Apparatus Competition

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Apparatus Title: **3D Printed Roberval Balance Improvements**

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This Roberval Balance design is a modification to a design posted online. The major improvement is the use of bearnings

Abstract: to make the motion smoother. Other versions show subtle mechanical changes to improve balance functions.

Construction of Apparatus:3D printed frame, Friction fit bearings, Mounted to empty printer filiment spool.

Use of Apparatus: The balance is insensitive to the location of the masses. The “pans” are contrained to remain horizontal balancing the torque for any mass placement. The bent-crossbar version demonstrates a self-centering mechanisim. And the beam balance version demonstrates the mechanics of a beam balance.

Apparatus Title: 3-in-1: Centrifugal Effect, Coriolis Effect, Thermal Instability

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Abstract: Acrylic disk-shaped enclosure contains rheoscopic fluid (water + crystals), food color and an air bubble, on a turntable base, which is slightly tilted to cause the bubble to be at rest at the top edge. RF and bubble simulate atmosphere and cloud, respectively. By spinning the disk the bubble, which is lighter than the RF, is forced to the center, demonstrating the centrifugal effect. Also, the Coriolis effect can be observed by noticing how the bubble sidles to right or left, depending on the initial spin direction, once the disk is stopped and the bubble moves back to its resting place. Furthermore, if the disk is placed on a cup of hot beverage, within 30-45 seconds convection cells are observed on the top surface. These arise due to the high temperature at the bottom and room temperature at the top of the disk.

Construction of Apparatus: Although this is a new disk enclosure, its construction follows published procedure in reference 1. Briefly, it is made of small length of acrylic tubing that is covered at its two ends by two disks. RF is dispensed into the disk via a hole drilled in the tubing. Once filling is done and appropriate size bubble is achieved (by squeezing the two disks), the hole is covered with a small piece of acrylic and glued/sealed. Ref. 1. Fluids Demonstrations, The Physics Teacher, pp. 248-252, April 2018.

Use of Apparatus: It is simple to use the disk enclosure. Simply spin the disk until the bubble is forced to the center (centrifugal effect). Stop the disk. Observe how the air bubble moves/sidles as it moves back to its resting position at the top edge. The direction of sidle depends on the spin direction, and is a demonstration of the Coriolis effect. For CCW spin, the sidle is to the right (Northern Hemisphere), and for a CW spin, the sidle is to the left (Southern Hemisphere). For observing thermal instability, a hot temperature source is need. A convenient source is a cup of hot beverage. Remove the disk from its base, and place it on the cup.

Within 30-45 seconds, thermal convection cells (known as Benard cells) are visible on the surface. These cells are developed due to temperature differential between the bottom of the disk (high temperature) and the top of the disk (low or room temperature).

Apparatus Title: Adjustable Laser Pointer Holder

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Abstract: 3D princt: ted design allows fine adjustment of rod-mounted laser pointer. Adapted from three other 3D designs shared by others and merged into this apparatus.

Construction of Apparatus: 3D printed parts, machine screws, springs, ball bearing

Use of Apparatus: Measuring the diffraction lines from a CD or DVD set on a table surface can be done by pointing a laser pointer directly down and measuring the angle of the outgoing diffraction directions. Precise adjustment to make the direction reflection from the disk return directly to the laser pointer insures that the laser is perpendicular.

Apparatus Title: An Affordable Physical Pendulum: The Pipe Pendulum

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Abstract: Introductory mechanics includes the study of mechanical oscillators, and oscillators with more than one control variable pose a useful challenge to students. We therefore built affordable physical pendulums from sections of PVC pipe suspended by string. We measured the period of small amplitude oscillations using a stopwatch and found that pipes shorter than 45 cm have measured periods that agree with theoretical predictions to within 2%. A 3D-printed clamp assembly facilitates variation of string length.

Apparatus Title: Apparatus for teaching the refraction of light by fluidic lenses formed by water-walking insects

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Abstract: This apparatus is used to simulate a water-walking insect's leg on the surface of water in order to observe the shadows created by fluidic lenses formed by the leg on the water surface. The apparatus accomplishes this by using wires coated in a hydrophobic material to simulate the insect leg. The wires are attached to a sample stage that is lowered to the water's surface using a micrometer screw. The apparatus can be used to create lab activities for physics students to help them better understand geometrical optics as well as the interactions between solids, fluids, and air.

Construction of Apparatus: Figure, instructions and additional parts are included online.

The full experimental setup; the height apparatus and LED lamp are connected to the ring stand, with a water (or other transparent liquid) reservoir and grid paper underneath the apparatus to measure the shadow size. The height apparatus; the wire is taped to the sample stage, which is lowered to the liquid's surface using the micrometer screw.

Use of Apparatus: The apparatus can be used to create a lab assignment for physics students to explore geometrical optics using a commonly observed real world phenomenon. Water striders deform the water surface such that the shadows formed on the bottom of a pond on a sunny day are more easily visible than the insect itself (see left panel of Fig. 2).

Some instructive lab activities related to this phenomenon are:

- experimental measurement of contact angles for different materials

- a comparison of dimple depth and shadow width for materials with different contact angles
- a comparison of shadow sizes at different water depths and/or distances between the LED lamp and the water surface
- a comparison of dimple depth and shadow width for fluids (e.g. water, ethanol, vegetable oil) with different indices of refraction and surface tension
- a comparison of dimple depth and shadow width for various leg radii
- computational modeling of the water surface and resultant shadows.

The goal for such a lab assignment is to improve student understanding of geometrical optics,

with respect to lenses and Snell's law, as well as the physics of interactions between a fluid and solid at the air-fluid-solid interface, with respect to surface tension, buoyancy force, and contact angles. Because of the complexity of the equations required to model the water's surface, this type of lab is well-suited for a computationally-oriented introductory physics course. It is also well-suited for an intermediate level experimental physics class.

The wire can be raised and lowered into the water using the 3D printed apparatus (see right panel of Fig. 1). A micrometer screw, when turned clockwise, is used to push the sample stage down, while the springs are used to provide tension and allow the stage to be raised as the micrometer screw is turned counter-clockwise. One full turn of the micrometer screw changes the height of the sample stage by 200 µm. The apparatus and lamp are attached to a ring stand (see left panel Fig. 1), the wire leg is taped to the sample stage, and it is lowered to where the simulated leg is just above the water's surface. The wire leg is then incrementally lowered using the apparatus and the resulting shadow cast on the lower surface of the water reservoir is measured using grid paper with a grid spacing of 1 mm placed below the reservoir (see right panel of Fig. 2). The shadow size is measured in this fashion until the wire leg fully penetrates the water's surface, resulting in the disappearance of the shadow.

Apparatus Title: Cohesion in Granular Flow

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Abstract: Acrylic cylinder partially contains sand and ceramic microspheres in two separated sides. The cylinder's upper and lower sections are separated with a disk that has identical holes exposed to both materials. When the cylinder is turned upside down, the materials flow though the holes but very differently. Because the average grain sizes differ by roughly an order of magnitude, there is significantly more cohesion among CMS grains, thereby leading to different flow characteristics.

Construction of Apparatus: Although this cylinder is newly designed, its construction follows the published procedure in reference 1. Briefly, it is made up of two equal length of acrylic tubings and three disks, one of which is the separating disk that has several holes. Acrylic cement and paste-like glue were used to construct the cylinder. One half of the cylinder was constructed and the separating disk was glued in place. Granular materials were poured in with the aid of an improvised paper funnel, and then the top half was added.

Ref. 1. Fluids Demonstrations, *The Physics Teacher*, pp. 248-252, April 2018.

Use of Apparatus: It is simple to use the cylinder. Simply, turn it upside down and observe. Sand and CMS start flowing through the holes, but very differently. CMS flows erratically showing landslide- and eruption-like behaviors, while sand flows more quickly and uniformly. This is due to more cohesion among small grains of CMS (absent in sand's larger grains), and it is a major problem in handling powder materials. Many industries deal with powder such as pharmaceutical, construction, cosmetic and food.

Apparatus Title: Effect of Partitions on Glycerin Flow in Thin Enclosures

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Abstract: A thin acrylic enclosure contains equal volumes of glycerin and air. Upon turning the enclosure upside down, an unstable condition is created and flow is initiated. As the fluids exchange their places, a host of interfacial phenomena are exhibited. How does addition of partitions affect interaction between the two fluids? Several arrangements and types of partitions were explored to answer the question. The results indicate that visually rich and engaging patterns are created especially with multiple parallel partitions.

Construction of Apparatus: Although all of the exhibited enclosures are new, their construction follows the published procedure in reference 1. Briefly, each enclosure is made of two acrylic sheets and four 1.6 mm thick acrylic strips that serve as spacers around the enclosure. Thin acrylic rods and squares are used as partitions. Glycerin is diluted by 10% water (volume basis) and colored with food color, and injected into the enclosure with a dispenser that has hypodermic outlet. Everything is sealed with acrylic cement and paste-like glue. A table saw with fine tooth blade would make cutting much easier, but not required. Many plastic shops cut acrylic at the point of purchase free of charge.

Ref. 1. Fluids Demonstrations, *The Physics Teacher*, pp. 248-252, April 2018.

Use of Apparatus: It is simple to use the enclosure. Simply, turn it upside down and observe. This creates an unstable condition, heavier fluid on top of lighter fluid, which initiates the flow. 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. Although simple in design and low-cost, the enclosure shows complexity (and beauty) of fluid motion. The apparatus is self-contained and requires no external power or maintenance. Furthermore, it produces engaging patterns, and therefore, it is accessible to everyone regardless of age or science background. Ideal for use in outreach activities as well as classroom lecture-demonstration of fluids topics.

Apparatus Title: Ferrofluid and Labyrinth-Like Instability

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Abstract: Thin enclosure, made of glass, contains small amount of commercially available ferrofluid (FF) and isopropyl alcohol. A magnet is used to manipulate the FF. If the magnet is rested on the FF, spikes are developed in the FF under the magnet poles, aligned with the magnetic field. If the magnet is moved over the enclosure, some of FF will be moved too. By adjusting the distance of the magnet from the enclosure while moving it, intricate labyrinth-like shapes are developed due to viscosity differential in the narrow space.

Construction of Apparatus: The enclosure was made of two glass plates and four strips of thin acrylic as spacers around the enclosure. Paste-like acrylic glue was used to seal the enclosure. A small section of one of the edge strips was cut to allow insertion of a needle to fill the liquids. The cut strip was then glued in place. Isopropyl alcohol serves as a marginal but conveniently available barrier against the notorious staining property of the FF. Cut glass can be purchased from local glass shops. Previous attempts using acrylic resulted in failure as alcohol caused cracks in acrylic.

Use of Apparatus: It is simple to use this device. Bring the magnet near the FF. Move the magnet around, away and toward the enclosure. Change magnet orientation. Observe how the FF is manipulated by the magnetic field of the magnet. One phenomenon that this device clearly shows (that is absent in commercially available FF demonstration bottles) is the labyrinth-like instability that occurs in thin spaces. This can be observed by lifting a small amount of the FF into the alcohol area, letting some of it to fall back by moving the magnet away from the enclosure, and then quickly bringing the magnet back towards the enclosure but not touching it. By adjusting the distance between the magnet and the enclosure, the instability can be observed, and fantastic patterns can be created.

Apparatus Title: Glycerin Flow in Double-Layer and Color Addition

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Abstract: A thin enclosure contains equal volumes of glycerin and air in two separate layers. Upon turning the enclosure upside down, an unstable condition is created and flow is initiated. As the fluids exchange their places, a host of interfacial phenomena are exhibited. Furthermore, glycerin is colored yellow in one layer and blue in the other. When the flows in the two layers superimpose, the resulting color green is seen, adding to the visual effect of the device.

Construction of Apparatus: Although this is a new enclosure, its construction follows published procedure in reference 1. Briefly, it is made of three acrylic sheets and eight 1.6 mm thick acrylic strips that serve as spacers between the layers and around the enclosure. Glycerin is diluted by 10% water (volume basis) and colored with yellow and blue food color, respectively. Glycerin is injected into each layer via a dispenser that has hypodermic outlet. Everything is sealed with acrylic cement and paste-like glue. A table saw with fine tooth blade would make cutting much easier, but not required. Many plastic shops cut acrylic at the point of purchase free of charge.

Ref. 1. Fluids Demonstrations, The Physics Teacher, pp. 248-252, April 2018.

Use of Apparatus: It is simple to use the enclosure. Simply, turn it upside down and observe. This creates an unstable condition, heavier fluid on top of lighter fluid, which initiates the flow. 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 different colored glycerin are superimposed in their flows downward. Although simple in design and low-cost, the enclosure shows complexity (and beauty) of fluid motion. The apparatus is self-contained and requires no external power or maintenance. Furthermore, it produces engaging patterns, and therefore, it is accessible to everyone regardless of age or science background. It is deal for use in outreach activities, as well as classroom lecture-demonstration of fluids topics.

Apparatus Title: Immiscible Fluids in Thin Enclosure and Shadowgraphs

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Abstract: Acrylic thin enclosure contains approximately equal volumes of glycerin and mineral oil, and some air. Upon turning the enclosure upside down, an unstable condition is created and flow is initiated. As the fluids exchange their places, a host of interfacial phenomena are happening but difficult to see as all three fluids are clear. However, by shining a flashlight through the enclosure, shadows of interfaces of the three fluids are cast onto a white board behind the enclosure. No dye was added to any of the fluids, on purpose, to solely rely on shadowgraphs for visualizing the complexity (and beauty) of the interaction among the fluids.

Construction of Apparatus: Although this is a new enclosure, its costruction follows published procedure in reference 1. Briefly, it is made of two acrylic sheets and four 1.6 mm thick acrylic strips that serve as spacers around the enclosure. Glycerin and mineral oil were added via a dispenser equipped with a hypodermic needle. Everything was sealed with acrylic cement and paste-like glue. A table saw with fine tooth blade would make cutting much easier, but not required. Many plastic shops cut acrylic at the point of purchase free of charge.

Ref. 1. Fluids Demonstrations, The Physics Teacher, pp. 248-252, April 2018.

Use of Apparatus: It is simple to use the enclosure. Simply, turn it upside down and observe. This creates an unstable condition, heavier fluid on top of lighter fluid, which initiates the flow. As glycerin and mineral oil flow downward and air pockets flow upward, complex interactions take place because at the same time, glycerin and mineral oil, due to their density differential, must exchange their spaces too. As a result, a variety of interfacial phenomena, from surface tension effect to bubble and drop formations to flow instability due to density differentials are taking place but are difficult to observe due to fluids being clear. However, by shining a flashlight through the enclosure, shadows of fluids interfaces are cast onto a white board behind the enclosure. No dye was added to any of the fluids, on purpose, to rely on shadowgraphs for visualizing the complexity (and beauty) of the interaction among the fluids. The enclosure can be used in classroom lecture demonstration as well as in outreach activities.

Apparatus Title: Parametric Speaker

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Abstract:The Parametric Speaker allows one to project highly directional audible sound through the use of modulated ultrasonic transducers. The modulated ultrasound is then demodulated when it passes through a nonlinear medium (air). This occurs due to the high sound pressure level (SPL) and frequency, and the fact that the air compression and relaxation take different amounts of time. This produces a wave that interacts with itself, creating waves of the sum and difference (heard).

Construction of Apparatus: The Parametric Speaker consists of a transducer array, a drive circuit, and audio source (phone, radio, computer, etc.). The drive circuit takes a 40 kHz carrier input which is then modulated with the audio source. After amplification, it is sent to the transducer array. The input audio signal might need to be separately amplified depending on the source.

The transducer array can also be used as a 2D acoustic trap as shown by UPNAlabs on Instructables.com where they review the software, circuit, and technique.

Use of Apparatus: The Parametric Speaker is best as a demo for small to medium size groups (1-50 people). To demonstrate it, point the speaker at a large group and move it around. Try pointing it at the ceiling and walls and ask where the sound is coming from. It is also nice to use a reflector (poster board) to direct the sound beam around the room.

Apparatus Title: Remotely-Controlled Browser-Based Apparatus Enabling Low-Cost Elementary Optics Experimentation

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Abstract: A remotely-controlled apparatus enables students to conduct experiments on the polarization of light and thereby demonstrates the sensitivity of photons to mechanical intervention. The experiment investigates how a laser beam is impacted by the angle between two linear polarizers. Each experimental component is connected via the internet to a web-based platform making the apparatus universally accessible to instructors and students. Ultimately, the apparatus may be improved/revised to include more sophisticated photonics experiments.

Construction of Apparatus: A budget and comprehensive list of the equipment pieces used in the apparatus can be found in Appendix A. A detailed bird's eye drawing of the apparatus can be found in Appendix B. Our apparatus is composed of both hardware and software elements. The hardware consists of a base, mounting, laser source, light-dependent resistor (LDR), optics, and stabilization equipment. Our base is constructed with two 27" x 12" plywood boards which are screwed together using four ⅝" wood screws to provide "top" (of 0.25" depth) and "bottom" (of 0.75" depth) parts of the base. Within the top base only, we cut small plots into which the mounts are inserted. This allows for any needed modifications/exchanges of mounting while also supplying stable support for each mount.

For the laser mount, a 0.75" by 1.25" plot is cut from the top base, centered along the width of the base, and starting 3.75" in from the left most side of the base. The laser mount is made of a rectangular strip of plywood 3" in height. A hole is drilled using a 0.5" drill bit to a 2" depth. A factory-made MTO-laser steel mount, which consists of a cylindrical (13.55mm inner diameter) shell atop a thin 2" rod, is inserted into this 0.5" diameter aperture. A 1" bolt is then fastened into the side of the wood mount 2.25" from the bottom until contact is made between it and the steel MTO rod. This helps to secure the MTO-laser mount in the wooden component of the laser mount. Similar to all mounts in the apparatus, this wood and steel mount is then nserted into its 0.25” deep plot in the top base where it stands securely and may be removed for later alterations. The laser can then be placed inside the metal shell to be at a 3.5” height.

Two 0.25” by 3.5” plots are cut from the top base 7.5” and 18” in from the leftmost side of the base to host the polarizer mounts. Both polarizer mounts are made of 5.5” tall plywood boards in which a 1.5” diameter aperture is drilled in each. The center of these apertures are 3.5” above the surface of the top base and centered laterally (1.75” in from either side of the board).

The LDR mount is made of a block of plywood, which is screwed into the top base using two 2” wood screws, and a plastic cover screwed to the side of this block with a 0.5” wood screw. The LDR can easily attach and detach from this cover through two small 0.25” machine screws on the top and bottom of the cover. The target for the laser beam on the LDR stands 3.5” above the top base as well.

The optics equipment pieces and secondary components are attached to these wooden mounts. The secondary components are utilized to decrease the chance of damage to polarization and electronics equipment and increase their maneuverability for remote control.

For Polarizer #1 a 58mm to 55mm step-down ring adapter was centered and glued on the wooden mount using epoxy. Polarizer #1 can then be fastened onto this ring adapter by utilizing its built-in screwing/rotation mechanism. A 55mm to 58mm step-up ring adapter is epoxyed in this same way to polarizer mount

#2. Polarizer #2 can then be screwed onto its mount. To allow rotation of Polarizer #2, we screw a 58mm to 55mm step-down ring adapter to the open side of the polarizer and glue a 58mm diameter, 56 tooth, plastic gear to the adapter. Implementing this additional ring adapter ensures that no glue remaining on the back of the gear will block the manufactured rotation mechanism in the polarizer. We fasten a second gear (a replica of the polarizer gear) on the servo using two small screws. To fasten the servo on the second polarizer mount, we first laser cut a plastic holster which surrounds the left, bottom and top sides of the servo. The holster is cut from a 3.75” by 1.75” plastic board. A 2.25” by 0.75” rectangle is cut out from the board’s top right corner. A 1.5” by 0.75” rectangle is then cut out starting from the left side of the previous cut and 0.25” from the top of the board. The servo is able to rest securely inside this cut crevice. A 0.2” diameter hole is then drilled 0.5” from the bottom and 0.1” from the right side of the board. We then drill a 0.2” diameter hole into the second polarizer mount ⅞” above the top base and ⅝” from the right side of the mount. We insert a 2” bolt through this drilled hole and the 0.2” hole in the plastic servo holster. The plastic holster should now be fastened on the same side of the mount as the polarizer as shown in Appendix B. A 0.25” nut is used from the opposite side of the mount to secure the holster and servo on the side of the polarizer mount. The gear on the servo should now interlock with the second polarizer gear. This also allows the option to “detach” the servo from the mount by loosening the nut around the 2” bolt and rotating it away. Thus, the polarizers, gears, and servo are all mounted securely with little risk of damage to the equipment, diligent attention to safety, and increased mobility.

Our apparatus construction has a software aspect as well. The primary goal of our software is to enable certain components of the apparatus to be remotely controllable or accessible over the web. There are three components which are accessible online: the laser, the servo, and the LDR. Each component is centrally connected to a Raspberry Pi which is an essential element in allowing the exchange of information or commands from remote instructors or students online. It is powered by an electrical outlet and USB cord.

Users are able to turn the laser “on” and “off”. This mechanism works by connecting the laser diode’s anode and cathode pins to a breadboard which can provide the laser with the required 5V. The power to this breadboard is controllable from the Raspberry Pi through a connection to its GPIO pins.

Users are able to control the rotation of the servo. The servo’s ground and control signal pins are connected directly to the Raspberry Pi-breadboard system. The servo requires more voltage then the laser. We draw power directly from an outlet by using a socket to 12V DC power converter, plugging this DC power cable into a DC power to pin converter which can connect easily to the power pin on the servo.

Users can also read an output value from the LDR, which displays measurements of light in lux (a unit from which luminous intensity can be derived). The LDR is a type of photoresistor and contains two legs which can be connected to pins on the Raspberry Pi. We apply a constant voltage to one leg through the Raspberry Pi and insert an analog to digital signal converter on the other output leg. We connect this converter to a digital input pin on the Raspberry Pi. This enables us to read the lux value resulting from the LDR based on the ncoming intensity of the laser beam.

The Raspberry Pi can connect to the internet through a wireless connection to a modem-router system. We have constructed a web server through Digital Ocean (a cloud nfrastructure provider) that hosts an online platform where users can access the apparatus remotely. Users can send commands to and receive updates/values from each component through a websocket, written in python (code available upon request), established between the server and Raspberry Pi. This allows users to control power to the laser and rotation of the servo (and thus rotation of the second polarizer through the gears system). Users can also view information on the “on” or “off” state of the laser, the current position of the servo given as an angle, and real-time LDR values. In addition, web cameras are positioned at strategic areas on the apparatus. We establish a live feed of the set-up from three different angles on our online platform so users may view their alterations made to the servo and laser in real-time. Using a web camera mount attached to the base of the experiment users have a bird’s eye view of their experiment. Two smaller mounts are clipped to the top and left side of the second polarizer mount to provide views of the servo-gear system and the “dot”, created by the resulting laser beam, on the target of the LDR. Users can therefore observe how their rotation of the servo (and thus the second polarizer), affects the intensity of the laser beam hitting the LDR. These web cameras are connected to the Raspberry Pi’s USB ports. With internet connection we can then establish a ive stream with the visual information being inputted to the Raspberry Pi.

Use of Apparatus:The apparatus enables instructors to run experiments with a class or group of students which demonstrate fundamental concepts of polarization and photonics. Components of the apparatus were designed to be interchangeable such that instructors may create different esson plans on optical physics using the same basic set-up and remote control technology.

Students may also design their own apparatus, with similar size and number of parts and mounts as the current design, to explore the entire process of creating a hypothesis, constructing an experiment to test that hypothesis, and recording the appropriate data to analyze these tests. An example of a lesson plan one can utilize with this set-up can be found in Appendix C.

While the cost to construct the entire apparatus is just under $300, instructors and students may conduct trials and demonstrations for very little to no cost because our software platform enables the remote manipulation of apparatus components using a web browser. This makes the apparatus universally accessible for instructors and students across the country (and around the world) who can connect to the internet. This was a primary goal for our apparatus: to not only demonstrate optical phenomenon, but to make these demonstrations easily accessible and free to use.

Apparatus Title: Something NEW from Something OLD - A tool for the Optics Lab

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Abstract: Many departments have old, but still useful equipment that may seem obsolete. In an effort to make use of an old student spectrometer, a new data acquisition scheme using an Arduino UNO and a low cost light sensor has allowed for re-purposing the old instrument, making for a "semi-automated" light scattering experiment.

Construction of Apparatus: An old (circa 1960's era) student spectroscope was used to construct a more useful tool that allows for light intensity vs. angle measurements for scattering experiments. The detector can also be used on an optical rail for performing Malus Law experiments.

Use of Apparatus:

Advantages
The major advantage in this project was in repurposing an otherwise obsolete piece of well-constructed equipment. The ability to precisely determine angle (and for students to practice using Vernier measurements) was a plus. The older apparatus provides precise determination of relative angular position due to the Vernier scale on the rotating arm. The 180 degree position was determined by monitoring intensity while adjusting the rotating arm without a sample. The relative angular position is noted. Angular position is then measured relative to this position. The TSL2591 sensor and simple fiber cable provided adequate sensitivity, even for relatively low intensity light sources (LED flashlight). The angular position was systematically changed by increments as small as 1degree. The Python code was launched manually after each angular change, with typical integration time of 10-30s per position.

The apparatus is used in a variety of light scattering experiments and can be couple with either a broad band white light source or a laser depending on the experiment. The detector can also be used on a rail, with the stopper inserted into a one-inch PVC pipe and mounted in a lens holder.

Drawbacks

One drawback is the limitation of the angular position of the rotating arm. Several different spectroscope scattering systems were constructed. Most limited the angular range to approximately 45 – 315 degrees (relative to light source arm)

Though the apparatus provides accurate measurement of angular position, the acquisition is tedious and time consuming when compared with reading a number from the analogue photometer in the old Pasco kit, primarily due to the manual repositioning and integration time required between each data point.

Low cost: Each setup was constructed for well under $100, making it possible to have multiple setups for a low overall cost. The apparatus is used in both the Applied Optics course and the Advanced lab course for different experiments.

Apparatus Title: Sound Interference and Vibrations of a Wine Glass

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Abstract: This apparatus serves to illustrate the way sound is produced by a resonating wine glass. The apparatus rotates a rubber finger against a stationary wine glass at a fixed angular speed to create a beating signal. Using two microphones to measure sound intensity, connections between beat frequency, phase, and finger rotational speed demonstrate sound interference between antinodes of the resonating wine glass.

Construction of Apparatus: We used aluminum and arcylic for most of the apperatus. Instructions and additional parts are included online.

Use of Apparatus: The apparatus consists of a wine glass mounted to a platform, with a rod connected to a rubber finger moved by a rotating turntable beneath. Two microphones can be positioned pointing towards the center of the glass, in the plane of the glass rim, with an angle of either 45 or 90 degrees between them. The apparatus rotates the rubber finger around the rim of a stationary glass at a constant speed that can be recorded with a stopwatch. As the rubber finger runs along the moistened glass rim, the tone produced can be recorded by the two microphones. The resultant waveform can then be put through a Fast Fourier Transform to observe constituent frequencies. The sound intensity waveforms exhibit beating patterns – the phase of which depends upon the relative angular offset between the two microphones. An angle of 90 degrees corresponds to a beat phase difference of 0, whereas an angle of 45 degrees corresponds to a beat phase difference of $\pi/2$. Students use this sound this sound intensity data and its Fourier spectra to draw connections between beating, standing waves, and sound interference.

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