A Simple Soda Can Steam Engine

Conservation of Energy

Introduction

Phase changes are taught at just about every level of science education, K–college. Rarely, however, is it emphasized what an important role they have played historically in our technological development. The boiling of water, after all, was what first allowed us to take significant advantage of chemical energy, enabling us to convert the heat given off during an exothermic reaction into useful work. How wonderful then that one of the earliest and most fundamental steam engines can be replicated with an aluminum soda can!

Concepts

- Energy conversion
- Phase changes
- Newton's third law of motion

Materials

Water
Bunsen burner
Fishing swivel
Pin
Soda can, unopened
String
Support stand with ring clamp

Safety Precautions

Caution should be taken whenever dealing with flame. Keep all flammable materials away from the demonstration. The can becomes quite hot during this demonstration. Keep hands and face away from the steam coming out of the can. Use heat resistant gloves or allow the can to cool completely before removing it from the swivel. Wear chemical splash goggles and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory. Follow all laboratory safety guidelines.

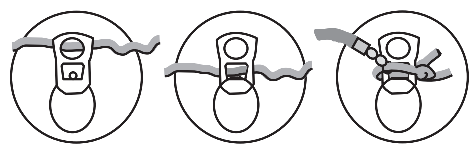


Figure 1.

Preparation

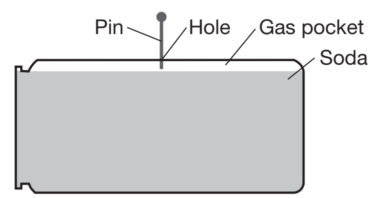


Figure 2.

1. Using an unopened soda can, gently slip a piece of string under the pull tab and pull it up so that it is wedged in over the rivet in the can's center.
2. Thread the string through a fishing swivel and tie the two loose ends of the string together (see Figure 1).
3. This step can get messy and should be done near a sink or even outdoors! Remove the soda can from the swivel and lay the soda can on its side. Push a pin in the side of the can about halfway up, and then withdraw the pin (see Figure 2). *Note:* If the can is kept horizontal and the hole is made on the very top of the curve, soda should not squirt out of the hole!
4. Empty as much of the soda as possible out of the can by shaking it with the pin-hole facing downward into a sink.
5. When shaking is no longer very effective, make a similar hole in the exact opposite side of the can—180° from the first slit (see Figure 3). Blow through this hole to force the remainder of the soda out of the can.

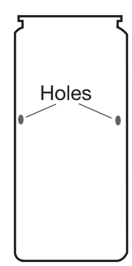


Figure 3.

6. Insert the pin back into one of the holes, and then push the pin head to one side to make the hole tangential to the wall of the can. Repeat this step for the second hole, pivoting the pin head to the same side as for the first. See Figure 4 for a top view cross-section of these tangential holes.
7. Add 20–30 mL of water to the can. This may be done by any of a number of ways. Perhaps the simplest is just to hold the can down on its side at the bottom of a deep basin sink and let the water flow into one of the holes for about 10 seconds. Or, hold the can in a pan containing 3–4 cm of water, with one hole on bottom (submerged) and the other hole on top, and let the water leak in over the course of 5–10 minutes. Gently moving the can back and forth under water can speed up the process.

8. Attach a ring clamp to a support stand, and tie a length of string to the outside edge of the ring. Tie the other end to the fishing swivel about 1 cm below the ring, and cut off any extra string. Reattach the loop of string by sliding it under the pull tab as in Step 1 (see Figure 5).

Procedure

1. Establish a cool flame on a Bunsen burner and place it under the can, adjusting the ring height if necessary (see Figure 5).
2. Once the water inside starts boiling and the steam starts spurting out of the two slits, the can will begin spinning quite rapidly, and continue for several minutes. If the can begins to wobble, reduce the flame.

Tips

- Diet sodas are preferable if this activity is being done inside, since they have less potential to create a sticky mess.
- To increase the duration of the spin, use more water, but expect a proportionately longer heat-up period.
- To make an engine that spins the other way, repeat the above procedure, but orient the holes in the other direction. In other words, instead of having the holes angled to the right, have them angled to the left.

Discussion

This activity demonstrates in a fun and very inexpensive way the conversion of chemical energy in the form of methane and oxygen (or ethanol and oxygen) into the thermal energy of the flame, which in turn can be converted into the mechanical energy of the spinning can, thanks to the phase change of water boiling. This, in turn, might be used to do useful work—perhaps some sort of spool placed over the can could coil up a thread as it is spun, which in turn might lift an object off the floor. Or perhaps the spinning engine could be used to turn a generator to convert the mechanical energy into electrical. Inasmuch as the can always spins counter to the direction the holes are pointing, this engine could also be used to illustrate that for every action force there is an equal and opposite reaction force.

Acknowledgments

Thanks to Ed Ginoza of Maui High School and Don Chaney of Baldwin High School in Kahului, HI for co-developing this activity with Bob Becker of Kirkwood High School, Kirkwood, MO.

Materials for *A Simple Soda Can Steam Engine* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Hero's Engine—Demonstration Kit* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP7115	Hero's Engine—Demonstration Kit
AP8228	Support Stand, 24″ Rod
AP8232	Support Ring with Rod Clamp, 4″
AP4823	String, Ball, 75 g

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Whoosh Bottle

Introduction

Wow your students with a whoosh! Students will love to see the blue alcohol flame shoot out the mouth of the bottle and watch the dancing flames pulsate in the jug as more air is drawn in.

Concepts

- Exothermic reactions
- Activation energy
- Combustion

Background

Low-boiling alcohols vaporize readily, and when alcohol is placed in a 5-gallon, small-mouthed jug, it forms a volatile mixture with the air. A simple match held by the mouth of the jug provides the activation energy needed for the combustion of the alcohol/air mixture.

Only a small amount of alcohol is used and it quickly vaporizes to a heavier-than-air vapor. The alcohol vapor and air are all that remain in the bottle. Alcohol molecules in the vapor phase are farther apart than in the liquid phase and present far more surface area for reaction; therefore the combustion reaction that occurs is very fast.

Since the burning is so rapid and occurs in the confined space of a 5-gallon jug with a small neck, the sound produced is very interesting, sounding like a "whoosh." The equation for the combustion reaction of isopropyl alcohol is as follows, where 1 mole of isopropyl alcohol combines with 4.5 moles of oxygen to produce 3 moles of carbon dioxide and 4 moles of water:

$$(CH_3)_2CHOH(g) + {}^{9}\!/_{2}O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g) \qquad \Delta H = -1886.6 \text{ kJ/mol}$$

Materials

Isopropyl alcohol, $(CH_3)_2CHOH$, 20–30 mL

Whoosh bottle, plastic jug, 5-gallon

Fire blanket (highly recommended)

Funnel, small

Graduated cylinder, 25-mL

Match or wood splint taped to meter stick

Safety shield (highly recommended)

Safety Precautions

Please read all safety precautions before proceeding with this demonstration.

- Isopropyl alcohol is a highly flammable liquid and vapor. Keep away from heat, sparks, open flames, and hot surfaces. May cause drowsiness or dizziness. Avoid breathing mist, vapors or spray. Use in a well-ventilated room.
- Isopropyl alcohol cause serious eye irritation. *Always* wear protective eyewear when performing this demonstration. Anyone viewing this demonstration should also wear eye protection. Please review current Safety Data Sheets for additional safety, handling, and disposal information.
- *Always* recap the alcohol bottle and move it far from the demonstration area. *Never* leave an open bottle of alcohol in the vicinity of the demonstration.
- A safety shield is highly recommended for explosions. Even the mildest explosion creates some chance of shattering and flying objects. Protective eyewear must be worn by the demonstrator as well as by anyone viewing the demo.
- *Never* perform alcohol explosions in glass bottles. The large quantities of gases (H_2O and CO_2) produced during the rapid combustion will easily shatter a glass container. Serious accidents have occurred performing this demonstration in a glass container—do not use glass. Only use a plastic jug, such as a 5-gallon water jug.
- Always pour out excess unvolatilized liquid alcohol from the plastic jug before igniting. If any liquid alcohol is left, it will increase the amount of gaseous afterburning. The liquid could also ignite, which may cause the plastic jug to melt. Always keep a lid or some sort of cover handy, which can be placed over the mouth of the jug to extinguish the flame if it begins to melt the plastic. Excess alcohol in the lip of the mouth of the jug and on the outside of the jug

should be wiped off in order to avoid its igniting and softening the plastic jug.

- *Never, ever* use a pure oxygen environment as the potential for an extremely violent and deadly explosion is possible.
- Never use methyl alcohol for this demonstration. The high volatility of methyl alcohol means that it has the potential for the most violent combustion of any alcohol.
- Replace the plastic "whoosh bottle" should it show grazing, frosting, cracking, or any small flaws. Routinely replace the bottle after approximately 20 uses or so.
- Do not perform this demonstration directly underneath smoke/heat detectors or sprinkler systems.
- Make sure the ceiling is at least 4 feet above the whoosh bottle to prevent possible scorching and fire.

Preparation

Before each demonstration, inspect the plastic whoosh bottle for grazing, frosting, cracking, or any small flaws. Replace the bottle if it shows signs of fatigue.

Procedure

1. Add about 20–30 mL of isopropyl alcohol to the 5-gallon plastic jug. Do not add more than 30 mL of alcohol. Recap the bottle of alcohol tightly and move it far from the demonstration area.
2. Lay the jug sideways on a flat surface allowing the alcohol to flow from base to mouth. Slowly swirl the jug for about 30 seconds, trying to spread alcohol liquid completely over the entire interior surface. This allows the liquid alcohol to volatilize and makes the vapor concentration uniform throughout the bottle. If a lot of liquid alcohol is still visible, swirl the bottle for another 30 seconds.
3. Pour out any excess liquid alcohol and shake out the bottle. Wipe the inside and outside neck of the bottle to remove any remaining liquid.
4. Stand the jug on the floor, placing it in the front of the room and behind a safety shield. *Note:* If desired, the demonstration can be performed on a fireproof demonstration table provided that the ceilings are at least 10 feet high.
5. Dim the lights in the room.
6. Light a match or wood splint that is taped to a meter stick or other long stick.
7. Stand back and, at arm's length, bring the burning match or wood splint over or slightly down into the mouth of the bottle. *Note:* Be sure you are on the safe side of the safety shield as well.
8. Observe the explosive "whoosh" that results.
9. After the reaction has subsided and all the flames are out, wait for a minute or two until the bottle has cooled slightly. Pour out the water droplets from the bottle into a 25-mL graduated cylinder using a small funnel. As much as 12–14 mL of water may result, showing that water is one of the products of the combustion of alcohol.

Repeating the Demonstration

The demonstration *cannot* be repeated immediately for a few reasons—for one, the demonstration *will not work* due to the buildup of CO_2 in the bottle. There is not enough oxygen in the bottle to allow combustion to occur. More importantly, it is extremely dangerous to add alcohol to the jug if the jug is still hot. A flash-back can occur, causing a fire.

In order to successfully repeat the demonstration for another class, follow the steps below:

1. Allow the bottle to cool to room temperature.
2. Pour out the water that forms as a result of the combustion.
3. Fill the bottle with about 10 of cold tap water and swirl the tap water around in the bottle. Pour the tap water into the sink, and repeat the washing with more cold tap water. Pour all the water out into the sink.
4. Dry out the bottle as much as possible by either allowing it to sit upside down or (to speed up the drying) by drying it with

a long string of paper towels pushed into the mouth. A few water droplets on the inside of the bottle do not seem to hinder the combustion.

5. In order to reduce the amount of water in the bottle and speed up the drying, try a double rinse of the bottle with a small amount of isopropyl alcohol.
6. Review the *Safety Precautions* again and follow steps 1–9 in the *Procedure* section.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. Excess alcohol may be disposed of by allowing it to evaporate in a fume hood according to Flinn Suggested Disposal Method #18a. Rinse the jug well before storing it for future use.

NGSS Alignment

This laboratory activity relates to the following Next Generation Science Standards (2013):

Disciplinary Core Ideas: Middle School
MS-PS1 Matter and Its Interactions
PS1.A: Structure and Properties of Matter
PS1.B: Chemical Reactions
Disciplinary Core Ideas: High School
HS-PS1 Matter and Its Interactions
PS1.A: Structure and Properties of Matter
PS1.B: Chemical Reactions

Science and Engineering Practices
Developing and using models
Constructing explanations and designing solutions

Crosscutting Concepts
Cause and effect
Energy and matter
Structure and function

Observations

The first effect that may be observed is the characteristic "whoosh," which involves a moderately violent thrust of flames and blue gas out of the mouth of the bottle. Some afterburning or dancing flames of burning vapor in the body of the bottle may also result.

The second effect is a slower burn of gas down the inside surface of the bottle, producing a ring, plate, or cone of fire, which may be accompanied by an upward thrust or ball of yellow flames in the center of the jug. The sound accompanying these slower burns is actually more of a "whomp." This effect can also be observed by using 70% isopropyl alcohol, illustrating reduced vapor pressure due to dilution and a slower rate of reaction.

Tips

- Various sound and flame effects may be produced depending on the alcohol used and its dilution with water. Try using ethyl alcohol or n-propyl alcohol. Compare the results to isopropyl alcohol. Ethyl alcohol proceeds somewhat faster and more violently due to its higher volatility. Propyl alcohol burns slower producing more heat, which may damage the bottle. *Do not try this demonstration with methyl alcohol.* The high volatility of methyl alcohol means that one must be particularly cautious when using methyl alcohol as it has the potential for the most violent combustion and possible rupture of the bottle.
- Depending on how much alcohol vapor is in the bottle, you may have to place the flame slightly inside the mouth of the whoosh bottle before it ignites.
- The demonstration works best if the alcohol vapor is prepared immediately before the demonstration. If the bottle with the vapor sits for a while, the vapor tends to settle and is harder to light.
- Reagent isopropyl alcohol (99%) or 70% isopropyl alcohol can be used for the demonstration. The 70% alcohol produces a slightly slower burn due to the water vapor.

- Use a graduated cylinder to measure the volume of water produced by the reaction. Instruct your students to perform calculations to determine the volume of water expected from the starting amount of isopropyl alcohol.

  For example, if 20 mL of isopropyl alcohol (density = 0.78 g/mL) are used:

  20 mL × 0.78 g/mL = 15.6 g × 1 mole/60 g = 0.26 mol isopropyl alcohol

  From the balanced equation,

  0.26 mol isopropyl alcohol × 4 mol H_2O/1 mol isopropyl alcohol = 1.04 mol H_2O

  So,

  1.04 mol H_2O × 18 g/mol = 18.7 g = 18.7 mL of H_2O expected

  Discuss possible reasons why the actual volume of water may have been slightly less, such as evaporation or the droplets of water remaining on the inside of the bottle.

Acknowledgments

Flinn Scientific would like to thank John Fortman, Dept. of Chemistry, Wright State University, Dayton, OH for all of his research in providing safety notes and variations on this excellent demonstration. John has written an excellent article on this demonstration; see the reference listed below. Lee Marek, Naperville North H. S., Naperville, IL (retired) and Bill Deese have also popularized this demonstration.

Reference

Fortman, J. J.; Rush, A. C.; Stamper, J. E. *J. Chem. Ed.* **1999,** *76*, 1092–1093.

Materials for the *Whoosh Bottle—Chemical Demonstration Kit* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP5943	Whoosh Bottle—Chemical Demonstration Kit
SE225	Safety Shield, 300 × 160
I0019	Isopropyl Alcohol, 500 mL
E0009	Ethyl Alcohol, 500 mL

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Standing Wave Generator

Introduction

Teachers can demonstrate a standing wave by using a centrifuge device with a simple attachment. The discussion of wavelength and amplitude will become much more concrete as students see these principles for themselves!

Concepts

- Properties of waves
- Wavelength
- Nodes
- Antinodes
- Frequency
- Amplitude

Materials

Battery, D size
Bracken's Demonstration Spinner
Candle or burner
Cotton cord
Paper clip or dissection needle
PVC elbow
PVC pipe, long
PVC pipe, short, with cup hook
Ring stand
Soda bottle cap
Strobe light (optional)
Swivel, hole and latch
Swivel, two holes

Safety Precautions

Make sure hooks are firmly connected before operating the centrifuge. Do not touch the motor axle while rotor is spinning. Remove the battery from Bracken's Demonstration Spinner when not in use and during storage.

Procedure

1. Thread one end of the cotton cord through the 2-hole swivel and tie.
2. Melt a hole in the center of the flat surface of the cap (see Figure 1) using a heated straightened paper clip or dissection needle. (A candle or burner may be used to heat the paper clip.) The motor axle of the centrifuge device should fit snugly through this hole.
3. Melt a second hole on the side of the bottle cap.
4. Place the cap, flat side down, on the axle of Bracken's Demonstration Spinner through the center hole.
5. Tie the loose end of the cord through the hole of the swivel with the hole and latch. Clip the latch of the swivel to the hole on the side of the bottle cap.
6. Attach the PVC elbow to the two PVC pieces as shown in Figure 2.
7. Place the 2-hole swivel onto the cup hook (see Figure 2).
8. Slide the long PVC piece over the rod of the ring stand.
9. Turn on the motor and observe the wave pattern in the cotton cord.
10. Vary the number of nodes by changing the tension on the rope. This is easily done by holding and raising the PVC pipe assembly to tighten the rope.

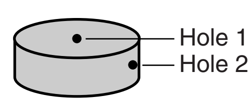


Figure 1. Cap

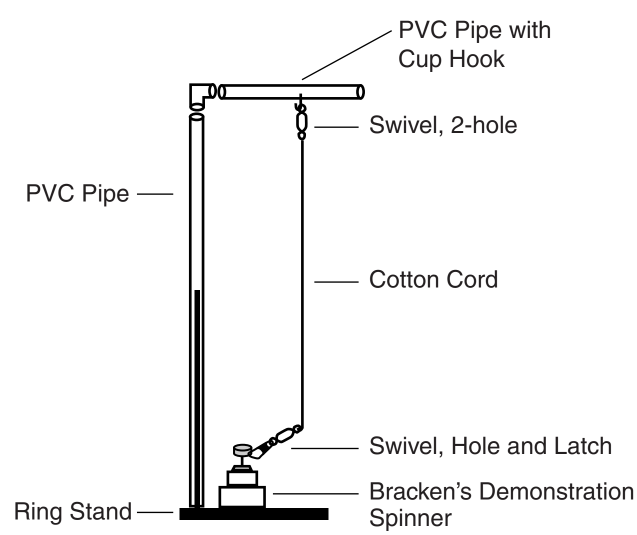


Figure 2. Setup

Tips

- Bracken's Demonstration Spinner, Flinn Catalog No. AP6202, is required and sold separately.
- Properties like frequency, wavelength, nodes, and antinodes can be discussed using this wave generator.
- A strobe light can be used with this demonstration to "fool" our eyes. If the strobe light is properly adjusted, the spinning rope will appear motionless! This should be done in a dark room. Be advised that the use of strobe lights can trigger epileptic seizures in some people—take all necessary precautions.
- A video presentation of the *Standing Wave Generator* activity is available through the Flinn Scientific Web site (www.flinnsci.com) in *Electron Configuration*, part of the Flinn Scientific—Teaching Chemistry™ eLearning Video Series.

Discussion

All traveling waves follow the *principle of superposition*. That is, when two or more waves meet at the same location the waves overlap with each other and add together to instantaneously create a new wave form. However, the original wave patterns are not lost. Instead, they travel through each other, interact with superposition, and then emerge with the same original shape.

The superposition of two or more waves creates two types of interference—constructive interference and destructive interference. *Constructive interference* occurs when two or more waves combine at the same location and instantaneously produce a wave form with a larger amplitude than any of the original waves. *Destructive interference* occurs when two or more waves combine at a given location to instantaneously produce a wave with a lower amplitude than any of the original waves. When two continuous waves traveling in opposite directions with the same frequency interact with each other, an interesting wave form can be created. If the waves are the correct frequency, a *standing wave* is produced. A standing wave form is the result of constructive and destructive interference of waves that interact in such a way to make the peaks (antinodes) and valleys (nodes) of the wave remain fixed in space.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Systems, order, and organization
Evidence, models, and explanation

Content Standards: Grades 5–8
Content Standard B: Physical Science, understanding of motions and forces

Content Standards: Grades 9–12
Content Standard B: Physical Science, motions and forces

Acknowledgment

Flinn Scientific would like to thank Jeff Bracken, chemistry teacher at Westerville North High School in Westerville, Ohio for sharing this original idea. Jeff would like to thank his student lab assistant, Ben Swanger, for his valuable assistance in creating this demonstration.

Reference

Tipler, Paul A. *Physics for Scientists and Engineers*, 3rd Ed., Vol. 1; Worth Publishers: New York, 1990; pp 414–424.

The *Standing Wave Generator* is available as a demonstration kit from Flinn Scientific, Inc.

Catalog No.	Description
AP6161	Standing Wave Generator
AP6202	Bracken's Demonstration Spinner
AP1425	Battery, Replacement, D size
AP5720	Stroboscope

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Singing Tube Demonstration

Introduction

Mysteriously play an organ pipe without an organ! This demonstration uses heated air to produce vibrations inside a long tube. The vibrations, in turn, produce standing sound waves with a unique tone, or timbre (tăm′ br)—the same concept that produces sound from an organ pipe.

Concepts

- Sound waves
- Open-ended resonance tubes
- Wind
- Organ pipes

Materials (for each demonstration)

Metal tube, 2″ dia. × 17″
Metal wire disks, 2½″ diameter, 3
Bunsen burner, or portable laboratory burner
Heat-resistant gloves, or oven mitts
Paper clip, metal
Pliers, needle-nose, with wire cutters

Safety Precautions

The edges of the metal wire disks are sharp. Please handle with care. Follow normal Bunsen burner safety guidelines. The metal tube and wire disks will get hot while in the burner flame. Wear heat-resistant gloves and safety glasses when performing this demonstration.

Preparation

1. Obtain the metal wire disks. Handle them very carefully.
2. Carefully bend one of the disks into a bowl shape (similar to a watch glass shape). Put pressure on the center of the disk with your thumbs and then evenly bend the edges of the disk with your fingers to form a bowl. See Figure 1. Be very careful not to cut yourself on the wire edges.
3. Form a bowl shape that has a slightly larger diameter than the inside diameter of the metal tube. If the wire disk is bent too much, it can be flattened out and adjusted to the proper diameter.
4. Repeat steps 2 and 3 for the two remaining wire disks.
5. Place one disk on top of the other to make a stack of three disks.
6. Obtain a metal paper clip and needle-nose pliers with wire cutters.
7. Straighten out the paper clip.
8. With the wire cutters, clip off a 1–2 cm paper clip piece.
9. Insert this paper clip piece through the center of the wire disk stack so that it goes through all three disks. See Figure 2.
10. Use a needle-nose pliers to bend the inserted paper clip piece into a "C" shape to secure the wire disks together. See Figure 2.

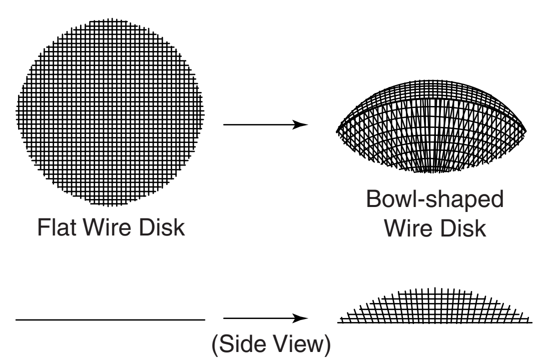


Figure 1.

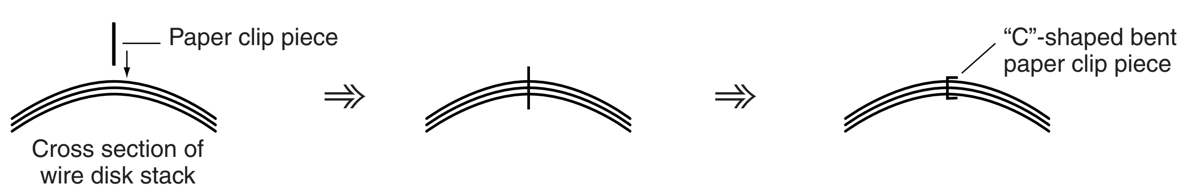


Figure 2.

11. Insert the curved end of the wire disk "stack" into the end of the metal tube, opposite to the label. See Figure 3. Carefully push and "massage" around the edges of the stack evenly in order to slide the disks into the tube so that they remain parallel with the tube opening. (When you look inside the tube, there should be no gaps between the disks' edges and the wall of the tube.) The friction between the wall of the tube and the edges of the disks should keep them secure inside the tube. If the disks are loose or fall out, remove them and flatten them out slightly to increase their diameter so they fit snugly inside the tube. If the wire disks are pushed in crookedly, use pliers to remove them completely and begin again. Proceed slowly in order to keep the wire disks parallel with the opening of the tube.

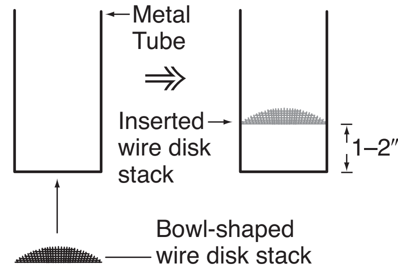


Figure 3.

12. Once the wire disks are inside the tube opening squarely, slide them down the tube so that they are about 1–2″ from the end of the tube. See Figure 3.
13. Set up a Bunsen burner or portable laboratory burner on a demonstration table.

Procedure

1. Light the Bunsen burner and adjust it to obtain a blue flame.
2. Wearing heat-resistant gloves or oven mitts, hold the metal tube at one end and position the other end of the metal tube vertically over the Bunsen burner flame to directly heat the wire disks inside the tube. See Figure 4.
3. Heat the wire disks for 10–15 seconds. Swirl the tube slightly to evenly heat the entire disk surface.
4. Remove the tube from the Bunsen burner flame and continue to hold it vertically. In a few seconds, a loud tone will begin to reverberate from the tube. The sound will last for several seconds (10–30 sec.), depending on how quickly the wire disks cool.
5. When the sound disappears, repeat steps 16–18 as often as necessary to reheat the wire disks and reproduce the sound.

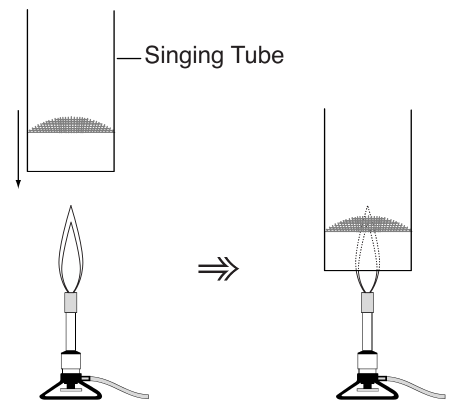


Figure 4.

6. **After the initial demonstration, perform this variation:** After heating the wire disks, remove the tube from the burner flame and immediately tip the tube 90° so that it is parallel to the floor. Notice that no sound resonates from the tube!
7. Quickly, but steadily, rotate the tube to the vertical position. The sound gradually increases in volume as the tube rotates towards the vertical position. (This should be done in 5–10 seconds—before the wire disks cool off.)
8. Discuss the observations with your students.

Disposal

The materials are completely reusable and should be saved for future demonstrations.

Tips

- Do not allow the metal tube to get too hot. The heat may scorch the tube label, heat-resistant gloves, and/or lab table it is stored on between trials.
- The Singing Tube can be silenced quickly, if it is too loud, by turning it horizontally, or by covering one of the ends (preferably the cool end).
- Pretend to pour sound into a beaker, or from a beaker into the tube. When the Singing Tube is "singing," begin to pour the "contents" of the tube into a beaker by rotating the tube 90°, with a beaker at the top opening of the tube. As the tube rotates, the "singing" decreases and makes it appear as if you are emptying the sound from the tube into a beaker. Reverse the process by pretending to pour sound into the tube. Start with a heated tube held horizontally and then quickly, but steadily, rotate it to the vertical position as you hold the lip of a beaker near the "top" of the rotating tube. The volume of the "singing" increases, simulating the act of pouring sound into the tube.

Discussion

The open tubes in this demonstration act in a similar manner to the flue-type organ pipe (see Figure 5). In a flue-type organ pipe, a stream of air is directed against a sharp edge in an opening of the pipe. The sharp edge creates turbulent, complicated swirls of air which set up vibrations in the air column. The vibrations that are at the correct resonance frequency of the pipe (depending on the length of the pipe, the design of the pipe, and the air temperature) will resonate and produce a very loud tone. The tone is not a specific fundamental frequency, but it is a combination of the different harmonics that the column will allow. The fundamental frequency is usually the most prominent frequency in a resonating column. The shorter the pipe, the higher the vibrational frequency must be to produce resonation inside the column. Therefore, a short column will produce a higher pitch than a long column.

The Singing Tube is an example of an open-ended resonating air column. When the metal wire disks are heated, and then removed from the heat source, the metal will retain the heat for a time. This heated metal will heat the nearby surrounding air, which then rises through the tube. As the hot air rises, cooler air from the room will flow into the tube from the bottom and through the wire mesh. When the air flows through the wire mesh it becomes turbulent. The swirling turbulent air sets up vibrations inside the tube, and the correct vibrational frequencies will begin to resonate loudly inside the tube to produce a note, just as in the organ pipe. When the tube is tilted parallel to the ground, the heated air does not rise through the column to cause a large inflow of cooler air through the wire mesh. Without the rush of cool air through the tiny holes, no vibrations, and therefore no sounds, are produced.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Systems, order, and organization
Evidence, models, and explanation

Content Standards: Grades 5–8
Content Standard B: Physical Science, understanding of motions and forces, transfer of energy

Content Standards: Grades 9–12
Content Standard B: Physical Science, structure of atoms, motions and forces, conservation of energy and increase in disorder

Acknowledgment

Flinn Scientific would like to thank David Katz, Pima Community College, Tucson, Arizona, for providing us the idea for this demonstration.

Reference

Tipler, Paul A. *Physics for Scientists and Engineers,* 3rd Ed., Vol. 1; Worth Publishers: New York, 1990; pp 452–457.

The *Singing Tube Demonstration* is available as a demonstration kit from Flinn Scientific, Inc.

Catalog No.	Description
AP6312	Singing Tube Demonstration Kit
AP6503	Triple Singing Tubes
AP6313	Metal Wire Disks, 2¼" dia, pkg of 10

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Simple Block and Tackle Pulley Demonstration

Introduction

How much easier is it to lift a heavy object using a pulley system? Use this simple broomstick-pulley system to effectively demonstrate why a block and tackle pulley system is so useful.

Concepts

- Pulleys
- Simple machines
- Mechanical advantage

Materials

Broom handle (or dowel rod), 1 to 1½″ diameter (or ¾″ PVC pipe), 2–3 feet long, 2

Rope, strong, 25 feet long

Student volunteers, 3

Safety Precautions

Please follow normal laboratory safety guidelines. Wear cloth gloves when holding the handles to avoid rope abrasions. Clear out the demonstration area to remove objects that could be tripped over. Do not jerk on the rope. Pull the rope gently with an even force.

Procedure

1. Select three student volunteers.
2. Assign two volunteers as broom-handle holders and the other as the rope puller.
3. Have the two broom-handle holders wear gloves and stand about 5 to 6 feet apart and extend their arms to hold the broom handles parallel to the floor at waist level.
4. Securely tie one end of the rope to the middle of one of the broom handles.
5. Wrap the rope around the middle of the other broom handle (see Figure 1) and give the free end to the rope puller. The rope puller should stand behind, and slightly to the side of one of the holders, so that the rope will be pulled perpendicular to the length of the broom handles. The free end of the rope should go under the arms of the broom-handle holder so that the rope is pulled parallel to the ground as well (see Figure 2).
6. Have the two broom handle holders try as hard as they can to prevent the broom handles from coming together as the rope puller pulls on the rope. Can the single rope puller draw the two broom handle holders together? What is the mechanical advantage of this pulley system?
7. Repeat steps 5 and 6 several times. For each new trial wrap the rope around the broom handles a different number of times (see Figure 1). How much more difficult is it for the holders with each new trial? How much easier is it for the puller? What is the mechanical advantage of the puller as a new loop is added to the pulley system? How close are the broom handle holders drawn together compared to the amount of rope pulled by the rope puller during each new trial?

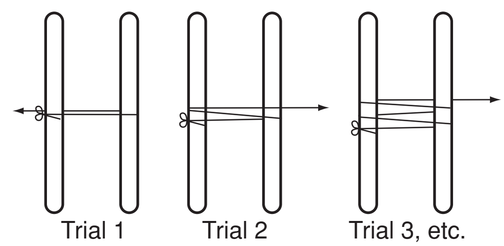


Figure 1.

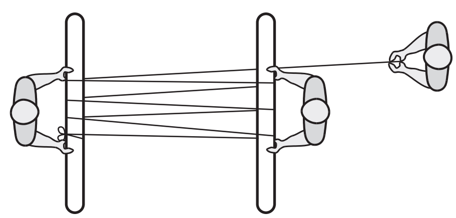


Figure 2.

Tip

- The purpose of this activity is to show how to increase the mechanical advantage of a pulley, not a contest of strength. Pulling too vigorously on the rope or jerking back on the handles may result in injury. The rope puller should take care to pull the rope evenly and straight, and avoid rubbing the rope against the hands of the other two volunteers. As a safety precaution, the volunteer handle holders may wear cloth gloves, available from Flinn Scientific (Catalog No. SE1030), to avoid abrasions from the rope.

Discussion

Pulleys are used extensively when heavy objects need to be lifted, especially in cranes in shipping and construction areas. Pulleys are one of six types of *simple machines* used to easily change the direction and/or the magnitude of an applied force. (The lever and fulcrum, inclined plane, wheel and axle, wedge, and screw are the five other types of simple machines.) How does a pulley decrease the amount of force necessary to lift an object? The advantage of a pulley is its ability to change the number of "ropes" lifting an object. This gives a lifter a greater mechanical advantage. *Mechanical advantage* is a ratio of the output force compared to the input force. The greater the mechanical advantage is for a system, the greater the output force is compared to the input force. The greater the mechanical advantage, the easier it is to do the work. For a block and tackle pulley system, the mechanical advantage is determined by the number of support ropes that are lifting the object (see Figure 3). Therefore, the more times the rope is wrapped around the broom handles, the greater the mechanical advantage is for the puller.

However, a pulley does not give something for nothing. A block and tackle pulley system gives a high mechanical advantage, but the sacrifice is that the applied force must be carried over a longer distance compared to the distance the lifted object actually moves. Ideally, due to the conservation of energy, the work in must be equal to the work out. *Work* is defined as a force times a distance. Therefore, even though a pulley (or any simple machine) makes it easier to lift a heavy object, the total amount of work necessary to lift the object will be equal. A smaller force will be used over a larger distance in order to lift a heavy object a short distance.

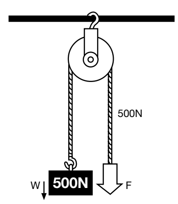
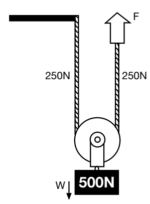
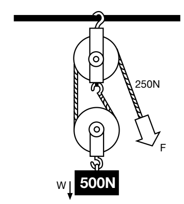
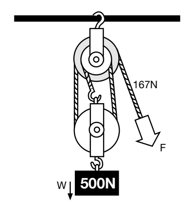
Mechanical Advantage	1	2	2	3
Pulley Setup				

Figure 3.

Alignment to the NGSS

This laboratory activity relates to the following Next Generation Science Standards (2013):

Disciplinary Core Ideas: Middle School
- MS-PS2 Motion and Stability: Forces and Interactions
  - PS2.A: Forces and Motion
- MS-PS3 Energy
  - PS3.A: Definitions of Energy
  - PS3.B: Conservation of Energy and EnergyTransfer
  - PS3.C: Relationship Between Energy and Forces

Disciplinary Core Ideas: High School
- HS-PS2 Motion and Stability: Forces and Interactions
  - PS2.A: Forces and Motion
- HS-PS3 Energy
  - PS3.A: Definitions of Energy
  - PS3.B: Conservation of Energy and Energy Transfer
  - PS3.C: Relationship Between Energy and Forces

Science and Engineering Practices
- Asking questions and defining problems
- Developing and using models
- Planning and carrying out investigations

Crosscutting Concepts
- Patterns
- Cause and effect
- Scale, proportion, and quantity
- Systems and system models

Reference

Bilash, B. *A Demo A Day: A Year of Physical Science Demonstrations;* Flinn Scientific: Batavia, IL, 1997; p 262.

Simple Block and Tackle Pulley Demonstration is available as a Physical Science Demonstration Kit from Flinn Scientific, Inc.

Catalog No.	Description
AP6890	Human Block and Tackle Demonstration
SE1030	Terrycloth Gloves

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

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Catalog No. AP5882
Publication No. 5882

Atmosphere Bar

Introduction

What does atmospheric pressure—14.7 pounds per square inch— really feel like?

Concepts

- Force
- Pressure

Background

Firemen use high-pressure hoses. Scuba divers must not dive too deeply because of water pressure. Mountain climbers must not climb too high because of low air pressure. What is pressure?

Pressure is not the same as force. Force is a push or pull one body exerts on another. It is what causes the interaction between two objects. Use the eraser end of a pencil and apply a specific force (push) onto the palm of your hand. You can feel the pressure. Now, turn the pencil around and place the sharpened end into the palm of your hand and apply the same force (push). *Caution:* Do not push too hard as to pierce the skin. Same force—different pressure! The same force on a smaller area produces greater pressure.

Pressure (P) is the amount of force (F) exerted per unit area (A). It is often expressed as:

$$P = F/A \qquad \textit{Equation 1}$$

The *Pascal* (Pa) is the SI unit for pressure. One Pascal of pressure is defined as the force of one Newton per square meter (1 Pa = 1 N/m^2).

The Earth's atmosphere exerts a pressure on everything within it. At sea level, atmospheric pressure is equal to one atmosphere (1 atm) or 101,325 Pa. Equivalent units for 1 atm pressure are 760 mm Hg or 14.7 lbs/in^2. This means that at the Earth's surface, the atmosphere exerts a force of about 100,000 Newtons on every square meter it "touches." This amount of force (100,000 Newtons) can be compared to the weight of a large truck!

Materials

One-inch square steel bar weighing approximately 14.7 lbs

Safety Precautions

Obviously, a 15-lb steel bar can be a dangerous item if used inappropriately. Do not leave the bar unattended and supervise all demonstrations with the bar. Be careful when using the bar in a vertical position and practice holding the bar to avoid any accidental slippage.

Procedure

1. Use a student volunteer. Have the student place his hand palm up on a table top. Carefully place the "atmosphere bar" flat (horizontally) into the palm of the student's hand. Since the force is spread over a fairly large surface, the pressure shouldn't be too great.
2. Carefully lift the bar into a vertical position and slowly let the full mass of the bar be focused on 1 in^2 of the palm of the student's hand. Support the bar carefully and only allow as much pressure as the student can withstand.
3. Have students discuss the pressure exerted by a 14.7-lb bar per square inch of a student's hand. Students will likely remember what one atmosphere of pressure really means for a long time.

Tips

- The concept of pressure being related to the area of the applied force is often difficult for students to understand. Have students try the "pencil" activity described in the background to start a discussion of pressure and area. Other pointed and blunted objects can be used to avoid potential punctures with pencil lead. High heel and flat heel shoes might provide an interesting discussion topic and/or demonstration.
- Introduce the idea of atmospheric pressure being equal to 14.7 lbs/in^2. Contrast that pressure with tire pressures of 30 lbs/in^2 or 90 lbs/in^2.
- Use the Atmosphere Bar to dramatically illustrate what 14.7 lbs/in^2 is really like. Pass the bar around the class and let each student lift it. Most will be quite surprised at its great mass.
- Use this demonstration bar to introduce other examples of air pressure as appropriate to your teaching unit. What role does air pressure play in our lungs and respiratory system? Why don't living organisms collapse under the pressure? What makes for good tire traction—large surface area or small surface area? How do we use air pressure to our advantage? When is air pressure a problem?
- The atmosphere bar may develop rust if you live in a humid area. Simply use steel wool to clean the bar.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Content Standards: Grades 5–8
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, understanding of motions and forces
Content Standard D: Earth Science, structure of the Earth system
Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, motions and forces

Acknowledgment

Special thanks to Walter Rohr (retired) of Eastchester High School, Eastchester, NY, for bringing this idea to the attention of Flinn Scientific.

Reference

Meloan, C. E. *J. Chem. Ed.* **1988**, 65, 69.

The *Atmosphere Bar* is available from Flinn Scientific, Inc.

Catalog No.	Description
AP5882	Atmosphere Bar

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Pressure Differential Bottle

Introduction

Blow up a balloon and have it stay inflated without tying it. Is it magic? Open up a world of understanding for your students regarding air pressure with this simple, clever device.

Concepts

- Atmospheric pressure
- Force

Materials

Bottle, 1-L PET

Balloon

Cork borer

Stopper/cork (optional)

Safety Precautions

Although the materials used in this demonstration are not considered hazardous, use caution especially when inflating or deflating the balloon. Latex (in balloons) may be an allergen. For proper hygiene, each person demonstrating the pressure differential bottle should use a separate balloon. Wear impact-resistant safety glasses for eye protection. Wash hands thoroughly with soap and water before leaving the laboratory. Follow all laboratory safety guidelines.

Preparation

A pressure differential bottle is a regular bottle with a secondary opening (see Figure 1). A pressure differential bottle is also known as a harbottle.

1. Obtain a 1-L PET plastic bottle.
2. Determine the size of the secondary opening (see *Tips* section).
3. Use a cork borer or drill to create the secondary opening on the side of the bottle near the bottom (see Figure 1).

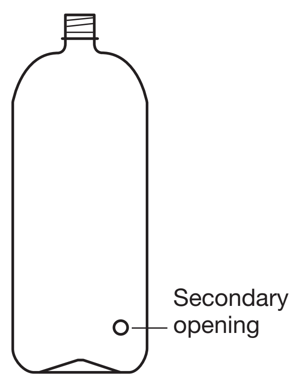


Figure 1.

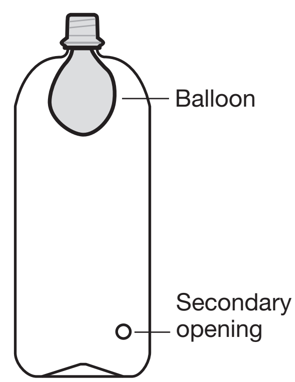


Figure 2.

Procedure

1. Obtain the pressure differential bottle from the *Preparation* step.
2. Place the balloon into the neck of the bottle and stretch the mouth of the balloon over the neck of the bottle (see Figure 2).
3. Blow up the balloon inside the bottle. Once the balloon is inflated, seal the secondary opening with a finger or stopper. The balloon will remain inflated even though the mouth of the balloon is unsealed.
4. Allow air into the secondary opening and the balloon will deflate.
5. *(Optional)* Try to blow up the balloon when the opening is sealed. It can't be done!

Disposal

The pressure differential bottle should be cleaned and then stored for reuse. If using a glass harbottle, store in proper packing materials to prevent breakage. Do not store the balloons inside the bottle. Dispose of used balloons at the end of each demonstration. Store unused balloons for future use.

NGSS Alignment

This laboratory activity relates to the following Next Generation Science Standards (2013):

Publication No. 10996
IN10996 / 061616

Disciplinary Core Ideas: Middle School
- MS-PS1 Matter and Its Interactions
  - PS1.A: Structure and Properties of Matter
- MS-PS2 Motion and Stability: Forces and Interactions
  - PS2.A: Forces and Motion
- MS-ESS2 Earth's Systems
  - ESS2.A: Earth's Materials and Systems

Disciplinary Core Ideas: High School
- HS-PS1 Motion and Its Interactions
  - PS1.A: Structure and Properties of Matter

Science and Engineering Practices
- Asking questions and defining problems
- Planning and carrying out investigations
- Constructing explanations and designing solutions

Crosscutting Concepts
- Cause and effect
- Stability and change

Tips

- Traditional harbottles, Flinn Catalog No. AP7205, are made of glass and the secondary opening is sealed with a stopper when demonstrating its use. Plastic bottles can be designed to function as the traditional model by adding a secondary opening to the bottle.
- A 1-liter plastic bottle makes an ideal pressure differential bottle. Make the secondary opening on the side near the bottom of the bottle or on the bottom of the bottle. For best results, make the opening at least 0.5 cm in diameter. If sealing with a stopper, match the size of the opening to the mid-stopper diameter. Reference the *Flinn Scientific Catalog/ Reference Manual* to coordinate cork borer and stopper/cork sizes. The opening is best made by a drill or a cork borer. A piece of masking tape placed on the bottle when using the drill/cork borer can reduce slippage. *Please note:* The bottom of a plastic bottle is usually thicker than the sides so making the opening on the bottom of the bottle might require more effort.
- When working with the pressure differential bottle a stopper can be used to seal the secondary opening, however, a finger works well for sleight-of-hand "magic."
- As an inquiry activity give students a regular bottle and one with a secondary opening and two balloons. Challenge students to inflate the balloon and have it remain inflated without sealing the mouth of the balloon.
- Air pressure accounts for many principles seen every day such as weather, flight, breathing, vacuums, and pumps. Have students research an everyday air pressure system.

Discussion

Air has mass, takes up space, and exerts pressure, even though it is not seen. So the question remains: when the balloon is blown up inside the bottle containing a secondary opening and the opening is then sealed, why does the balloon stay inflated? Why doesn't the air rush out of the mouth of the balloon?

The balloon expands into the bottle because of a difference in air pressure. When air is blown into the balloon, the air pressure inside the balloon increases and the balloon expands forcing air out of the secondary opening. (If there is no secondary opening or the opening is sealed, it is difficult if not impossible to overcome the air pressure inside the bottle to blow up the balloon. This can be demonstrated.) When the air is pushed out of the pressure differential bottle's secondary opening due to the expanding balloon, the resulting air pressure inside the bottle around the balloon is lowered and is less than atmospheric pressure. If the secondary opening of the bottle is then plugged with a finger or stopper before removing your mouth from the balloon, the air pressure is not allowed to equalize. Therefore, the air pressure in the bottle around the balloon remains lower than the pressure inside the balloon and the balloon stays inflated. When the secondary opening is unplugged, the higher air pressure outside the bottle will push air into the secondary opening to equalize the pressure in the bottle. As the air pressure increases around the balloon, the air inside the balloon is pushed out of the balloon's mouth until the balloon deflates. The air pressure is again equal both inside and outside the deflated balloon.

Materials for *Pressure Differential Bottle* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP7205	Harbottle, Glass
AP1900	Balloons, 12″ Round, Latex, 20/pkg
AP7669	Plastic Soda Bottle, 1-L
AP8326	Cork Borer, Set of 6

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Earthquakes and Resonance

Introduction

An earthquake with a magnitude of 8.5 struck Mexico on September 19, 1985. Mexico City, 250 miles from the epicenter, sustained considerable damage. A high percentage of 6- to 15-story buildings suffered damage while a very small number of one- and two-story buildings were damaged. A 48-story building experienced only minor damage—a few broken windows. While many variables affect the amount of damage a building suffers as a result of an earthquake, the natural frequency of a building is a major contributing factor.

Concepts

- Natural frequency
- Resonance
- Seismic waves

Materials

Chenille wires, 12″, 3
Rigid foam base, 15 cm × 5 cm
Ruler
Scissors
Styrofoam® balls, 1½″ diameter, 3

Safety Precautions

While unlikely, vigorous shaking of the apparatus may cause the Styrofoam balls or the wires to shake loose. Wear safety glasses during this activity. Wash hands thoroughly with soap and water before leaving the laboratory. Please follow all laboratory safety guidelines.

Preparation

1. Obtain three chenille wires. Cut the wires to the following lengths: 25 cm, 20 cm, and 15 cm. *Caution:* The ends of the cut wires may be sharp.
2. Obtain three 1½″ diameter Styrofoam balls. Gripping one wire near the end, carefully push the end into a ball with a twisting motion. Push the wire so it is inserted more than half way through the ball, keeping the wire as centered in the ball as possible.
3. Repeat step 2 for the other two wires and balls.
4. Obtain a 15 cm × 5 cm rigid foam base. Insert the free end of the 25-cm chenille wire into the center of the base, being careful that the end of the wire does not poke through the bottom of the base.
5. Centering the wire width-wise, insert the 20-cm wire one cm from one end of the base.
6. Insert the 15-cm wire one cm from the opposite end of the base, in line with the other two wires (see Figure 1).

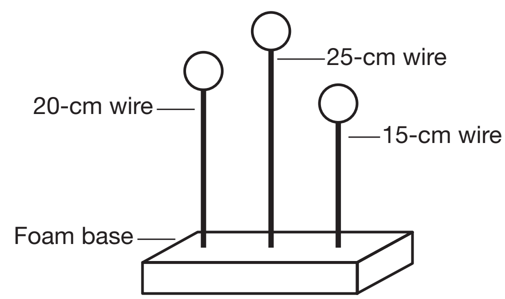


Figure 1.

Procedure

1. Place the foam base of the resonance apparatus on a flat surface.
2. Slowly slide the base forward and back as shown in Figure 2. Start with a low frequency and gradually increase the frequency until the tallest wire begins to resonate. Keep this frequency constant and observe the motion of the other two wires.
3. Gradually increase the frequency of the back-and-forth motion of the base until the 20-cm wire begins to resonate. Keep this frequency constant and observe the motion of the other two wires.
4. Once again, gradually increase the frequency of the back-and-forth motion of the base until the shortest wire begins to resonate. *Note:* This will be a very vigorous back-and-forth motion. Keep this frequency con-

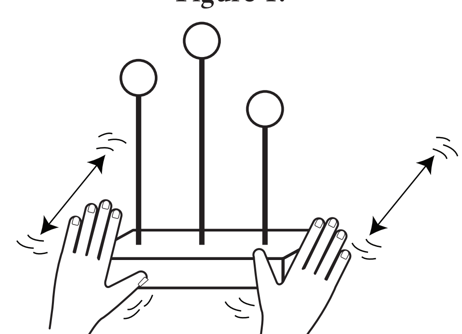


Figure 2.

stant and observe the motion of the other two wires.

5. Stop the motion of the base and instruct students to record all observations. Repeat steps 2 to 4 as needed to confirm observations.

NGSS Alignment

This laboratory activity relates to the following Next Generation Science Standards (2013):

Disciplinary Core Ideas: Middle School
- MS-ESS2 Earth's Systems
  - ESS2.A: Earth's Materials and Systems
  - ESS2.B: Plate Tectonics and Large-Scale System Interactions
- MS-PS4 Waves and Their Applications in Technologies for Information Transfer
  - PS4.A: Wave Properties

Disciplinary Core Ideas: High School
- HS-ESS2 Earth's Systems
  - ESS2.A: Earth's Materials and Systems
  - ESS2.B: Plate Tectonics and Large-Scale System Interactions
- HS-PS4 Waves and Their Applications in Technologies for Information Transfer
  - PS4.A: Wave Properties

Science and Engineering Practices
- Developing and using models
- Planning and carrying out investigations
- Constructing explanations and designing solutions

Crosscutting Concepts
- Patterns
- Cause and Effect
- Scale, proportion, and quantity
- Systems and system models

Tips

- The foam base may be made from rigid foam insulation or florist foam. Use caution when using a sharp knife to cut the foam.
- If desired, stop all movement of the chenille wires before increasing the frequency.
- Flinn Scientific's *Exploring Earthquakes—Activity Stations Kit*, Catalog No. AP7406, is a great way for students to examine what causes earthquakes, why they are so unpredictable, and investigate factors that impact the effects of seismic activity.

Discussion

All objects including buildings have a *natural frequency* or set of natural frequencies at which they vibrate. The frequency of a vibration is the number of back and forth cycles *(oscillations)* that occur per second. The natural frequency of an object depends on its size and composition. Seismic waves traveling through the ground cause the ground to vibrate at its natural frequency. If the natural frequency of the ground matches the natural frequency of a structure built on that ground, then the motion of the building will be amplified, resulting in a vigorous oscillating movement. This higher amplitude oscillation is known as *resonance*. A common occurrence of resonance is a child being pushed on a swing. If the push is given in rhythm with the natural frequency of the swing, the child will swing higher and higher.

This demonstration illustrates how the length of a material affects its natural frequency. Three chenille wires of different lengths topped with identical Styrofoam balls are placed into a rigid foam base and moved back and forth, causing the wires to vibrate. When the back-and-forth motion of the base matches the natural frequency of one of the wires, that particular wire will vibrate vigorously, achieving resonance. By varying the frequency of the back-and-forth motion of the base, each wire will resonate at a different frequency.

Sample Data Table

Frequency	Observations
Low	*The longest wire resonated, moving back and forth vigorously. The medium-length wire only moved slightly and the shortest wire barely moved at all.*
Medium	*The medium-length wire resonated, moving back and forth vigorously. The longest wire and shortest wires vibrated slightly, but neither resonated.*
High	*The shortest wire moved back and forth very vigorously. The medium-length wire and the longest wires vibrated slightly.*

Sample Questions and Answers

1. Summarize the observed relationship between the resonance frequency and the length of the wire.

   The longer the wire the lower the frequency at which the wire resonates.

2. Based on your observations, do any of the wires share the same natural frequency? Give reasons for your answer.

   None of the wires shared the same natural frequency since none resonated at the same time.

3. Based on your observations, explain why a high percentage of 6- to 15-story buildings suffered considerable damage during the 1985 Mexico earthquake, while shorter and taller buildings did not.

   The middle-sized buildings must have had the same natural frequency as the ground shaking during the earthquake. This caused the6- to 15-story buildings to resonate. The shorter buildings would require a higher frequency and the tallest buildings would require a much lower frequency to resonate.

Reference

Geis, D.; Arnold, C. Mexico City as Seismic Laboratory. *Architecture*, July 1987, pp 75–77.

Materials for Earthquakes and Resonance are available from Flinn Scientific, Inc.

Catalog No.	Description
AP8862	Chenille Wires, Black, pkg/10
AP2280	Styrofoam Balls, 1½″, pkg/12

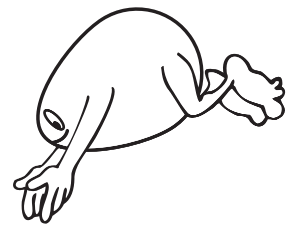
Consult your *Flinn Science Catalog Reference Manual* for current prices.

Diving Eggs

A Demonstration of Inertia

Introduction

Students experience the effects of inertia every day—riding in a car, playing sports, even when picking up their backpacks. Present a more dramatic demonstration of Newton's first law by safely dropping three raw eggs into glasses of water, without touching the eggs! Applause is guaranteed!



Concepts

- Balanced forces
- Inertia
- Newton's first law of motion

Materials

Eggs, raw, 3	Drinking glasses, 3
Water, tap	Pie pan or pizza pan, sturdy aluminum
Broom	Table
Cardboard tubes, 3 (empty toilet paper tubes)	Towel
Demonstration tray or jelly roll pan	

Safety Precautions

Take care when handling raw eggs. Wash hands thoroughly with soap and water after handling eggs. Clean up spills immediately. Wear safety glasses. Observers should be a safe distance away from the trajectory of the pie pan. Follow all laboratory safety guidelines.

Procedure

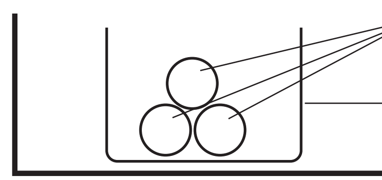


Figure 1. Overhead view

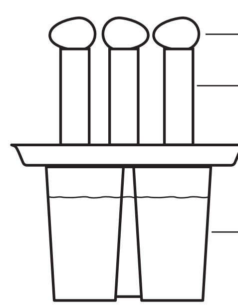


Figure 2.

1. Obtain three identical tall drinking glasses, large enough for an egg to fit in sideways.
2. Fill each glass about three-fourths full with tap water.
3. Place a demonstration tray or jelly roll pan 1 cm from the edge of a table. *Note:* The bottom of the tray must be completely flat.
4. Place two of the glasses in the tray next to the edge. The rim of the glasses should be near, but not extending over, the edge of the table.
5. Place the third glass between the other two, forming a triangle shape. See Figure 1.
6. Obtain a sturdy aluminum pie plate or a small aluminum round pizza pan.
7. Center the aluminum pan on top of the three glasses. The edge of the pan should extend slightly beyond the edge of the table.
8. Obtain three empty cardboard toilet paper tubes.
9. Stand the tubes vertically on the aluminum pan, centering one tube over each glass (see Figure 2).
10. Obtain three raw eggs. *Note:* For practice, hard boiled eggs may be used. Once the demonstration has been perfected, use raw eggs.
11. Balance one egg on top of each cardboard tube, laying the egg lengthwise across the top of the tube. Do not fit the narrow end of the egg into the tube; the egg should just rest on top (see Figure 2).
12. Obtain a broom and place the bristles on the floor by the table with the handle extending upward.
13. Holding on to the broom handle, and facing the egg setup on top of the table, step on the bristles of the broom with one foot.

14. Pull back on the broom handle like a lever. See Figure 3.
15. *Without letting go of the broom handle*, carefully test to see if the handle will hit the aluminum pan *between* the two closer glasses when the handle is released. If not, adjust the position of the broom accordingly. The handle should not hit any of the glasses or the tray.
16. Continuing to step on the bristles, pull the broom handle back.
17. Let go of the broom handle and watch as the eggs "dive" safely into the glasses of water.

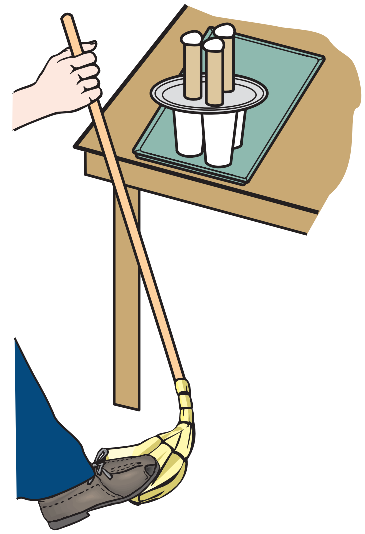


Figure 3.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory wastes. Eggs may be disposed of in the trash according to Flinn Suggested Disposal Method #26a. Egg whites and yolks from broken eggs may be disposed of down the drain with plenty of water according to Flinn Suggested Disposal Method #26b. If necessary, sterilize the glasses and demonstration tray with a 10% bleach solution, then rinse with water.

NGSS Alignment

This laboratory activity relates to the following Next Generation Science Standards (2013):

Disciplinary Core Ideas: Middle School
MS-PS2 Motion and Stability: Forces and Interactions
PS2.A: Forces and Motion
PS2.B: Types of Interactions

Disciplinary Core Ideas: High School
HS-PS2 Motion and Stability: Forces and Interactions
PS2.A: Forces and Motion
PS2.B: Types of Interactions

Science and Engineering Practices
Developing and using models
Planning and carrying out investigations

Crosscutting Concepts
Patterns
Cause and effect

Tips

- Practice with other objects before using raw eggs. Hard boiled eggs, rubber balls, or any other objects similar in size and mass may be used.
- Thin aluminum pie pans may dent with the force of the broom handle, resulting in a less elastic collision. These pans are not recommended for this demonstration.
- Diving Eggs is available from Flinn Scientific as a Super Value Kit, "Diving Eggs Inertia Challenge" (Catalog No. AP7419). The kit includes weighted plastic eggs for practice.
- Using clear drinking glasses allows students to see the eggs after they have dropped into the water. Large beakers may be used instead of drinking glasses.
- Videotape the demonstration, and then play it back in slow motion.

Discussion

Newton's first law of motion states that an object at rest tends to stay at rest unless a net force acts on it. This law is also known at the law of inertia. *Inertia* is the tendency of an object to resist change in motion. Inertia is directly related to mass—the greater the mass of an object, the greater its inertia. In the "Diving Eggs" setup, all the forces are balanced with all objects at rest. A net horizontal force is supplied by the moving broom handle. This force acts upon the aluminum pan, which then accelerates in the direction of the applied force. When the edge of the pan hits the cardboard tubes, the tubes accelerate in the direction of the force also. The eggs do not move with the tubes because of their greater inertia. Since no horizontal force acts on the eggs, however, once the force holding them up is gone, the only remaining force is gravity, and the eggs drop into the glasses of water.

Materials for *Diving Eggs* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP7419	Diving Eggs Inertia Challenge—Super Value Kit
GP1025	Beaker, 400-mL

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Absorption of Light Energy

Light, Energy, and Electron Structure

FLINN SCIENTIFIC CHEM FAX!

Introduction

Why does the color of a copper chloride solution appear blue? As the white light hits the paint, which colors does the solution absorb and which colors does it transmit? In this activity students will observe the basic principles of absorption spectroscopy based on absorbance and transmittance of visible light.

Concepts

- Spectroscopy
- Absorbance and transmittance
- Visible light spectrum
- Quantized electron energy levels

Background

The visible light spectrum (380–750 nm) is the light we are able to see. This spectrum is often referred to as "ROY G BIV" as a mnemonic device for the order of colors it produces. Violet has the shortest wavelength (about 400 nm) and red has the longest wavelength (about 650–700 nm).

Many common chemical solutions can be used as filters to demonstrate the principles of absorption and transmittance of visible light in the electromagnetic spectrum. For example, copper(II) chloride (blue), ammonium dichromate (orange), iron(III) chloride (yellow), and potassium permanganate (red) are all different colors because they absorb different wavelengths of visible light.

In this demonstration, students will observe the principles of absorption spectroscopy using a variety of different colored solutions. Food coloring will be substituted for the orange and yellow chemical solutions mentioned above. Rare earth metal solutions, erbium and praseodymium chloride, will be used to illustrate line absorption spectra.

Materials

Copper(II) chloride solution, 1 M, 85 mL
Erbium chloride solution, 0.1 M, 50 mL
Potassium permanganate solution ($KMnO_4$), 0.001 M, 275 mL
Praseodymium chloride solution, 0.1 M, 50 mL
Water, deionized
Beaker, 250-mL
Black construction paper, 12 × 18, 2 sheets
Colored pencils
Diffraction grating, holographic, 14 cm × 14 cm
Microchemistry solution bottle, 50 mL, 6
Overhead projector and screen
Red food dye
Stir rod, glass
Tape
Yellow food dye

Safety Precautions

Copper(II) chloride solution is toxic by ingestion and inhalation. Potassium permanganate is a strong oxidizing agent. It is irritating to the skin and eyes and slightly toxic by ingestion. Wear chemical splash goggles and chemical-resistant gloves while preparing solutions. Wash hands thoroughly with soap and water before leaving the laboratory. Please review current Material Safety Data Sheets for additional safety, handling, and disposal information.

Preparation

1. Transfer the copper(II) chloride (blue) and potassium permanganate (red) solutions to labeled microchemistry solution bottles. Fill each bottle as close to the top as possible without spilling. Any extraneous room will cause air bubbles to show when the bottle is turned on its side and can interfere with the electromagnetic spectrum appearance.
2. Prepare a yellow solution by placing 200 mL of deionized water into a 250-mL beaker. Add one drop of yellow food

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IN91812A / 061616

dye and stir. Transfer the solution to a microchemistry bottle.

3. Prepare an orange solution by placing 200 mL of deionized water into a 250-mL beaker. Add two drops of red food dye and stir. Transfer the solution to a microchemistry bottle.
4. Transfer the erbium chloride and praseodymium chloride solutions into appropriately labeled microchemistry bottles.

Procedure

Part A. Displaying an Overhead Visible Light Spectrum

1. Obtain two sheets of black construction paper.
2. Form a 2-cm wide slit in the center of the stage of the overhead projector using two sheets of black construction paper. Position the slit on the stage so that the image of the slit projected onto the projection screen is vertical (refer to Figures 1 and 2).
3. Place the holographic diffraction grating film above the lens of the overhead projector (see Figure 1). Wear gloves when handling the diffraction grating. If the spectra are not projected to the left and right of the screen, rotate the diffraction grating 90 degrees (the alignment of the grating is important). Once two bright spectra (mirror images of each other) are displayed horizontally to the left and right of the film screen (see Figure 2), the diffraction grating should be secured to the lens with tape. Tape only the outside edges of the diffraction grating and make sure the diffraction grating is flat.

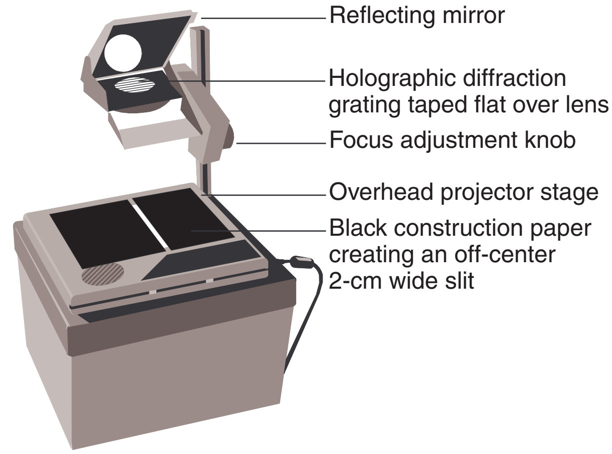


Figure 1. Overhead Projector

4. Adjust the focus of the overhead projector so that the image of the slit is in sharp focus on the screen. The two spectra should also come into focus.
5. Once the slit is aligned so the "selected" spectrum is in the proper location to be viewed by the students, the construction paper should be secured to the overhead projector with tape.
6. Several activities can be performed to demonstrate the principles of light absorption and transmittance.

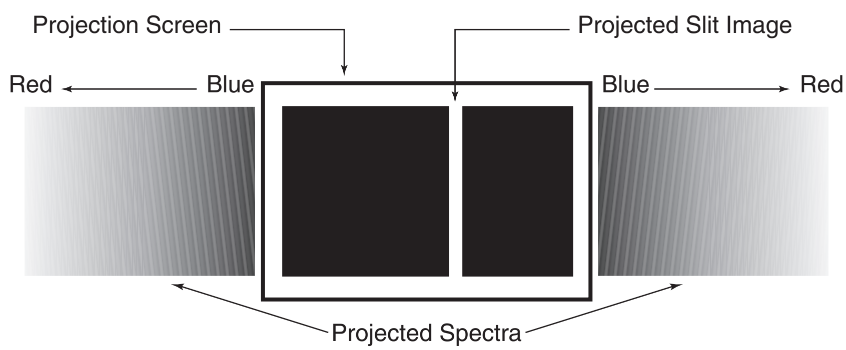


Figure 2. Projected Spectra

Part B. Absorption Spectra

1. Place the overhead projector 10–15 feet from the projection screen.
2. Turn on the overhead projector and aim the light at the projection screen. Eliminate as much light in the room as possible by turning off lights and closing window blinds or curtains. *Note:* The visibility of the spectrum will be best in a very dark room.
3. Position the overhead so one of the two vertical spectra is on the screen or flat wall. Rotate the overhead stand 15–20° to the right or left so the spectrum is centered.
4. Have students observe the appearance of the visible spectrum without any filters in place.
5. Ask students to sketch the observed spectrum on the Absorption Spectrum Worksheet using colored pencils.
6. Place the orange solution in the middle of the overhead projector stage across the 2-cm slit opening. The bottle should be placed on its side, cap pointing either left or right, not up and down, so that the side with the most surface area is touching the overhead.
7. Have students draw the color spectrum they observe in the appropriate box of the worksheet.
8. Discuss with students which colors are absorbed (blue and violet—hence the black spot where those colors used to be) and

which colors are being transmitted (green, yellow, orange and red—the colors that are still visible).

9. Remove the orange solution and repeat steps 6–8 three more times using the copper(II) chloride (blue), potassium permanganate (red), and yellow solutions.
10. Remove all bottles from the overhead projector screen. Hold up the praseodymium chloride solution. Have students note the color and predict what they expect to see based on the results obtained with the other solutions.
11. Initial observations will be different as all the colors in the spectrum are present, as well as several dark, fine lines. Closer examination will reveal two significant lines in the blue-violet region. Have students sketch the absorption lines on the worksheet.
12. Repeat steps 10 and 11 using the erbium chloride solution.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory waste. Potassium permanganate may be disposed of according to Flinn Suggested Disposal Method #12a. Copper(II) chloride may be disposed of according to Flinn Disposal Method #26b.

Tips

- As an extension to this activity, make "artificial" purple and blue solutions and see if they yield the expected results when used as light filters.
- To optimize spectrum viewing, the microchemistry bottles should be as full as possible. Once each solution has been transferred to the microchemistry bottle, fill any remaining space with distilled or deionized water using a Beral pipet.
- Acrylic or gelatin light filters may be used in place of the colored solutions. The same principles will apply.

Discussion

White light is composed of wavelengths of light from the visible spectrum as well as light wavelengths that are invisible to our eyes (i.e., infrared and ultraviolet). The visible spectrum is often referred to as "ROY G BIV" after the colors of light that are produced when white light is transmitted through a prism: red, orange, yellow, green, blue, indigo and violet.

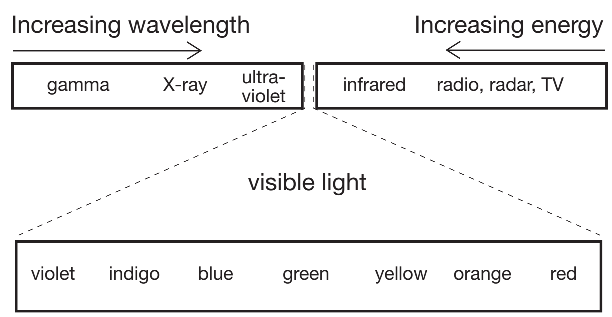
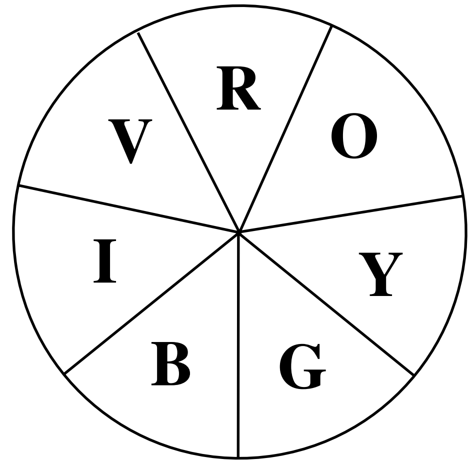


Figure 3.

The color of an opaque object results from the reflection of light from that object. Grass appears green when exposed to white light because the "green-colored" light waves that compose the white light are reflected from the surface of the grass and the other wavelengths ("blue," "red," "yellow," etc.) are absorbed. The green wavelengths of light reflect back to our eyes and interact with the cones in the retina of the eye. The cones are the color receptors of the eye. Our brain receives the signals sent from these cones and interprets that our eyes are seeing the color green. However, most materials do not reflect a pure single wavelength color and absorb all the other colors in the spectrum. Most materials reflect a combination of colors from the visible spectrum; this gives objects their own distinctive colors. Wavelengths and intensities of light generate an enormous variety of colors that we see.

The color of a transparent solution or material in visible light corresponds to the color of light transmitted or passed through the solution. The solutions used in this demonstration are examples of white light filters. For example, a solution that appears yellow absorbs mostly violet light—most of the other colors in the visible spectrum are transmitted and thus observed in the projected spectra. See the *Observations* below for a description of the relationship between the color of each solution and the colors that are absorbed. Spectroscopy is defined as the measurement of the amount or intensity of light or electromagnetic energy absorbed by a substance as a function of the wavelength. Different types of absorption spectroscopy result from different types of radiation used, namely X-ray, UV, visible, infrared, etc. The absorption of visible light by a substance results from the excitation of electrons to higher energy levels. Because electron energy levels are quantized, different substances absorb different colors of visible light. The visible absorption spectra of transition metal ions consist of fairly broad bands due to d-electron transitions.



In contrast, many rare earth metals exhibit fine line absorption spectra. (These spectra are indeed “rare.”) The absorption peaks appear as sharp, discrete dark lines against a colored spectrum. They result from electron transitions involving the f orbitals. The relationship between the colors of absorbed vs. transmitted light is evident of the concept of *complementary colors*.

In general, colors opposite each other on the color wheel are complementary colors. For example, by looking at the wheel, the fact that violet (purple) and yellow are complementary colors can be seen. Therefore, in analogy to the red filter, it can be assumed that the violet filter absorbs yellow light and transmits violet light. The color wheel and the idea of complementary colors can be used as a first estimation of the wavelengths that are absorbed by a substance based on its color.

The following table lists the wavelengths associated with each of the colors in the visible spectrum and their complements. The representative wavelength can be used as a benchmark for each color. For example, instead of referring to green as light in the wavelength range 500–600 nm, one could simply say that green light is 520 nm.

Representative Wavelength, nm	Wavelength Region, nm	Color	Complementary Color
410	400–425	Violet	Yellow-green
470	425–480	Blue	Orange
490	480–500	Blue-green	Red
520	500–560	Green	Red-Violet
565	560–580	Yellow-green	Violet
580	580–585	Yellow	Violet
600	585–650	Orange	Blue
650	650–700	Red	Blue-green

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Content Standards: Grades 5–8
Content Standard B: Physical Science, transfer of energy
Content Standard C: Life Science, structure and function in living systems
Content Standards: Grades 9–12
Content Standard B: Physical Science, interactions of energy and matter
Content Standard C: Life Science, the cell

Answers to Worksheet Questions

Observations

The sketches should resemble the electromagnetic spectrum with the appropriate colors that are observed or transmitted shown in color. The regions (colors) of the spectrum that are absorbed will appear black or very dark. Below is a list of the colors that should appear in each box.

Potassium permanganate (red solution)—blue, indigo, violet, red and orange are observed (transmitted)

Copper(II) chloride (blue solution)—red, orange, yellow, green, blue, and violet are observed

Orange solution—green, yellow, orange and red are observed

Yellow solution—red, orange, yellow, green, and blue are observed

Praseodymium chloride—absorption line present between the orange and yellow, there are additional lines in the blue and violet.

Erbium chloride—major absorption lines in the green with faint lines in the red and blue

Answers to Post-Lab Questions

1. Compare the relationship between the blue solution and orange solution in terms of their absorbance of visible light and give the definition of complementary colors.

   Blue and orange are complements of each other. Thus, the orange solution absorbs blue light and the blue solution absorbs orange light.

2. If a green solution had been placed on the overhead, predict which colors of light would be absorbed and which colors would be allowed to pass through.

   Red would be absorbed and green, yellow, orange and violet would be transmitted.

3. What do the spectra of the rare earth elements, erbium and praseodymium, demonstrate?

   They demonstrate fine line absorption spectra. The absorption lines correspond to energy transitions involving electrons in the f orbitals.

4. Did erbium and praseodymium yield the results you initially predicted? Why or why not?

   The erbium did support the hypothesis because there were major absorption lines in the green and yellow-green, and faint lines in the red and blue. The praseodymium did not support the hypothesis that it should absorb bands in the red/orange region. There was a strong absorption line between the orange and yellow; there is also an absorption line in the blue and violet regions.

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Absorption of Light Energy* activity, presented by Annis Hapkiewicz, is available in *Light, Energy and Electron Structure* and in *Absorption Spectroscopy*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Absorption of Light Energy* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Absorption Spectroscopy—Chemical Demonstration Kit* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP8823	Absorption Spectroscopy—Chemical Demonstration Kit
C0212	Copper(II) Chloride, Reagent, 25 g
P0077	Potassium Permanganate, Reagent, 100 g
V0003	Food Coloring Dyes, Dye Set
AP1047	Holographic Diffraction Grating Film
AP1449	Mircrochemistry Solution Bottle, 50 mL
P0269	Praseodymium Chloride Solution, 0.2 M, 50 mL

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Absorption of Light Energy Worksheet

Observations

Draw your observations in the seven boxes below using colored pencils.

Electromagnetic spectrum

Potasium permanganate

Copper(II) chloride

Yellow solution

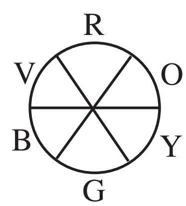
Orange solution

Erbium chloride

Praseodymium chloride

Post-Lab Questions

Use the pie chart presented to assist in answering Questions #1 and #2. Colors opposite each other on this wheel are known as complements.



1. Compare the relationship between the blue solution and orange solution in terms of their absorbance of visible light and the definition of complementary colors?

2. If a green solution had been placed on the overhead, predict which colors of light would be absorbed and which colors would be allowed to pass through.

3. What do the spectra of the rare earth elements, erbium and praseodymium, demonstrate?

4. Did erbium and praseodymium yield the results you initially predicted? Why or why not?

Can Crush

What Is Pressure?

Introduction

Here's a pressure-packed demonstration that will convince students that air exerts significant pressure!

Concepts

- Pressure differential
- Atmospheric pressure

Materials

Can, metal with screw top lid

Hot plate

Tap water, 50 mL

Water bath

Zetex™ gloves, for high and low temperatures

Safety Precautions

Be careful of the hot can and the steam created by heating the water in the can. Wear goggles and protective gloves during the demonstration.

Procedure

1. Locate a metal can with an airtight screw top lid.
2. Remove the lid from the metal can. Be sure the can is clean and free of chemicals—a new, unused can is preferred.
3. Add approximately 50 mL of tap water to the metal can. This should be enough to cover the bottom of the can to a depth of approximately 1 cm.
4. Place the can on a hot plate and heat it until the water boils and steam flows out of the uncapped hole.
5. Using protective gloves, remove the steaming can from the hot plate. Place the can where it can be easily viewed.
6. Immediately place the cap on the can and close tightly.
7. The can will be dramatically crushed and it will likely do so in a loud fashion. For a quick crush, place the sealed can into an ice-water bath to cool the can rapidly.

Tips

- It is important that the cover on the can has an airtight seal. Be sure to get the lid placed tightly on the can before the cooling process begins.
- The collapsed can and an identical un-crushed can make a nice exhibit in a classroom display case.
- If a cap to the can is not available, try a rubber stopper. Be sure the rubber stopper fits snugly in the can opening.
- For a more impressive implosion, immerse the can into a sink of cold water.
- This demo can be downscaled or upscaled, depending on the size of the metal can and your ability to safely heat the water. A soda can heated, then immersed upside down in chilled water works nicely.
- For the largest demo, take a 55 gallon drum and put a dent in the side. Add about 1 gallon of water to it. Hot water will really speed up the process. Heat it on a camping stove until the water boils vigorously for at least ten minutes. If the can is painted, the paint may really stink if heated on an open flame, so have adequate ventilation. A cloud of condensed water vapor should escape from the mouth of the can for at least ten minutes. Coat the threads of the screw top with silicone sealing materials to ensure an airtight fit. Turn off the stove and, using gloves, put the top on the can as tight as you can with pliers or special tools for tightening drum tops. The can should collapse within

several minutes. Please view video and follow all safety precautions.

Discussion

The tremendous pressure required to “crush” the can comes from the differential in pressure that exists between the outside of the can (normal air pressure) and the partial vacuum created inside the can by the condensing steam. The pressure differential is caused by the condensation of the steam inside the closed system as the can cools. There is only a little air in the can to take the steam’s place. There is much less gas on the inside of the can so there is less pressure inside. The pressure on the outside of the can remains at atmospheric pressure (14.7 lb/in^2) while the pressure inside the can is significantly reduced as the steam condenses. Remember that the can is not “sucked in”—it is the greater pressure on the outside of the can that pushes in on the can and “crushes” it. The total pressure exerted on the outside of the can may be calculated by determining the surface area of the outside of the can and multiplying this area by atmospheric pressure per unit area. The air is pushing on the outside with about 15 pounds per every square inch. With a 5 gallon can this is over 18,000 pounds. The cans are not designed to withstand such pressure differentials so the cans implode.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Content Standards: Grades 5–8
Content Standard B: Physical Science, properties and changes of properties in matter, understanding of motions and forces
Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter, motions and forces

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Can Crush* activity, presented by Lee Marek, is available in *What Is Pressure?*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Can Crush* are available from Flinn Scientific, Inc.

Materials required to perform this activity are available in the *Collapsing Can Demonstration* available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP4695	Collapsing Can Demonstration
AP3242	Gloves, Zetex™, 14″ Length

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

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Publication No. 1900

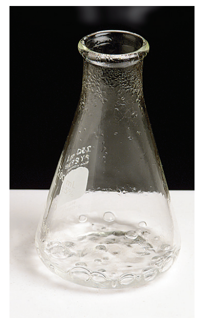
Balloon in the Bottle

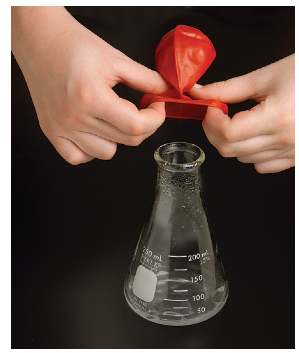
Introduction

Heat some water in a flask, then attach a balloon, cool the flask, and watch as the balloon collapses into the flask. An easy-to-perform and colorful variation of the common *Crush the Can* demonstration.

Concepts

- Pressure differential
- Vacuum





Materials

Erlenmeyer flask, borosilicate glass, 250-mL

Balloon, latex, 11-inch size (size to fit flask)

Hot plate or Bunsen burner

Ice bath or cold running water

Water, 25 mL

Safety Precautions

Always practice a demonstration before presenting it to students. Be careful of the hot glass and steam. Wear chemical splash goggles and heat-resistant gloves.

Procedure

1. Add approximately 25 mL of water to a 250-mL Erlenmeyer flask. Heat the water using a hot plate, Bunsen burner or other heat source.
2. As the water comes to a boil and steam begins to rise out of the flask, remove the flask from the heat. Quickly place the balloon over the mouth of the flask.
3. Place the flask under cold running water and the balloon will be pushed into the flask until it fills the entire flask. If the balloon stretches too much, it may break.

Tips

- Use a borosilicate (e.g., Pyrex®) flask with a heavy-duty rim. Do not use an economy-choice flask. Check the flask for chips or cracks before use.
- Stretch out the balloon by inflating and deflating it before using it.
- The demonstration works best if the balloon is centered on the opening when placed over the mouth of the flask. It also helps if the balloon is slightly pushed into the flask when it begins to collapse. If not, it may collapse onto itself and not get drawn into the flask. The demonstration will work without holding it under cold water, but it takes longer to cool the glass and condense the water vapor.
- A hard-boiled, shelled egg can also be used in place of the balloon. A larger flask may be needed depending on the size of the egg.

Discussion

The *Balloon in the Bottle* demonstration is an easy-to-perform and colorful variation of the common *Crush the Can* demonstration. Both demonstrations rely on the creation of a pressure differential caused by the condensation of steam inside a closed system. As the steam condenses, a partial vacuum is formed inside the closed system. The pressure outside the closed system is still at atmospheric pressure (approximately 14.7 lb/in^2). This pressure difference will cause the balloon to be pushed into the flask. The balloon is not "sucked" into the flask—it is pushed in by the greater atmospheric pressure that exists outside the closed system. The balloon will continue to be pushed into the flask until the pressure inside the closed system is approximately equal to the atmospheric pressure.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Systems, order, and organization
Evidence, models, and explanation

Content Standards: Grades 5–8
Content Standard B: Physical Science, properties and changes of properties in matter, understanding of motions and forces

Content Standards: Grades 9–12
Content Standard B: Physical Science, structure and properties of matter, motions and forces

Reference

Shakhashiri, B. Z. *Chemical Demonstrations: A Handbook for Teachers in Chemistry;* University of Wisconsin: Madison; Vol. 2, pp 6–8.

Materials for *Balloon in the Bottle* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP1900	Balloons, Latex, pkg/20
AP7234	Hot Plate, Flinn, 7″ × 7″
GP3045	Erlenmeyer Flask, Borosilicate Glass, 250-mL

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.

Bottomless Bottle

A Fluid Pressure Demonstration

Introduction

Use this old parlor trick to teach about the incompressibility of liquids and Pascal's law of equal pressure.

Concepts

- Pascal's law
- Incompressibility of liquids
- Pressure

Materials

Food dye (optional)
Glass bottle, tall with thin neck and wide body
Glass disposal container
Gloves, cotton (long enough to provide lower arm protection)
Rubber mallet
Safety glasses
Safety shield (optional)
Transparent tape
Water

Safety Precautions

Use caution when striking the top of the glass bottle with a rubber mallet. Strike the top squarely so the lip of the bottle does not crack. If the lip cracks, but the bottle's bottom does not fall out—do NOT hit the bottle again. Throw the bottle away and use a new bottle. Students observing the demonstration need to wear safety glasses. Students need to stand at least 10 feet away when the demonstration is performed. The bottle may crack in areas other than the bottom and broken glass may fly several feet from the demonstration site. Wear thick cotton or Playtex®-type latex gloves, a long-sleeved shirt or lab coat, and safety glasses. Practice this demonstration several times before performing in front of the class. A safety shield should be used if students do not have safety glasses available.

Preparation

1. Obtain an empty, clear glass bottle—beer, wine-cooler or sauce bottles work best. Glass soda bottles do not work as well.
2. Use hot soapy water to clean the bottle and remove any labels that may be on the bottle (especially if it once contained an alcoholic beverage).
3. Wrap transparent tape around the bottom of the bottle and half-way up the bottle (see Figure 1). This will help contain any broken glass once the bottom cracks out.
4. Fill the bottle about three-quarters to seven-eighths full with water so that the water level is in the neck of the bottle, just above the wider "body" part of the bottle (see Figure 1). Add food dye if desired.
5. Allow the water to sit for several minutes or longer so that some of the trapped air can escape.

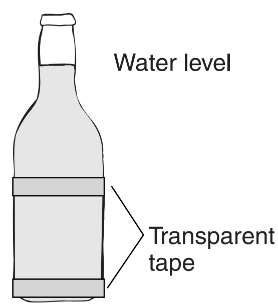


Figure 1.

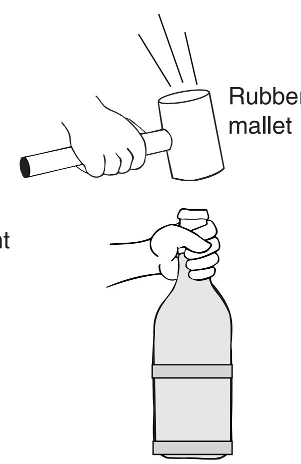


Figure 2.

Procedure

1. Obtain a rubber mallet, long cotton or Playtex-type gloves, safety glasses, and the partially filled, taped bottle.
2. Grip the neck of the bottle tightly with a gloved hand and hold it over a glass disposal container. *Caution:* Make sure everyone near the demonstration is wearing safety glasses!
3. Firmly strike the top opening of the bottle with the rubber mallet. Make sure the end of the rubber mallet strikes the opening squarely (see Figure 2). *(The bottom of the glass bottle should break and fall into the glass disposal container along with the water.) Caution:* If the bottom of the bottle does not "fall out" with the first blow, but the bottle's body or the lip cracks or chips—do NOT strike the bottle again. Use a new bottle.
4. Show the broken bottle to the class. *Caution:* Do NOT pass the bottle around to the class or allow the students to hold it.

There will be many sharp edges that could easily injure the students.

5. Dispose of or recycle the broken glass appropriately.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures, and review all federal, state and local regulations that may apply, before proceeding. It is recommended that this demonstration be done directly over a glass disposal container. Paper towels may be placed in the bottom of the container to absorb the water. If done over a garbage can, dispose of the broken glass properly.

Tips

- It is important to practice this demonstration several times before performing in front of the class to get a feel for how hard to strike the top of the bottle. It typically does not take a very hard hit to break the bottom out of the bottle. It may take two or three hits the first time.
- Large, flat-headed rubber mallets work the best.

Discussion

Blaise Pascal (1623–1662) is well known as a mathematician but he also performed many experiments involving pressure in fluids. One of the principles he developed to explain the properties of fluids is known as Pascal's principle or Pascal's law. *Pascal's law* states that pressure applied anywhere to a fluid is transmitted undiminished in all directions. This law serves as a basis and exploration for much of what is now known as *hydraulics*.

In the *Bottomless Bottle* demonstration, the force of the rubber mallet striking the top of the bottle causes the air inside the bottle's neck to compress slightly (because of inertia and the brief airtight seal around the bottle's opening). The compressed air travels through the bottle's neck as a shock wave (through compression and rarefraction) until the compression wave reaches the water level. At this point, the water will not compress. Instead, the force from the shock wave increases the pressure on the liquid. This pressure is then distributed equally to all points of the bottle holding the water. Pressure is equal to a force per unit area ($P = F/A$). Therefore, under constant pressure, a region of the container with a large surface area will experience a greater force compared to a region with a smaller surface area. The small force that is applied to the water in the narrow neck of the bottle (from the compressed air) multiplies into a much larger force in the wider "body" portion. Depending on the bottle dimensions (neck diameter versus bottom diameter), this force may increase by 5 to 20 times at the bottom of the bottle. This large force causes the bottom of the bottle to "pop" out.

An alternative explanation for the force that "pops" the bottom out has to do with cavitation. When the top of the bottle is struck with the mallet, the bottle moves downward. The water inside the bottle, however, does not move down due to inertia. This briefly creates a vacuum at the bottom of the bottle. As a result of the low pressure area, tiny bubbles of water vapor form. When the water does move down, the bubbles collapse, creating a shock wave. This rapid formation and implosion of bubbles is known as *cavitation*. The combined force of all the collapsing bubbles is enough to break away the bottom of the bottle.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12

Systems, order, and organization
Evidence, models, and explanation

Content Standards: Grades 5–8

Content Standard B: Physical Science, properties and changes of properties in matter, understanding of motions and forces, transfer of energy

Content Standards: Grades 9–12

Content Standard B: Physical Science, structure and properties of matter, chemical reactions, motions and forces, conservation of energy and increase in disorder

Acknowledgment

Special thanks to Todd Everson, Milwaukee School of Languages, Milwaukee, WI for providing the cavitation explanation for this activity to Flinn Scientific.

Materials for *Bottomless Bottle—A Fluid Pressure Demonstration* are available from Flinn Scientific, Inc.

Catalog No.	Description
AP6643	Bottomless Bottle Demonstration Kit
SE1041	Gloves, for rough/sharp materials
AP8829	Glass Disposal Container

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.