improvement compared to an earlier version of the demo exhibited first at the 2019 Apparatus Competition and then published in The Physics Teacher.[2] The partition regulates the flow from one chamber to another, allowing for a longer time to observe the demonstration.* Approximately equal volumes of air and differently colored glycerin occupy each layer. The glycerin in the front layer is dyed blue with 4-5 drops of food color and the back layer contains yellowed glycerin. This combination of colors results in green when the flows of glycerin in the two layers overlap. For comparison purpose, the glycerin in the front is diluted by adding water (90% glycerin, 10% water on volume basis), and the glycerin in the back layer is not diluted (100%). The enclosure is held on an A-frame stand, made of scrap cardboard. Figure 1 (on the next page) shows the enclosure at rest and during the demonstration.
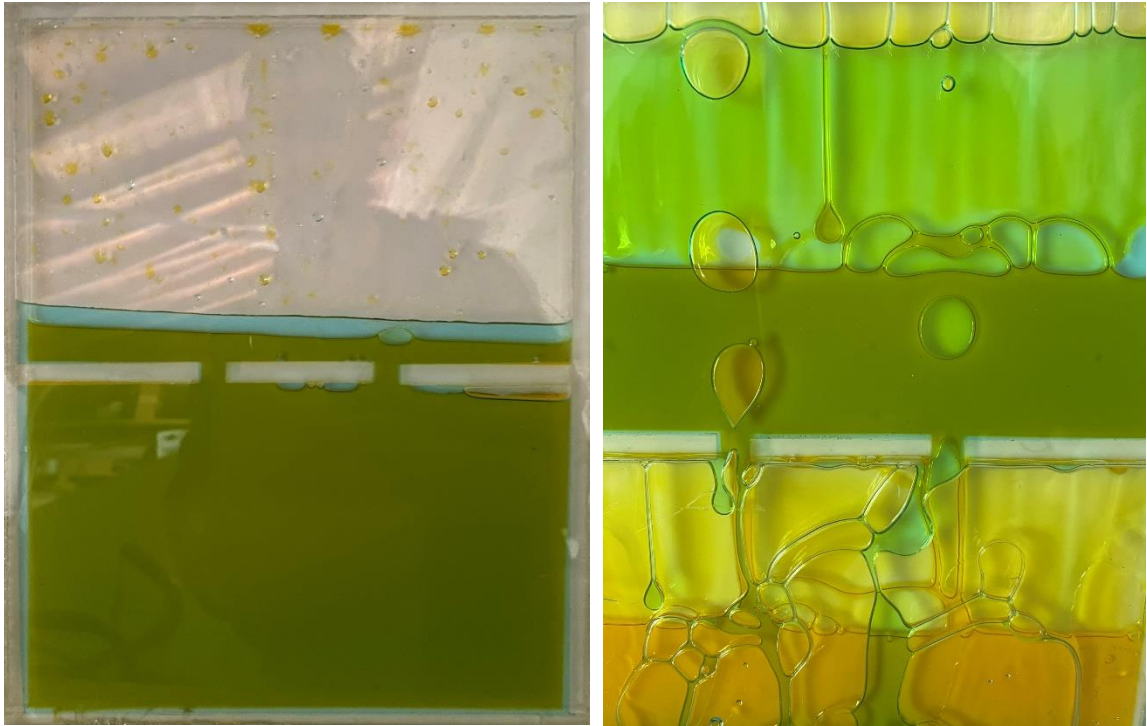
Figure 1 – (Left) Enclosure at rest. (Right) Several interfacial phenomena (e.g., drops, bubbles) are evident.

Use of Apparatus:

It is simple to use the enclosure. Simply, turn it upside down and observe. As glycerin flows downward and air pockets flow upward, complex interactions take place that demonstrate a variety of interfacial phenomena, from surface tension effect to bubble and drop formations to flow instability due to density differential. Furthermore, color addition is exhibited as blue and yellow colored glycerin are superimposed in their flows downward. Also notice that the blue colored glycerin flows faster because of its lower viscosity. (At 20°C, the dynamic viscosity of glycerin in the front and back layers are 0.30 and 1.41 Pa.s, respectively.[3])

So What?

1. The demonstration is applicable to enhancing lectures in physics and fluid dynamics courses. Also, it is a useful device for show-and-tell in informal science education (outreach).

2. The demonstration is simple, self-contained, and requires no power to operate. It is portable and can be reused without waiting or mess.

3. Most importantly, it exhibits bubble dynamics in a viscous liquid and an optical phenomena (color addition).

4. As a bonus, the demonstration is visually engaging and as such accessible to everyone, regardless of age or science background.

Reference

1. Shakerin, S., "Fluids Demonstrations: Trailing Vortices, Plateau Border, Angle of Repose, Flow Instability," *The Physics Teacher*, Vol. 56 (4), pp. 248-252, 2018.
2. Shakerin, S., "Fluids Demonstrations III: Viscous Flow in Modified Thin Enclosures, Centrifugal Effect, Vortical Flow, and Turbulence," *The Physics Teacher*, Vol. 59 (7), pp. 569-572, 2021.
3. http://www.met.reading.ac.uk/~sws04cdw/viscosity_calc.html (accessed 5/30/2023)

Apparatus Cost:

Quantity	Item	Cost $
4	8inx10in 1/8in-thick acrylic sheet	40
1	bottle of acrylic cement	14
1	tube of Weldon (glue)	14
1	16 oz bottle of glycerin	9
Total		**77**

Notes:

1. Acrylic stock and cement can be purchased from a plastic shop or online. I purchased from our local TAP Plastics store. One of the 8x10 sheets was cut to 1/4in-wide strips for spacers and partitions. If the local shop does not cut the acrylic strips, you would need a table saw equipped with fine saw tooth blade to make those cuts.
2. The cement, Weldon, and glycerin as purchased are more than needed for the enclosure built here, and therefore can be used for other acrylic projects thereby bringing the total cost lower than $77.
3. Glycerin can be purchased from a drugstore or online.

2023 AAPT Summer Meeting
Sacramento, CA

Apparatus Title: Meandering of Stream of Water

Name: Said Shakerin

Address: Department of Mechanical Engineering
                     University of the Pacific
                     Stockton, CA 95211

Phone: 209-946-2377

e-mail: sshakerin@pacific.edu

Abstract:

A low-cost flow visualization device demonstrates meandering of a stream of water flowing in between two flat sheets of acrylic. The device is a double-sided enclosure made of acrylic that contains colored water and air. Horizontal partitions regulate the flow of water.

Construction of Apparatus:

To make the demonstration device portable and self-contained, I chose a simple design of double sided, sealed enclosure, which is made of acrylic and measures 8in x 10in with a spacing of 1/8in between the front and back on each side. Instruction to fabricate a simple enclosure is available.[1] The enclosure contains water, which is dyed with red food color, and air. Two horizontal partitions on one side and one horizontal partition on the other side divide the enclosure space into chambers to hold the water to start the demonstration. Each partition has two small gaps to allow simultaneous flows of air and water in and out of respective chambers. The gaps measure between 1/8-1/4 inch in width. Figure 1 shows the enclosure at rest and during the demonstration. The enclosure is held on an A-frame stand, made of scrap cardboard.
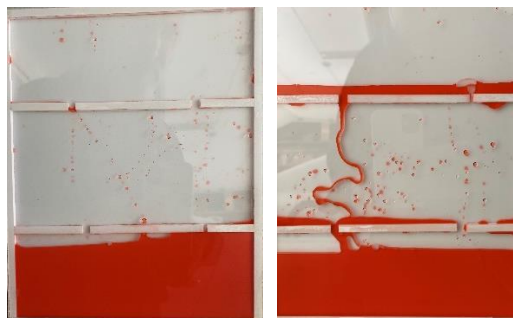

Figure 1 – The enclosure at rest (left) and during the demonstration, exhibiting meandering (right).

Use of Apparatus:

Turn the enclosure upside down, place it back on its stand, and observe the ensuing flow. Notice how the liquid flows down and air moves up until the liquid and air completely exchange their places. Sometimes, a little tilting of the enclosure is needed to initiate the flow. For relatively small flow rates, such as produced in the present demonstration, the water stream flows in random meandering fashion. The meandering is due to surface tension of water and minute surface non-uniformities in smoothness (micro scratches) as well as wettability. (The meandering in river flow is a different phenomenon, which is based on erosion.)

So What?

1. The demonstration is applicable to enhancing lectures in physics and fluid dynamics courses. Also, it is a useful device for show-and-tell in informal science education (outreach).

2. The demonstration is simple, self-contained, and requires no power to operate. It is portable and can be reused without waiting or cleaning.

3. Most importantly, it exhibits meandering of a stream of water flowing between two seemingly smooth surfaces.

4. As a bonus, the demonstration is visually engaging and as such accessible to everyone, regardless of age or science background.

References

1. Shakerin, S., "Fluids Demonstrations: Trailing Vortices, Plateau Border, Angle of Repose, Flow Instability," *The Physics Teacher*, Vol. 56 (4), pp. 248-252, 2018.

Apparatus Cost:

Quantity	Item	Cost $
4	8inx10in 1/8in-thick acrylic sheet	40
1	bottle of acrylic cement	14
1	tube of Weldon (glue)	14
1	gallon of distilled water	3
Total		**71**

Notes:

1. Acrylic stock and cement can be purchased from a plastic shop or online. I purchased from our local TAP Plastics store. One of the 8x10 sheets was cut to 1/4in-wide strips for spacers

and partitions. If the local shop does not cut the acrylic strips, you would need a table saw equipped with fine saw tooth blade to make those cuts.

2. The cement and Weldon as purchased are much more than needed for the five enclosures built here, and therefore can be used for several other acrylic projects thereby bringing the total cost lower than $71.

3. Distilled water can be purchased from a drugstore or online.

2023 AAPT Summer Meeting
Sacramento, CA

Apparatus Title: 1000-Fold Viscosity Variation in Glycerin-Water Mixtures

Name: Said Shakerin

Address: Department of Mechanical Engineering

University of the Pacific

Stockton, CA 95211

Phone: 209-946-2377

e-mail: sshakerin@pacific.edu

Abstract:

A flow visualization device demonstrates the effect of viscosity of glycerin-water (G-W) mixture on its flow in enclosures. The device consists of five enclosures made of acrylic. Each enclosure contains approximately equal volumes of air and a liquid. The five liquids are: glycerin, three different mixtures of G-W, and distilled water. Most importantly, the demonstration shows nonlinearity of mixture viscosity with respect to the G-W ratio.

Construction of Apparatus:

To make the demonstration device portable and self-contained, I chose a simple design of sealed enclosure. Instruction to fabricate a simple enclosure is available.[1] Five geometrically identical thin enclosures, made of acrylic stock, contain approximately equal volumes of air and a liquid as shown in Figure 1. Each enclosure measures 8in x 10in with a spacing of 1/8in between the front and back, and is divided into two chambers by 3 staggered partial partitions in the middle. The five liquids are, in order, glycerin as bought from store and colored with several drops of green food color, 75%-25%, 50%-50%, and 25%-75% G-W mixtures (on volume basis), and non-colored distilled water.

Figure 1 - Five enclosures at rest, from L to R, colored glycerin, 75%-25%, 50%-%50%, 25%-75% glycerin-water mixtures, and water.

Each mixture was made by diluting the original colored glycerin with appropriate volume of water. Hence the reduction in color intensity is a qualitative indication of the dilution. The roll of partitions is to regulate the flow once a given enclosure is turned upside down. The enclosures are held on an A-frame stand, made of scrap cardboard.

Use of Apparatus:

Turn each enclosure upside down, place it back on its stand, and observe the ensuing flow. Notice how the liquid flows down and air moves up until the liquid and air completely exchange their places. Patience is required when observing the enclosure containing 100% glycerin. For other cases, sometimes air bubbles get stuck in between the partitions. A little tilting of the enclosure would release the stuck air bubble and the flow is started again.

Notice the 100% glycerin flow is extremely slow and 100% water flow is much faster, as the glycerin viscosity is 1000 times of water viscosity. When glycerin is mixed with water, the mixture's viscosity diminishes rather quickly and non-linearly; this is non-intuitive. For example, a 50%-50% G-W mixture has a viscosity of only about 10 times that of water. Similarly, the flow behavior of water and 25%-75% G-W mixture are very close. In cases of 50% or more water, the liquid (mixture) flow exhibits meandering, which depends on several factors such as surface properties such as wettability and smoothness and surface tension.

In addition, other fluid dynamics phenomena are demonstrated such as flow instability and periodic exchange of liquid-air flow. Figure 2 shows the enclosures containing glycerin, 50%-50% G-W mixture, and water during the demonstration.
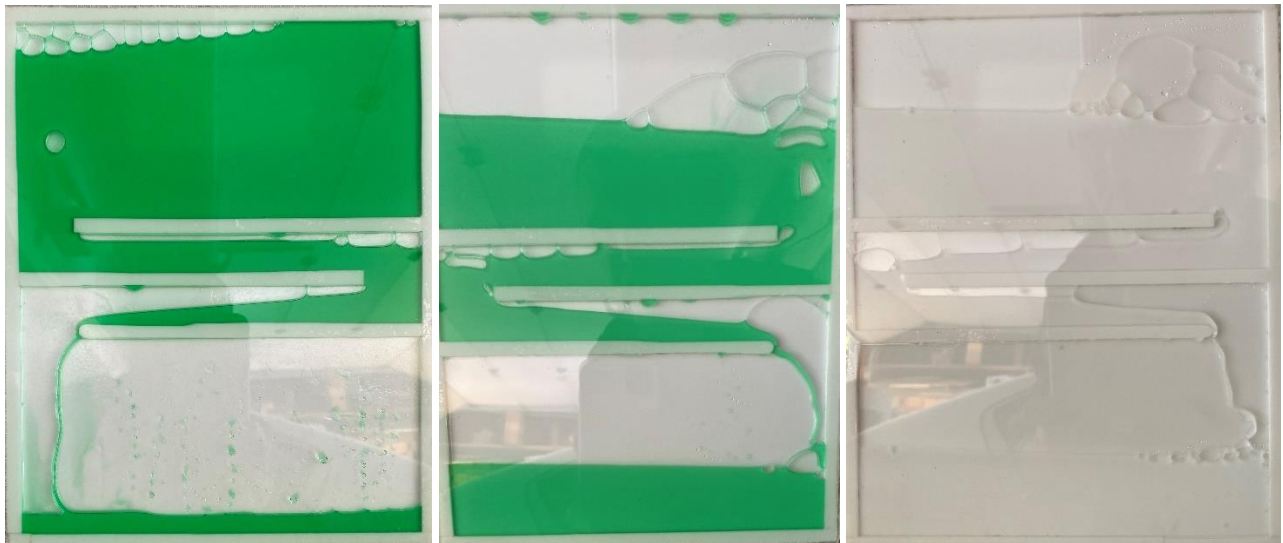

Figure 2 – From left to right, 100% glycerin, 50%-50% G-W mixture, and water flows during the demonstration.

For comparison purpose, viscosities of the five liquids used in the demonstration are given in the table below (next page).

Dynamic Viscosity (Pa.s) of G-W Mixture at 20°C[2]	
Glycerin (0% W)	1.413
75%-25% G-W	0.055
50%-50% G-W	0.008
25%-75% G-W	0.002
Water (0% G)	0.001

So What?

1. The demonstration is applicable to enhancing lectures in physics and fluid dynamics courses. Also, it is a useful device for show-and-tell in informal science education (outreach).

2. The demonstration is simple, self-contained, and requires no power to operate. It is portable and can be reused without waiting or cleaning.

3. Most importantly, it exhibits nonlinearity of viscosity with respect to the percentage of liquids in the mixture.

4. As a bonus, the demonstration is visually engaging and as such accessible to everyone, regardless of age or science background.

References

1. Shakerin, S., "Fluids Demonstrations: Trailing Vortices, Plateau Border, Angle of Repose, Flow Instability," *The Physics Teacher*, Vol. 56 (4), pp. 248-252, 2018.
2. http://www.met.reading.ac.uk/~sws04cdw/viscosity_calc.html (accessed 5/30/2023)

Apparatus Cost:

Quantity	Item	Cost $
11	8inx10in 1/8in-thick acrylic sheet	110
1	bottle of acrylic cement	14
1	tube of Weldon (glue)	14
1	16 oz bottle of glycerin	9
1	gallon of distilled water	3
Total		**150**

Notes:

1. Acrylic stock and cement can be purchased from a plastic shop or online. I purchased from our local TAP Plastics store. One of the 8x10 sheets was cut to 1/4in-wide strips for spacers and partitions. If the local shop does not cut the acrylic strips, you would need a table saw equipped with fine saw tooth blade to make those cuts.
2. The cement and Weldon as purchased are much more than needed for the five enclosures built here, and therefore can be used for several other acrylic projects thereby bringing the total cost lower than $150.
3. Glycerin and distilled water can be purchased from a drugstore or online.

Apparatus Competition Entry Form
2023 AAPT Summer Meeting
Sacramento, CA

Name: Toby Dittrich

Institution: Portland Community College, Oregon

Address: PO Box 19000

Portland OR 97280-0990

Phone: 503 516 2981

Fax:

E-mail: tdittric@pcc.edu

Support required for apparatus:

Can this apparatus be constructed for under $100?   yes☐*** no■

***If yes, you must also provide a materials list with your apparatus description including prices and vendors of each item. Your apparatus will then be considered for both the unlimited cost and the low cost categories of the competition. Please see additional rules for the low cost category.

Approximate size (width and depth of table and/or floor space)

Does this apparatus require Electrical Power?   yes☐   no■

Will you be present to set up your apparatus?   yes■   no☐

　　　If no, who will be setting up the apparatus?

　　　(It is possible for the apparatus to be shipped to the meeting and then setup by the competition director. But be sure to make prior arrangements with the competition director before doing so.)

When do you plan to set up your apparatus (on Sunday July 15)?

　　　　　12-3 PM■   I need to arrange a different time (contact the competition director).☐

What day do you plan to take down your apparatus? It is preferred that all apparatus be displayed until Wednesday, July 19. Wednesday, noonish   Wed noon

Other support needed for the proper operation of this apparatus:

On Sunday I am doin a workshop from noon to 5pm with the Advanced lab group. I can set up right at 5pm, since it should not be to far from the space for the workshop.

Abstract:

History was made and Einstein became famous in 1919 when Eddington and Dyson measured the Einstein Coefficient. Between 1919 and 1957 several additional experiments were performed with varying success, but the images obtained were entirely beyond twice the radius of the sun, and the data was very limited (7 stars for 1919 and only a total of about 100). At this distance the gravitational deflection is very small and lies out in the tail of the hyperbolic curve (1/r) for photon deflections. This makes a curve fit verification questionable. After no experiments being performed until 2017, two experiments were successful one by Don Bruns and one by Dittrich/Berry (involving four undergraduate students who became the first to ever measure the curvature of space). The modern CCD cameras used captured hundreds of images. For the April 2024 eclipse, Professor Dittrich has organized more than 10 teams using new CMOS cameras that will be able to capture hundreds of thousands of images, many between R = 1-2 solar radii. This will enable the creation of the first ever adequate curve fit verification of Einstein's hyperbolic deflection relationship. This Modern Eddington Experiment will involve many colleges and undergraduates as well as amateur astronomers from around the world. This workshop will discuss the MEE2024 project.
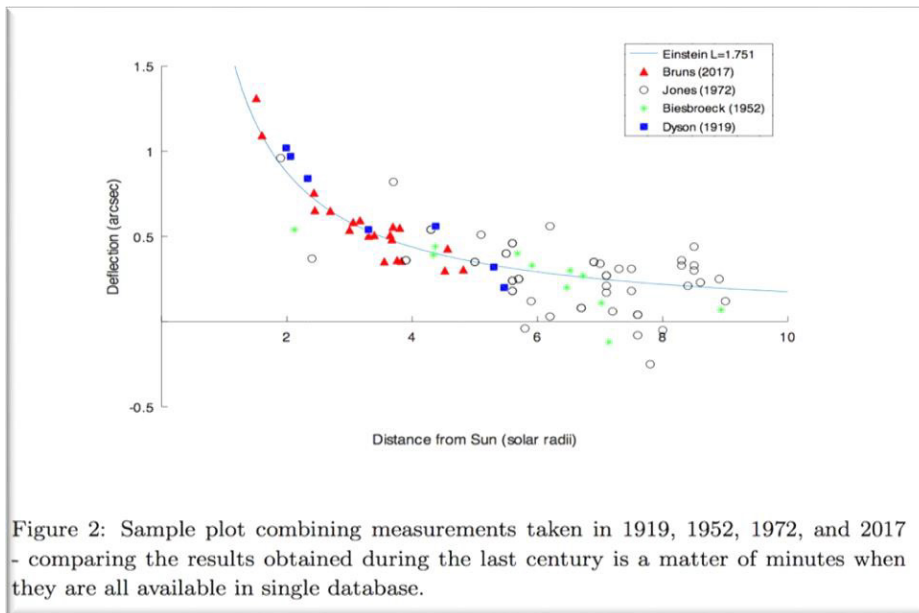
Construction of Apparatus:

The apparatus consists of items purchased but only these items can be used, not any general astronomical telescopes or cameras. Televue NP 101 telescope, ZWO 1600mm Pro or ZWO 6200mm Pro CMOS camera, a programmable mount and tripod like the Celestron AVX, and a very fast laptop with a large solid-state drive.

ZWO 1600mm Pro

ZWO ASI1600MM Pro Monochrome Astronomy Camera # ASI1600MM-P

Use of Apparatus:

The immediate goal for this apparatus is to adequately verify Einstein's Law for Deflection of Light Gravitationally, a hyperbolic (1/r) relation for the deflection angle versus the radial distance from the center of the sun. Because the ZWO cameras (just recently released) have such a short download time (0.1-0.2 seconds) very large numbers of images (plates) can be taken during the eclipse with short exposures. When these plates are stacked on top of each other, the very few electrons from the CMOS sensor chip pixels which come from stars in the inner bright corona will add up to produce a stellar image that can be used to get the stellar centroid. This stacking technique tested during full moon simulations of a total eclipse, allowed stars to be observed and centroided even though they were behind a thin cloud layer. Therefore, by creating as many as 2500 plates per camera with 100-200 stars each, these CMOS cameras can produce in one eclipse for 4.5 minutes hundreds of thousands of data points (compared to Eddington's 14). Since many of these data points are within the radial distance of R=1-2 for the first time in the region where the hyperbolic relationship turns from roughly linear to upward in a hyperbolic curve, this apparatus (and the ten other ones like it from schools and amateur astronomers from around the world) will create the first adequate curve fit for photon deflection by mass. Past experimental results are shown below:

Figure 2: Sample plot combining measurements taken in 1919, 1952, 1972, and 2017 - comparing the results obtained during the last century is a matter of minutes when they are all available in single database.

The Einstein Deflection Law has been verified with high accuracy in radio frequencies with single radio telescopes and global networks of radio telescopes (VLBI). The most accurate verification has occurred with the Hipparchus and Gaia satellites. These accurate measurements were done at very large distances from the sun using micro arc-sec deflections, very accurately applying the deflection relationship far out in the tail of the above figure. This emphasizes the value of MEE2024 apparatus, and more specifically the ZWO cameras, in collecting orders of magnitude more data over the range of distances from the sun thereby finally adequately verifying the relationship by curve fit. This apparatus puts the MEE back in

the running for experimental physics in the field of general relativity as shown in the following figure:

Anticipated Results – MEE2024 Apparatus
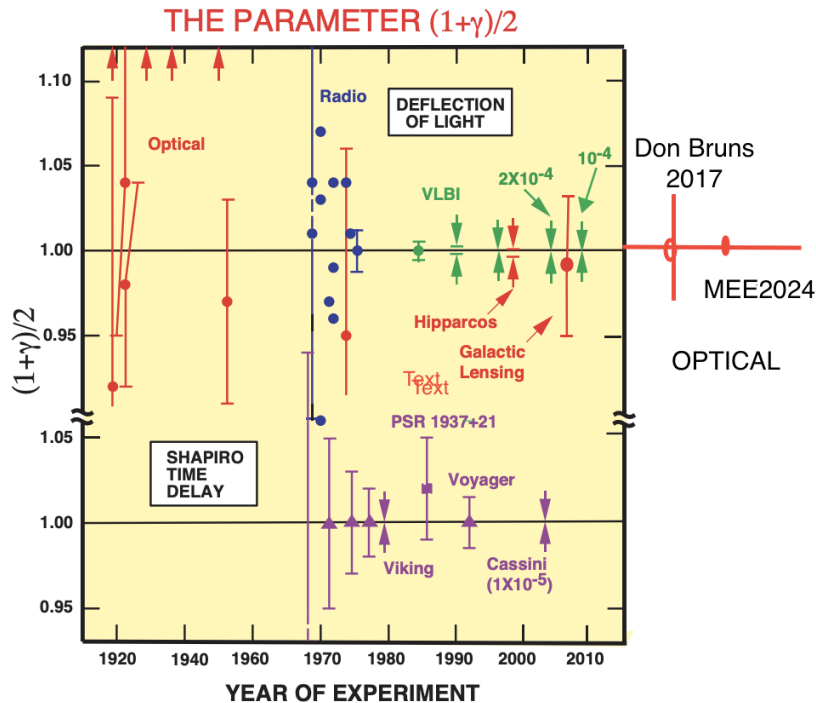
The second and long-term goal for the use of this apparatus is to make the Modern Eddington Experiment a routine experiment available to universities and colleges everywhere to use as a standard experiment in their Advanced Lab courses whenever an eclipse occurs. This has been supported by the Advanced Laboratory Physics Association (ALPhA). For the 2024 eclipse, colleges and universities around the world are taking part in MEE2024.

Apparatus Competition

2023 AAPT Summer Meeting

Sacramento, CA

Apparatus Title : Affordable Magnetic Potential Energy Barrier

Name: Ray Walsh

Address: 97 S. Pit Lane
Nampa, ID 83687

Phone: (214)608-4941

e-mail: ray.walsh@urayn.us

Abstract (50-75 words): This improvement of the magnetic "Coulomb" barrier apparatus costs less than $10, vastly expanding the affordability of the apparatus within the developing world. The magnetic "Coulomb" barrier models nuclear fusion by creating a model of the Coulomb potential barrier that students can build, see, and feel. Overcoming the Coulomb barrier is key to achieving nuclear fusion, and now this abstract concept can be demonstrated affordably using readily available materials.

Construction of Apparatus: The apparatus has a set of two identical magnet arrays centered one above the other on a ¼" wood shaft attached to a wood base. Alternating single and double 1/4" N52 Nd cube magnets (9 total) are arranged around a ferromagnetic steel washer. A 1" length of plastic straw is inserted into the washer hole extending through the center of the magnets. Putty is used to temporarily seal the washer around the straw. This is wrapped in transparent tape to form a moat into which epoxy is poured up to the level of the double magnets. The putty is removed after the epoxy hardens.

Use of Apparatus: The apparatus qualitatively demonstrates two important points about fusion. First, the two arrays are removed from the shaft, one placed in each hand. When the arrays are brought close to each other so that they oppose each other, the student can feel the initial repulsion. Then, if the arrays are pushed closer together, repulsion suddenly transitions to strong attraction and the arrays slap together. Second, the arrays are placed back on the shaft and stand. The top array is elevated to progressive greater heights along the shaft and allowed to drop until overcoming the barrier. This qualitatively demonstrates the role of kinetic energy in overcoming the Coulomb barrier.

[Your description of the apparatus should explain how to construct and use the apparatus along with the educational value or use of the apparatus. Figures, pictures, sample lab write-ups, etc. may be included as appropriate. This description (made anonymous) will be available to the judges of the apparatus. This description will also be posted on the apparatus competition web page.]

Magnetic "Coulomb" Barrier

Ray Walsh

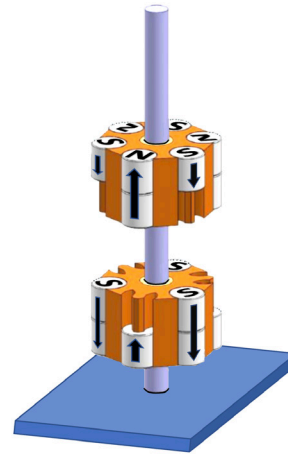Science Department, College of Western Idaho, USA

ray.walsh@urayn.us

Abstract

The Coulomb barrier is a classic introductory physics concept that is key to understanding nuclear fusion. Yet the idea that fusing nuclei within a single system could exhibit both far-range repulsion and short-range attraction can result in significant cognitive dissonance in students. There are no classical examples of this behavior and no commercially available demonstration kits. The magnetic "Coulomb" barrier allows a visual and tactile demonstration of the central challenge of nuclear fusion: overcoming the electrostatic forces inherent in the Coulomb barrier. Students directly determine the kinetic energy required to overcome the magnetic potential energy

The apparatus

The apparatus shown in Figure 1 consists of a base through which a 6mm hole is drilled. A polished 6mm aluminum rod is inserted into this hole. A pair of magnet arrays are mounted on this rod, as shown. The magnet arrays each have a series of alternating magnets inside a 3D-printed plastic housing. The 3D print housings are identical, except the bottom array housing accommodates a ceramic bearing. A full materials list in the online supplement. [1] A video of the apparatus can be found at https://youtu.be/6pDiiyorwec , and instructions for making a model for personal use and the 3D print files at https://www.tinkercad.com/things/l93kiuYv8Zl and https://www.tinkercad.com/things/5v6kdKpf928 .

The potential barrier lab

The goal of the Coulomb barrier lab is to determine the height of the potential barrier. The upper array is raised to s uccessively greater heights along the shaft and allowed to drop onto the lower array. The minimum height above the magnetic potential barrier at which sufficient energy is imparted to overcome the barrier is recorded as h_i .

The aluminum rod is then replaced by a graduated plastic straw split down the middle with a pair of scissors (to prevent binding) and graduated in 1 cm and 1mm increments with a fine permanent marker.

The lower array and base are placed on a gram scale sitting on an aluminum lab jack lift set to the lowest position. With the upper array removed from the system, the scale is then tared. Using the straw as a guide, the upper magnet array is placed at least 10 cm above the lower array and secured by a non-magnetic clamp. The magnetic poles (arrows in Fig. 1) are aligned. The initial scale value is recorded. The lift is lowered incrementally, and the scale value is recorded at each height. When the arrays are separated by a distance of 2 cm, measurements are recorded every 1 mm. These values are converted to force in newtons (grams are converted to kilograms, then multiplied by the acceleration of gravity, 9.8 m/s2), and a force/distance curve is plotted (Figure 3). Forces of attraction and repulsion are equal at the x-intercept. The plot crosses the x-axis at point **A** where the magnetic force transitions from repulsive to attractive. This height is recorded as h_f.

Students may then calculate the potential energy and velocity required to overcome the magnetic potential energy barrier (neglecting friction between the shaft and upper array). The formula for gravitational potential energy is:

$$E_p = mgh \qquad (1)$$

where m is the mass of the upper magnet array, g is the acceleration of gravity, and h is the difference in height between h_f and h_i .

At height h the potential energy equals the kinetic energy required to overcome the magnetic potential energy barrier according to the formula:

$$E_p = E_k = \frac{1}{2}mv^2 \quad (2)$$

Solving for velocity v yields:

$$v = \sqrt{(2/m)E} \quad\quad\quad (3)$$

Results

The mass m of the upper magnet array is 0.05812 kg ± 0.00003 kg, and the height h_i is 0.0089 m ± 0.0005 m.. The height at which the upper array reliably overcomes the magnetic force barrier is 0.0052 m ± 0.0005 m. The difference h is 0.0043 m ± 0.001 m. The acceleration due to gravity is 9.81 m/s2. Converting to SI units and plugging into Formula (1) yields a potential energy E_p = 2.5 x 10-2 J to overcome the magnetic potential barrier. Thus, per Formula (3), a velocity of at least v = 0.93 m/s is required to overcome the magnetic potential barrier.
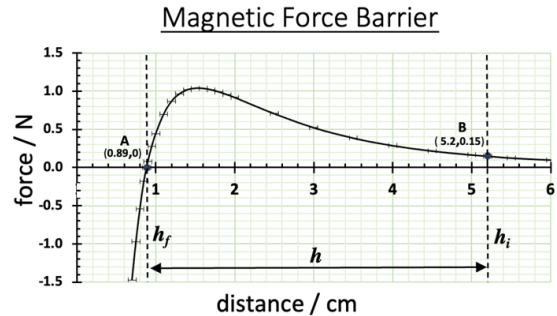
Materials

- 6mm aluminum shaft that slides within the aluminum spacer (Hoppes 7.62 cleaning rod, $13.95 per kit Amazon, 3 rods/kit)
-Two aluminum inline skate bearing spacers, 23.5mm x 7.9 mm, 6.3 mm ID ($6.99 for 16pack, Amazon)
-22mm x 7mm ceramic bearing with 8mm ID ($9.95 Amazon)
- 3/8" x 3/8" neodymium cylinder magnets 9 per housing, 2 housings ($1.07 each, AppliedMagnets.com, $19.26 total)
-Clear epoxy ($4.60, Amazon)
-black and red permanent paint pens ($12.29, Amazon)
-3D print housings, base PLA ($30 if ordered from www. fictive.com, but much less if 3D printed in-house)

TOTAL = $97.04

Apparatus Title: # Lecture Demonstration Multimeter

Name: **Steven K. Wonnell**

Address: Johns Hopkins University
Department of Physics & Astronomy
Bloomberg Room 366
3400 N. Charles Street
Baltimore, MD 21218

Phone: 410-516-5468

Email: wonnell@jhu.edu

Abstract (50-75 words):

Digital Multimeters with a display large enough to read in a large classroom or auditorium have become hard to find. One was constructed by combining a handheld multimeter with an old computer and writing software to display the multimeter output on the computer screen. The device is made so that it can be retrieved from storage, plugged in, turned on, connected to the object under investigation, and lo behold the audience can see the measurement.

Construction of Apparatus:

Bill of Materials:
- Fluke 287 multimeter. ($544, should last a lifetime) The Fluke 289 and 189 should work as well.
- Fluke IR189USB, an IR-to-USB cable to connect the Fluke to the computer. About $74.
- Surface Pro 4, with power supply. Any old computer will work for this, but an old Surface

Pro is ideal for its small size and no need for a mouse or keyboard.

- Assembly materials. Plywood in small sheets of 1/4" and 1/2" thick was used here.

- Nuts, bolts, washers, a handle, and paint for assembly.

- LargeDMM.exe (PC) or LargeDMM.app (Mac) software. The source code for the program can be compiled for PC, Mac/intel, or Linux. PC and Mac/intel have been tested successfully.

The goal is to build a holder for the computer display and multimeter such that they can be easily seen while hiding everything not relevant for instructional purposes.   The main complication is that the IR end of the cable is large, and three inches of clearance above the top of the multimeter is required.

Figure 1: Front of device. Ignore the Labquest mini mounted at top. A U-shaped piece of wood hides the cable coming out of the multimeter. The computer is an old Surface Pro 4. There is an approximately 60 millisecond delay in communications between the Fluke and the computer, which is normally not noticeable unless a still shot is taken as above, where the Fluke has already moved on to the next measurement while the previous voltage is still shown on the computer.
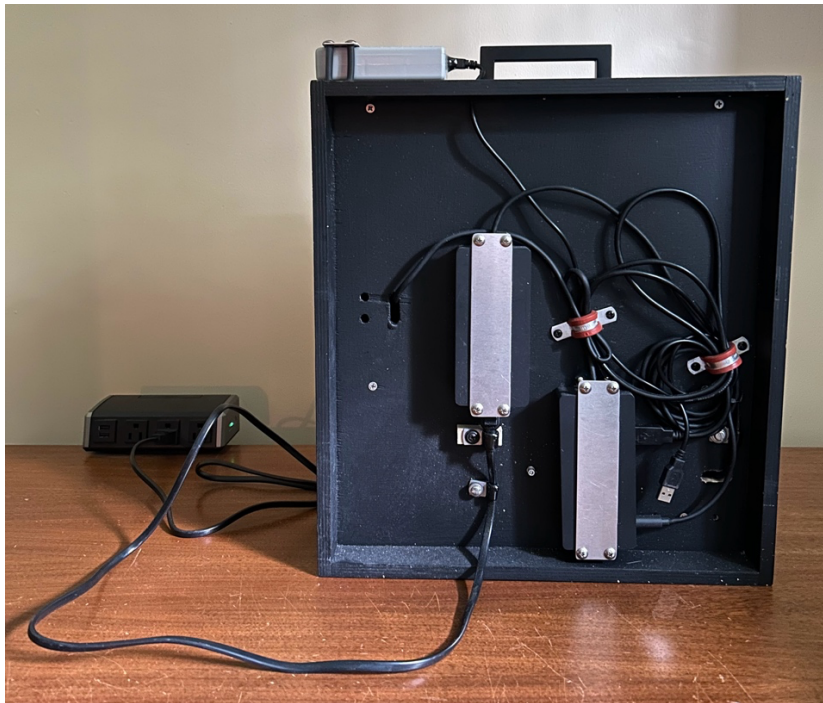
Figure 2: Back of device, not seen by audience. Device is about 4.5 inches thick, with wood panels used to arrange the faces of the computer and the multimeter to be near the front face of the device. This particular setup has both the power supply and a dock attached to it, but the dock is not needed for this purpose.

As seen in the photos, the multimeter was chosen to be set on its side with the computer above it. The computer had to be configured so that it didn't, sleep, hibernate, require a username or password, or a software update. A shortcut to the program is in the startup directory of the PC so the LargeDMM program starts automatically, but this doesn't have to be done.

Use of Apparatus

Use anywhere where you normally use a multimeter.

To use, plug in the device, turn on the multimeter, turn on the computer, and wait until everything is up and running. Settings are controlled by the multimeter; the computer merely shows the output. If the LargeDMM program is accidently stopped, it can be restarted by clicking on the arrow in the upper left hand corner that appears when the program is stopped, or by launching the program from the LargeDMM icon on the desktop.

Apparatus Title : Qunnect 4: A Novel Hands-on Educational Apparatus Based on Quantum Mechanics with Simulated Bichromatic Photons

Name: Avery Yang

Address: 3225 Carpenter Creek Pl
Cary, NC 27519

Phone: 919-701-7686

e-mail: avery.y.yang123@gmail.com

Please see the attached description.

Abstract (50-75 words):

Construction of Apparatus: Please see the attached description.

Use of Apparatus: Please see the attached description.

[Your description of the apparatus should explain how to construct and use the apparatus along with the educational value or use of the apparatus. Figures, pictures, sample lab write-ups, etc. may be included as appropriate. This description (made anonymous) will be available to the judges of the apparatus. This description will also be posted on the apparatus competition web page.]

Qunnect 4: A Novel Hands-on Educational Apparatus Based on Quantum Mechanics with Simulated Bichromatic Photons
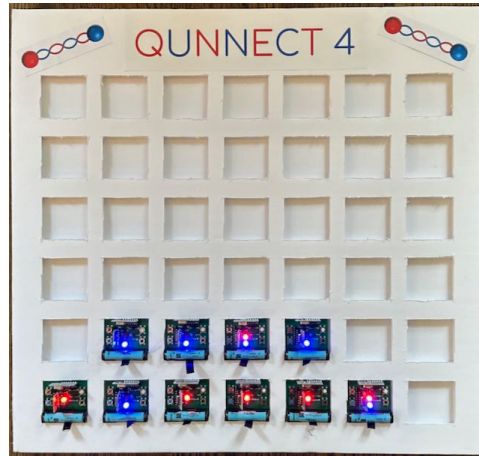
Abstract

By applying quantum physics to the classic board game Connect 4, Qunnect 4 is designed as a hands-on educational apparatus, with using simulated bichromatic photons to intuitively introduces key quantum mechanics concepts of superposition, collapse, and entanglement. By operating this simple apparatus, students can easily grasp these concepts without facing steep learning curves. Qunnect 4 seamlessly merges gameplay and education, fostering curiosity and promoting a deeper understanding of quantum mechanics.

Construction of Apparatus

The apparatus consists of 42 tokens and 1 game board.

Each token is made with a PCB, assembled with one blue and one red LED, two resistors, four diodes, one radio transmitter and one receiver, four push buttons, and one battery holder. Powered by a battery, a token simulates a bichromatic photon. The token is superposed when turned on initially, emitting both blue and red LEDs. When a button is pushed, the token collapses, emitting only one LED.

The 42 tokens are grouped into 21 pairs. Each pair of tokens simulate a pair of "entangled photons", with using the paired radio modules. Measuring one token will collapse both tokens simultaneously (one red and one blue).

The game board is made with foam board and printed paper.
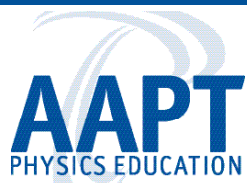
Use of Apparatus

Qunnect 4 is a quantum adaptation of the popular game Connect 4, designed to provide hands-on experiences that enable students to grasp key quantum concepts such as superposition, collapse, and entanglement with ease.

Students are encouraged to use the apparatus in a manner like playing Connect 4, with following differences:

- In classic Connect 4, each player places 1 token each turn.
- In Qunnect 4, each player places a pair of entangled tokens each turn.
- A player may choose not to place tokens. Instead, the player can press a button to collapse a pair of entangled tokens on board.
- To prevent a cycling condition, where one player always collapses the tokens placed by the other, in Qunnect 4, a player is not allowed to collapse the pair of tokens that were most recently placed. This rule ensures a fair and balanced gameplay experience for both players.

The apparatus is user-friendly, facilitating learning with its hands-on approach. Students are encouraged to play, discuss, and collaborate while exploring the variety of gameplay options it offers.

Additionally, the apparatus can be used as a simple and practical tool to assist researchers in probing advanced quantum theories, such as Quantum Game Theory and Quantum Group Theory.