Apparatus Competition

2018 Summer Meeting of the American Association of Physics Teachers

AAPT PHYSICS EDUCATION 2018 SUMMER MEETING July 28-Aug. 1 Washington, DC

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

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2018 AAPT Summer Meeting
Washington, DC

Apparatus Title: A Better Resonance Apparatus for the Undergraduate Laboratory

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Abstract: Commercially available acoustic resonance apparatus used in the introductory physics laboratory use water as the closed end or a piston with a long rod that protrudes in the way. Here we present a simple and inexpensive resonance apparatus that uses magnetic coupling to move the closed end piston. Not only is it easy to use but it does not lead to water puddles or broken shafts.

Construction of Apparatus: The construction drawings and instructions are in an attached document "2018 Apparatus."

Use of Apparatus: An example of the use of the apparatus is in the document, "EXAMPLE EXPERIMENT" at http://www.aapt.org/Contests/Apparatus-Competition-Summer-2018.cfm

Apparatus Competition, 2018 AAPT Summer Meeting, Washington DC

Abstract Title: A Simple Device to Control ON/OFF on a Laser Pointer

Name: Roger Key
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Abstract:

Laser pointers are a great tool in the classroom. Keeping one powered on while having hands free for other things can be a challenge. This small block of 3D printed plastic has a tapered notch that allows a laser pointer to slide into the opening while the power button on the laser goes into the tapered notch. The depth of the pointer into the notch controls whether the button is pressed.

This also means the laser can be aligned with a clamp and the clamp itself is not controlling the ON/OFF state of the pointer – this block simply slides over the switch when desired.

Construction of the Apparatus:

The 3D printed parts are made, and a laser pointer is inserted.

The STL files for this project are available as a zip file at http://bit.ly/AAPTAC18

Materials List:

- 3D printer filament (cost for a full roll of PLA) $23

Total Cost: $23

Apparatus Competition, 2018 AAPT Summer Meeting, Washington DC

Apparatus Title: A Three Color Laser Single Slit Demonstration

Name: Roger Key
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Abstract: Laser pointers are available in red, green and violet at reasonable prices. Using our 3D printer, we designed and build a holder for three laser pointers held vertically in a line to match the orientation of the variable width slit. We use this to demonstrate the wavelength and slit-width dependence of the single slit diffraction pattern.

Construction of the Apparatus: The 3D printed parts are made, and the laser printers are disassembled, removing the lasers. The original switch on the laser pointer laser heads are depressed to the ON position and superglue is introduced around the edge of the switch to hold them ON. They are then wired into the switch block and on to the battery holders. Our slit had a circular tube beyond the slit so we hold it by friction in the custom holder. If other slits are used, this will need to be redesigned. Some adjustment and reprinting may be needed if the lasers are not shining straight.

The STL files for this project are available as a zip file at http://bit.ly/AAPTAC18
Some photos are on the next page.

Materials List:

3 double AA battery holders – A set of 5 are currently available on Amazon	$4.
6 AA batteries – Certainly available for $1 each	$6
Scrap board.	$3
Some short bits of wire	$2
3 small toggle switches (10 pack on Amazon)	$7
3D printer filament (cost for a roll of PLA)	$23
Set of 3 laser pointers purchased on Amazon	$9
Slit (ours came as old stock, new can be purchased and the design adapted. We assume a new purchase for this price list)	$200
Total Cost:	**$254**

Apparatus Competition, 2018 AAPT Summer Meeting, Washington DC

Apparatus Title: Bubbles in Mondrian Painting

Name: Said Shakerin, Sponsored by David Kardelis
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Abstract: A sealed thin enclosure, which contains dyed glycerin and air in three separate sections, demonstrates air bubble motion in a viscous liquid. The enclosure was designed primarily as a decorative device. However, after the enclosure is turned upside down multiple times, large bubbles eventually break into smaller bubbles and some of the more subtle bubble dynamics, such as interactions between tandem bubbles, are visualized too.

Construction of Apparatus: Since all materials were purchased in the US, inches are used to specify parts. The enclosure is made entirely of acrylic sheet stock and measures 10" x 8"x 5/16". The front and back are 1/8" thick, clear and white acrylic, respectively. Four 1/4"-wide strips cut from thin, 1/16" thick, acrylic sheet serve as spacers around the enclosure. Several more strips divide up the enclosure into six separate sections. This is to resemble one of the paintings of Dutch painter, Piet Mondrian (1872-1944). His most famous paintings are abstract compositions of black-bordered rectangles of white, red, blue and yellow. I added a fluid dynamics twist, namely air bubbles, to the painting. A small part of an outside strip of each of the sections to be filled with glycerin is cut, but saved, to provide an opening for later filling of glycerin in that section. All parts, except the small cutouts, are glued together with acrylic cement. Glycerin is dyed with a few drops of food color and injected into the desired section with a hypodermic needle. The saved cutout piece for that section is then placed in the opening and glued. This step is repeated for other sections to be filled with glycerin, and in our case, three sections were filled with glycerin. Syrup-like acrylic glue is then applied around all edges to further reinforce and seal all joints.

To make this enclosure one needs to know basic fabrication techniques, and especially how to make leak proof joints in acrylic. Online resources to help with acrylic fabrication techniques are available. For example, view instructional videos on cutting and gluing acrylic at tapplastics.com. Special care is also required to ensure the internal strips are glued to both front and back surfaces. Practice on scraps before final fabrication. Further fabrication tips will be provided upon request (send email to the author).

Use of Apparatus: The enclosure is designed for demonstration in class or outreach, or as an interactive device for individual experimentation. It has a simple design and can be instantly set up, does not require electricity or maintenance, and can be used repeatedly without a need to clean up.

It is easy to use the enclosure to demonstrate air bubble motion in viscous liquid. Pick the enclosure up from its cardboard stand, turn it upside down in the vertical plane, and observe how air bubbles rise to the top. After several turnings, bubbles are divided into smaller bubbles which result in exhibiting some subtle bubble dynamics, for example bubble merging, and more visual engagement.

Cost: $26

Materials/Supplies List: (price as of March 2018) See online support files at http://www.aapt.org/Contests/Apparatus-Competition-Summer-2018.cfm

Acknowledgement: Funding was provided by the Faculty Research Committee, University of the Pacific.

Apparatus Competition 2018 AAPT Summer Meeting, Washington, DC

Apparatus Title: Electric Force via Atwood Machines

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Abstract:
This low cost apparatus transitions students from mechanics (gravity) to electrostatics (E&M) with an atwood machines where students investigate this "new force that can be turned on and off". The apparatus presented here creates an electric field and an electrical force that overcomes gravity such that the object moves upwards on the atwood machine. Students say things like "wow that is magic". The vital aspect of this atwood machine is that video tracker can be used to calculate the acceleration from distance and time measurements and therefore the new force from free body diagrams. Acceleration and free body diagrams give students confidence to begin to understand the basics in electrostatics.

Construction of Apparatus:
Here is a list and description of the major components of the apparatus:

- General Lab Equipment: Simple Atwood's Machine setup consisting of two pulleys on stands
- General Lab Equipment: Clear Thread or Fishing Line
- General Lab Equipment: Paper Fasteners
- Amazon Purchase: 50 - 5 inch Foil Pot Pie Pans $20.99
- Arbor Scientific Purchase: Levitation Wand $12.99
- Pasco Purchase: 1 Conductive Sphere (Pasco ES-9059C): $47.50

Use of Apparatus:

This equipment can be used to investigate the electrical force strength overcoming the gravitational force.

This laboratory can first be set-up as an inquiry investigation with various numbers of charging wands (Van de Graaff) and pie plates. With an increase in number of wands, the faster the electrons pile onto the pie plates and the faster the pie plates accelerate upwards. With an increase in the number of pie plates, the mass increases and the slower the pie plates accelerate upwards.

Upon finishing the inquiry-based investigation, students can either implement a traditional cookbook laboratory or our experimental design laboratory (both laboratory write-ups and sample lab reports are listed in the Reference Section). In either case, students will measure distance versus time to calculate acceleration and electric force. Set up the equipment as shown below.

Here is a set of sample data where students have to split the data into parabolic curve and linear curve and describe when the electric force is acting to create an acceleration. Below is the students presenting all their data in the data section of their lab report and then the Lab TA grading them as if they did not understand. However, the students then grab only the data with acceleration (and electric force causing acceleration) and the Lab TA writing, "ahh, I see nice!".

The analysis methodology used in this lab report typically involves regression-based and then error propagation pathway analysis for calculating acceleration and uncertainty of acceleration, then error propagation for electrical force. Students typically vary number of pie plates and number of wands. Here is a linked student video of data taken with student cell phone and video Tracker analysis (from ComPadre).

References:

- Cookbook Lab:

- Experimental Design Lab:

- Sample Lab:

Apparatus Competition 2018 AAPT Summer Meeting, Washington, DC

Apparatus Title: Granular Flow: Angle of Repose and Clumping

Name: Said Shakerin, Sponsored by David Kardelis

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Abstract: Angle of repose and clumping, which are among important characteristics of granular flows, are demonstrated with this thin enclosure. Divided into two separate sections, the enclosure partially contains sand in one section and ceramic microspheres in the other; air fills the rest of the volume. Identical multiple rod segments (partitions) serve as obstacles in both sections to alter the flow. The enclosure is designed to compare flows of relatively coarse and fine granular materials side-by-side. The average grain sizes between these two granular materials differ by an order of magnitude.

Construction of Apparatus: Since all materials were purchased in the US, inches are used to specify parts. The enclosure is made entirely of acrylic sheet and rod stocks. The front and back are 1/8" thick and 8” by 10”. White acrylic is used for the back to provide contrast with the granular materials. Four 1/4"-wide strips cut from thin, 1/16" thick, acrylic sheet serve as spacers around the enclosure. Thin rod, 1/16" diameter, cut to various lengths serve as partitions. A small part of one of the edge strips in each section is cut, but saved, to provide an opening to fill the sand or ceramic microspheres (CMS). All parts, except the small cutouts, are glued together with acrylic cement and let to completely dry overnight. The sand and CMS are carefully and slowly poured into the enclosure through an improvised trough made of simply a piece of folded paper that is partially inserted in the opening. (Average CMS grain is 0.006”, which is approximately 1/10th of sand. CMS is typically used as a thickening agent in epoxies.) About 40% of the volume of each section is filled with granular material. The saved cutout
pieces are then placed and glued in the openings. Syrup-like acrylic glue is then applied around all edges to further reinforce all joints.

To fabricate this enclosure one needs to know basic fabrication techniques. Online resources to help with the techniques are available. For example, view instructional videos on cutting and gluing acrylic at tapplastics.com. Special care is also required to ensure the small partitions are glued to both front and back surfaces. Practice on scraps before final fabrication. Further fabrication tips will be provided upon request (send email to the author).

Use of Apparatus: The enclosure is designed for demonstration in class or outreach, or as an interactive device for individual experimentation. It has a simple design and can be instantly set up, does not require electricity or maintenance, and can be used repeatedly without any need to clean up.

It is easy to use the enclosure to demonstrate angle of repose and clumping. Pick the enclosure up from its cardboard stand, turn it upside down, or through 90o steps in the vertical plane; and observe the resulting flow of sand and CMS to lower surfaces due to gravity. Once the flow stops, angle of repose, i.e., the slope of the mound of granular material, is clearly demonstrated, especially for the sand. However, the angle of repose for CMS is not as clearly demonstrated, mainly due to clumping that takes place in CMS. Notice there is no clumping in the sand. The reason for clumping is friction among the grains, which is much more in CMS than sand. Occasionally, air pockets are entrapped in CMS, and this is a demonstration of 2-phase (gas-solid) in granular flow. Sample images are shown in the online support files at www.aapt.org/Contests/Apparatus-Competition-Summer-2018.cfm

Acknowledgement: Funding was provided by the Faculty Research Committee, University of the Pacific.

Apparatus Competition 2018 AAPT Summer Meeting, Washington, DC

Apparatus Title: Granular Flow: Landslide and Eruption

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Abstract: Landslide- and eruption-like flows, which are among important characteristics of granular materials, are demonstrated with this acrylic cylinder that contains ceramic microspheres (average grain = 0.006") and air. The cylinder is made of two chambers, separated by a disk that has different shaped holes.

Construction of Apparatus: Since all materials were purchased in the US, inches are used to specify parts. The 4" diameter cylinder is made of two shorter cylinders, each one capped by a solid disk at one of its ends, with a perforated disk between them. A laser cutter was used to cut different shaped holes in that disk. (In the absence of a laser cutter, a milling machine with appropriate cutting heads would be needed.) The ceramic microspheres (CMS) were poured into one of the cylinders before gluing the other cylinder. Care was taken to pour CMS slowly to reduce scattering of its fine dust. Three 3/16" rods were glued around the middle of the cylinder to reinforce the assembly. (CMS is typically used as a thickening agent in epoxies.)

To fabricate this enclosure one needs to know basic fabrication techniques. Online resources to help with the techniques are available. For example, view instructional videos on cutting and gluing acrylic at tapplastics.com.

Use of Apparatus: The cylinder is designed for demonstration in class or outreach, or as an interactive device for individual experimentation. It has a simple design and can be instantly set up, does not require electricity or maintenance, and can be used repeatedly without any need to clean up.
It is easy to use the cylinder to demonstrate landslide and eruption. Simply, turn the cylinder upside down and observe the flow of CMS as it falls through the holes. The flow starts with a series of irregular landslides (similar to avalanches) and eruptions. Each eruption is venting due to pressure build up in the lower chamber. Notice the order in which holes are cleared, usually square hole first and always cluster of five small holes last. In rare occasions, jamming occurs above the five small holes. Also, I tried sand instead of CMS in the cylinder. The sand flow was steady and quick, i.e., much less complex.

Sample images and Materials supply List are in the online resoyrce files at www.aapt.org/Contests/Apparatus-Competition-Summer-2018.cfm

Acknowledgement: Funding was provided by the Faculty Research Committee, University of the Pacific. Jeremy Hanlon fabricated the disk with laser cutter.

Apparatus Competition 2018 AAPT Summer Meeting, Washington, DC

Apparatus Title: Hall Switch Enabled EM Pulser

Name: Stephen Irons
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Abstract: Presented is a circuit that can be built cheaply, which will reliably turn a solenoid/inductor on and off very quickly in response to a magnetic field applied to a Hall-effect switch. We have designed it to permit the acceleration of objects with embedded magnets, such as a top or a fidget spinner to high angular velocities. The design is simple and can be constructed either on a prefabricated PCB or generic perf board.

Principle of Operation: The pulser works by using a sensor to turn on an electromagnet at a point when a magnet mounted in the edge of the spinning object will be momentarily attracted to an electromagnet. The sensor is placed so that it turns the electromagnet on and off at just the right time to provide a pulse of torque in same direction each time the magnet nears the sensor . It is best explained in the following time progression diagram included in the online resource files at www.aapt.org/Contests/Apparatus-Competition-Summer-2018.cfm

Operation and Construction of Apparatus: See the online Resource files at www.aapt.org/Contests/Apparatus-Competition-Summer-2018.cfm

Use of the Apparatus: The EM pulser can be used in a variety of ways to create student engagement and promote the learning of important physics skills and concepts.

Simple Electronics Project
This is an interesting yet simple circuit to understand, and it contains several important principles while making use of a variety of components.

1. It demonstrates the use of a FET to control a large current with an applied voltage.
2. It uses an NPN transistor to create a NOT gate to flip a signal from LOW to HIGH.
3. It makes use of a digital device, the Hall switch to flip a system between two discrete states.
4. It uses a diode across an inductor to prevent damaging voltage spikes due to the inductive load

created when the inductor is switched on and off.
5. It is a good lesson in soldering and component placement, whether you use the prefabricated PCB board or lay it out on a generic perf board.

Electromagnetic Fields

This device shows how permanent magnetic fields can interact with electric currents and vice versa. It is common and understandable for students to view ferromagnetism as essentially different from magnetism created by moving charges. The clear interaction between the inductor and the permanent magnets, is powerful reinforcement that they in fact do derive from the same physical underpinnings. Students may also notice the similarity of this device to an electric motor and how it is essentially converting electrical energy into mechanical energy.

Rotational Motion and Gyroscopic Effects

Tops and fidget spinners are great examples of rotational motion and a good way to motivate discussions of their dynamics, kinematics and angular momentum. The test points on the circuit board can be fed into an oscilloscope and the signal visualized as the top's angular velocity increases demonstrating the difference between angular velocity and angular acceleration. Alternatively, a microphone and a scope can be used to visualize to the increasing frequency of the hum as the top speeds up. Once the top is spinning on the tabletop, the instructor can also discuss the forces and torques that give rise to the balancing effect of the top, as well as the precession, precession speed and ultimate instability as friction slows the top down.

Apparatus Competition 2018 AAPT Summer Meeting, Washington, DC

Apparatus Title: Lazy Spinner: You spin me right round

Name: Marc “Zeke” Kossover

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Abstract:
Lazy Susans are really useful for physics, but they often slow down too fast to be useful. The problem is that the typical bearings are strong but full of friction. Fidget spinners have great bearings and they are easy to install.

Construction of Apparatus:
Please see https://tinyurl.com/2018-AAPT-entry

Use of Apparatus:
Lazy susans have lots of uses, but a typical use is to attach a thin aquarium through the center to examine centripetal force

Apparatus Competition 2018 AAPT Summer Meeting, Washington, DC

Apparatus Title: Magnetic Force via Atwood Machines

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Abstract:
This low cost apparatus transitions students from mechanics (gravity) to magnetism (E&M) with an atwood machines where students investigate this "new force that can be turned on and off". The apparatus presented here creates a magnetic field and an magnetic force that overcomes gravity such that the object moves upwards on the atwood machine. Students say things like "wow that is magic" with a discussion about what is an electromagnet. The vital aspect of this atwood machine is that video tracker can be used to calculate the acceleration from distance and time measurements and therefore the new force from free body diagrams. Acceleration and free body diagrams give students confidence to begin to understand the basics in magnetism.

Construction of Apparatus:
Here is a list and description of the major components of the apparatus:

- **General Lab Equipment: Simple Atwood's Machine setup consisting of two pulleys on stands**
- **General Lab Equipment: Clear Thread or Fishing Line**
- **General Lab Equipment: Power Supply**
- **Amazon Purchase: 4 Magnet Hooks**
  $ 9.99
- **K&J Magnetics: 10 Permanent magnets**[1]
  $16.90
- Quanta Magnetics: 1 Coil 3"Dia x 3/4"W incl. Alligator Clips
  $25.00
- (OR) General Lab Equipment: Field Coil

Use of Apparatus:
This equipment can be used to investigate the magnetic force strength overcom-

1 https://www.kjmagnetics.com/proddetail.asp?prod=D84PC-BLK

ing the gravitational force.

This laboratory can first be set-up as an inquiry investigation with various strengths of voltage (from power supply) and different numbers of magnets. With an increased voltage, the strength of the magnetic field increases and the permanent magnet accelerates upwards faster. With an increase in the number of magnets, the mass increases and the slower the permanent magnets accelerate upwards. When the direction of the current changes, the permanent magnet moves down instead of up which encourages students to ask about the direction of the magnetic field and force.

Upon finishing the inquiry-based investigation, students can either implement a traditional cookbook laboratory or our experimental design laboratory (both laboratory write-ups and sample lab reports are listed in the Reference Section). In either case, students will measure distance versus time to calculate acceleration and magnetic force.

A set of sample data where students have to split the data into parabolic curve and linear curve and describe when the electric force is acting to create an acceleration is included in the online resource files at www.aapt.org/Contests/Apparatus-Competition-Summer-2018.cfm.

The analysis methodology used in this lab report typically involves regression-based and then error propagation pathway analysis for calculating acceleration and uncertainty of acceleration, then error propagation for magnetic force. Students typically vary number of magnets and strength of voltage.

References:

- Cookbook Lab:
- Experimental Design Lab:
- Sample Lab:

Apparatus Competition 2018 AAPT Summer Meeting, Washington, D.C.

Apparatus Title: Newton's Third Law, Internal, and External Force Demonstrator

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Abstract: Two simple structures created from three 12 Volt muffin fans provide a tool for understanding Newton's Third Law. The corresponding demonstration has many elements of good teaching: it connects to a good story that piques the students' interest, gives them the chance to make predictions, helps them visualize forces, and provides a model to guide their free-body analysis of a system of objects that have the same acceleration.

Construction:
Materials needed:
- 3 12 Volt Muffin fans (computer cooling fans)
- 6 feet red wire
- 6 feet black wire
- Shrink wrap tubing or electrical tape
- 4 Alligator clips or lug nut wire terminals
- 1/8" dowels (double check the diameter of the mounting holes of your muffin fan before purchasing)
- 1/8" to ¼" square profile balsa wood (approximately 14 linear feet)
- Balsa Wood Cutter or Razor Saw
- Wood glue
- Wire strippers, soldering iron, and solder

Additional Lab Supplies:
- 9 to 12 Volt power source (A 9 Volt battery works, but does not provide as significant a difference in scale reading.)
- Digital balance
- A piece of cardboard or plastic large enough to cover the fan.

Use of Apparatus:
Demonstrations are in the online resource files at www.aapt.org/Contests/Apparatus-Competition-Summer-2018.cfm

Cost and References are included in the online resource files

Apparatus Competition 2018 AAPT Summer Meeting, Washington, DC

Apparatus Title: Rotational Flow Instability

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Abstract: Rotational flow instability, which is an advance topic in physics of fluids but easily observable, is demonstrated with this sealed acrylic tube that is vertically held on a turntable. The tube contains dyed rheoscopic fluid, which is water plus pearl-like crystals highly sensitive to local shear. The tube is spun about 20 revolutions by flicking the turntable, and then stopped. As the fluid spins down horizontal rings, known as Taylor vortices, appear along the tube. The toroidal vortices show the secondary flow imposed on the original rotational flow.

Construction of Apparatus: Since all materials were purchased in the US, inches are used to specify parts. The 1” diameter tube is capped by acrylic disks and sealed at both ends, and then covered with plastic caps. Detailed construction of a similar tube, which was previously used in a completely different demonstration, is available.1 The disk and the base are glued to the opposite sides of a plastic turntable. Four small brackets are cut from scrap acrylics and glued to the disk to hold the tube in the vertical orientation. To make this tube one needs to know basic fabrication techniques, and especially how to make leak proof joints between acrylic parts. Online resources to help with the fabrication techniques are available. For example, view instructional videos on cutting and gluing acrylic at tapplastics.com.

Use of Apparatus: The tube is designed for demonstration in class or outreach, or as an interactive device for individual experimentation. Furthermore, it has a simple design and can be instantly set up, it requires no electricity or maintenance, and can be used repeatedly without a need to clean up. It is easy to use the tube to demonstrate flow instability due to rotation. If the tube has been idle, shake it to mix the crystals. Place the tube vertically in its holder, inside the four brackets. While holding the base with one hand, flick the turntable (white disk) 4-5 times to cause about 20 revolutions, and then stop the disk. As the liquid spins down, horizontal rings, known as Taylor vortices, appear along the tube as a result of secondary flow imposed on the main rotational flow. Sample images appear in the online resource files at www.aapt.org/Contests/Apparatus-Competition-Summer-2018.cfm.

Reference:
Shakerin, S., "Fluids Demonstrations:..," The Physics Teacher, Vol. 56(4), pp. 248-252, (2018).

Acknowledgement: Funding was provided by the Faculty Research Committee, University of the Pacific.

Apparatus Competition 2018 AAPT Summer Meeting, Washington, DC

Apparatus Title: Timecage

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Abstract: Strobe lights have been used for years to demonstrate wave behavior and beat frequencies. This apparatus drives an arbitrary object at a selectable frequency and illuminates the object at different selectable frequency, revealing stroboscopic effects in a single convenient display.

Construction of Apparatus: Coil winding, LED selection, material selection, consideration of mechanical resonances, power electronics, microcontroller programming, machining and woodworking.

Use of Apparatus: This apparatus can be mounted to a wall or may be used in a freestanding environment. The demonstration is beautiful and perplexing, yet still allows the user to play with the drive and illumination parameters to uncover properties of resonance, waves, exposure and beat frequencies.

Additional information is in the online resource files at www.aapt.org/Contests/Apparatus-Competition-Summer-2018.cfm

Apparatus Competition 2018 AAPT Summer Meeting, Washington, DC

Apparatus Title: Ultrasonic Ear with Transmitter

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Abstract: The Ultrasonic Ear detects and makes audible ultrasonic frequencies through the use of a heterodyne circuit that mixes a detected acoustic signal with a stable local oscillator that is subsequently filtered and made audible with an ordinary speaker. Similar circuits are often referred to as a bat detectors, though here we have adapted it to a lab investigating the speed of sound through the phenomenon of the doppler effect in a swinging pendulum.

Construction of Apparatus: While the Ultrasonic Ear can in principle detect any ultrasonic signal near it, we also provide a simple transmitter that can be attached to any number of objects or apparatus. It consists of a 555 timer in a simple astable configuration driving a 10mm 40 kHz transducer. A trim pot is used to locate the transducer's particular resonance so as to provide the largest possible output. To tune the transmitter, look at the signal going to the transducer on an oscilloscope and adjust the trim pot until a maximum amplitude is displayed on the scope.

PCB Transmitter Construction and assembly

The transmitter is driven by and mounted on a custom designed circuit board in the shape of a bat (of course).The emitting transducer is secured to the circuit board by a screw terminal, which allows the transducer to be at 90 degrees to the board surface. As with all PCB circuits, start soldering small parts like resistors first, then move on to the larger parts (double check polarity). The transmitter is designed to have two anchor points to connect easily to a meter stick (or any other object) with a bolt or zip tie. When mounted on a pendulum, you should use a meter stick with predrilled hole in the end so it can be hung on a horizontally mounted pin or screw so it can swing freely. A schematic is shown in the appendix, and the PCB board files are on github (https://github.com/penoel/Bat-Detector).

PCB Heterodyne Receiver Operation

The heterodyne receiver consists of 7 modules: pre-amp, op amp, diode mixer, local oscillator, low pass filter, audio amplifier, and speaker (see Fig. 1).

The preamp amplifies the signal and using the popular 2n3904 transistor in a common emitter configuration.

The Op-amp further amplifies the signal using the LM358 which can operate from a single supply and is commonly available.

The local oscillator module again uses the 555-timer in astable mode. The tuning pot on the local oscillator allows the user to adjust the ultimate output frequency of the speaker.

The diode mixer takes the local oscillator signal and adds it to the amplified input signal. It is an unbalanced mixer that does not require a special diode, only a standard 1N4007.

The low-pass filter eliminates everything except the beat frequency (the difference between the local oscillator and received signal frequencies.

The audio amplifier (LM386) amplifies this signal so it can drive a speaker without the need for a push-pull amplifier.

The speaker outputs the beat frequency which will fluctuate based on the fluctuations in the received signal.

As with the transmitter, take care in soldering in the components.

Uses: Student Physics Laboratory – At our institution, we have a speed of sound lab in which students use an ultrasonic transmitter on a pendulum to measure the Doppler shift with an arbitrary waveform generator. From these data they calculate the speed of sound. The Ultrasonic Ear allows students to hear the doppler effect as well.

Demonstration – This is a powerful alternative illustration of the Doppler effect. In contrast to the ubiquitous (and annoying) spinning buzzer. The Ultrasonic Ear and Transmitter can be used to very clearly (and pleasantly) shows how the frequency shifts up when the source and receiver are moving toward each other and downward when they are moving away. If one mounts the transmitter at the end of a pendulum (of varying length) and places the receiver facing it (as shown in Fig. 2), students can measure the period audibly, allowing visually impaired students to investigate the frequency dependence of the pendulum on amplitude, length and mass.

Bat Detector – With some adjustments to the gain of the Preamp, the Ultrasonic Ear can be turned into a bat detector. Taken outside, in the presence of flying bats you will be able to hear their echolocating chirps as they hunt for food. While you won't be hearing the actual frequencies they are emitting, you will hear the fluctuations in their calls which vary by species and prey type.

Warning: Many modern buildings now have ultrasonic sensors that control lighting. This detector will sense this signal and may interfere with your experiment.

Basic Doppler Theory

As the source and receiver move relative to each other, frequency shift is given by:

$f=f_0$ ((c±v_r)/(c±v_s))

where f0 is the transmitter frequency, c is the speed of sound, vr is the velocity of the receiver, and vs is the velocity of the source (transmitter). The ± addresses motion toward each other (+) and away from each other (-). In the case of a 1 m pendulum with a reasonable amplitude the doppler shift will be a maximum of about 200Hz. While this is small compared to the transducer frequency (about a 1% shift), when mixed with the local oscillator frequency down to audible ranges, such a shift is easily noticeable.
As the theory demonstrates, when the pendulum approaches the receiver, the wavelength is compressed and the frequency upshift will be a maximum as it passes through the lowest point. At the top of the swing, the velocity is 0 so no shift occurs. As it travels away from the receiver, the wavelength is stretched but the frequency downshifts and is a maximum at the lowest point.

Basic Operations:
Connect the transmitter to the meter stick and the meter stick to the lab stand. Place the receiver in front of the pendulum so that the transducers are aligned (ultrasonic transducers are fairly focused)
Turn both on
Adjust the local oscillator on the receiver to a pleasant frequency
Start the pendulum swinging

Note: If it doesn't make a sound, adjust the pots on the mixer. These pots are to make sure the signal the diode sees is around turn on. About 90 percent of the motion of these pots will work.

Conclusion: The Ultrasonic Ear and Transmitter makes for a fun way to illustrate the Doppler effect and offers an introduction to ultrasonic sound and how it can be manipulated to make detectable signals that our ordinary senses cannot discern. The electronics that make the ultrasonics audible are a good introduction to several important electronic devices (amplifiers, mixers, filters, oscillators).

Appendix and images are inclided in the online resource files at http://www.aapt.org/Contests/Apparatus-Competition-Summer-2018.cfm

Apparatus Competition 2018 AAPT Summer Meeting, Washington, DC

Apparatus Title: Wake Vortices

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Abstract: Wake vortices, which form behind an object moving through a fluid, are demonstrated with this double-sided thin enclosure. Wake vortices are an important consideration in determining drag. The enclosure contains, on each side, dyed rheoscopic fluid (RF) and a large air bubble that serves as the object. The RF is water plus pearl-like crystals (additive) that are sensitive to local shear, thereby enabling flow visualization. On the green side there is a partition with a central gap, while there is no partition on the pink side.

Construction of Apparatus: Since all materials were purchased in the US, inches are used to specify parts. The enclosure is made of acrylic sheet and rod stocks. The front and back are 1/8" thick and cut to desired size, in this case 12" by 2". White acrylic is used for the back to increase contrast. Four 1/4"-wide strips cut from thin, 1/16" thick, acrylic sheet serve as spacers around the enclosure. A small section of one of the strips is cut, but saved, to provide an opening to fill the rheoscopic fluid. All parts, except the small cutout, are glued together with acrylic cement.

The rheoscopic fluid is dyed with a few drops of food color, and injected into the opening with a dispenser equipped with a hypodermic needle. The saved cutout piece is placed in the opening and glued. Syrup-like acrylic glue is then applied around the edges to further seal and to reinforce all joints. Following the above steps another enclosure is made on the back, making the overall enclosure double-sided. To provide variety, and to somewhat regulate air bubble generation, one side has a partition with a ¼" gap. The partition is made of 1/16" rod.

To fabricate this enclosure one needs to know basic fabrication techniques, and especially how to make leak proof joints between acrylic parts. Online resources to help with the fabrication techniques are available. For example, view instructional videos on cutting and gluing acrylic at tapplastics.com.

Use of Apparatus: The enclosure is designed for demonstration in class or outreach, or as an interactive device for individual experimentation. It has a simple design and can be instantly set up, it requires no electricity or maintenance, can be used repeatedly, and without a need to clean up.
It is easy to operate the enclosure. If it has been idle, pick it up from its stand and shake it well to remix the content as settling of crystal does take place in rheoscopic fluid. Wait a few seconds to allow large eddies to settle, and then turn

it upside down. On the green side, if needed, gently tap the enclosure to break the surface tension of RF to get the air bubbles going at the gap in the partition. Observe the wake vortices as a series of air bubbles rise above the partition. On the pink side, shake the enclosure vigorously to break the large bubble into smaller ones. Then, turn the enclosure upside down and observe the wake vortices behind clusters of small air bubbles.

Images and the Materials/Supplies List are online in the Resource Files at http://www.aapt.org/Contests/Apparatus-Competition-Summer-2018.cfm

Apparatus Competition 2018 AAPT Summer Meeting, Washington, DC

Apparatus Title: Wireless Power Transmission using Pancake Coils

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Abstract: Wireless Power Transmissin (WPT) has many current and future applications from charging portable electronic devices to charging electric cars. A pancake transmitter coil connected to a simple transistor circuit and supplied a direct current generates an alternating current that is picked up by a receiver coil with an LED attached. This system provides a phenomenal example of WPT for classroom demonstrations and interesting opportunities for making a variety of measurements in the lab.

Construction of Apparatus

This system is inspired by Nikola Tesla's 1894 Patent No.512,340 for a pair of electromagnets, shown in Figure 1 (See online Resource Files at http://www.aapt.org/Contests/Apparatus-Competition-Summer-2018.cfm), in which the transmitter was meant to be connected to a high frequency alternating current.
This setup uses a direct current input and a transistor circuit to achieve the time-varying current. First, the transmitter coil and receiver coil must be wound into a flat, spiral shape (i.e a pancake shape).

The transmitter coil is made using bifilar wire (two wires for the core, covered by a sheath) while the receiver is made using unifiliar (single-stranded) wire.

For this setup, 16-gauge bifilar and 14-gauge unifilar wire are used, but any gauge could be used in principle. One effective way to achieve the pancake shape of the coils is using an old CD-rack as a frame and winding tightly around the center post. While winding, a fast-drying super glue (or another strong, fast-drying adhesive) is applied between the wires and is reapplied on top every 3-4 new turns. (It is recommended that the glue be allowed to set between every new 3-4 turn interval for at least 30 minutes.

Compressing it under masses helps the coil remain flat and keep its shape.) Once the coil is fully assembled, the coils are coated in more adhesive and wrapped in packing tape to ensure the coils keep their shape and stay tightly wound. It is recommended that the coils sit overnight with masses on top to ensure the adhesive is set.

Next, alligator clips are soldered to the ends of the receiver coil, and a load can be connected as shown in Figure 2 (See online Resource Files). For classroom demos, an LED works well as a load in order to provide a visual demonstration of wireless power transfer.

The transmitter coil shown in Figure 3a (See online Resource Files) has the leads labeled for connection to the positive end of the battery (+), the base-leg of the transistor (b), and the collector-leg of the transistor (c).
Figure 3b shows the circuit diagram for the transmitter coil. It should be noted that two wires A' and B (A being the outer wire within the sheath, and B being the inner wire within the sheath) are both connected to the positive battery terminal (+). B', which comes from the center is connected to the base leg of the transistor, and A is connected to the collector leg of the transistor. Figure 3c is another schematic for the circuit using Tesla's coil illustration with the transistor circuit overlaid.

Direct current flows through both coils of the transmitter but in opposite directions. When current flows to the transistor's base, current is also allowed to flow from the collector leg to the emitter leg, which in turn completes the circuit. The strength of the field generated by the coil is dependent on the amount of current flowing in the circuit. When another coil (receiver) is brought into the vicinity of the transmitter's varying electromagnetic field, current is induced in the receiver via mutual inductance. This coupling between the two coils allows an alternating current to flow through the receiver. Because the current is oscillating at such a high frequency

Fig. 4. (See online Resource Files) (a) Completed setup from above. The transmission coil is sitting under the receiver coil. (b) The two coils separated with the LED illuminated, demonstrating wireless power transmission.

Use of Apparatus:

1. Classroom demonstrations

Wireless Power Transmission using pancake coils is a great demonstration of Faraday's Law, showing that time--varying currents in the transmitter produce time-varying magnetic fields around the coils, which, in turn, induce an emf and therefore a current in the receiver coil allowing the LED to illuminate. Moving the receiver coil vertically away from the transmitter shows that the magnetic field strength falls off with distance, and at some separation, the LED turns off when the induced emf is not large enough. It is also instructive to show the time-varying nature of the system using an oscilloscope.

By including a potentiometer in the circuit in series with the current limiting resistor, while using a DC power supply, one can demonstrate that as the voltage and current increase, the coil separation can increase while the LED remains illuminated. It is important to note that a current--limiting resistor (around 10 Ω) should remain in the circuit with the potentiometer because the 2N2222 transistor can only handle a current of up to 600mA so it is easy to blow the transistor if only a potentiometer is used. Including an ammeter to monitor current is recommended. It is interesting to note that an LED requiring 1.9 !" to illuminate can be illuminated by providing only about 1 V to the transmitter coil. Why? The induced emf peaks above the turn-on threshold, but with relatively low current compared to the transmitter. The frequency of the EMF driven by the transistor switching on and off in the transmitter coil leads to the appearance that the LED is constantly on.

This demonstration is very portable when using a single AA along with the other specified components (rather than using a stationary DC power supply).

Additional Dmonstrations, Materials and costs are in the online Resource Fikes at http://www.aapt.org/Contests/Apparatus-Competition-Summer-2018.cfm

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