

For Instructors

An added feature to the eighth edition of *Physics Laboratory Experiments* is a set of pre-lab demonstrations. The purpose of these demonstrations is to “break the ice,” so to speak. Students often come to the laboratory unenthusiastic. If something attention-getting (a demo) is presented initially that is related to the lab experiment, or some other physics principle that has been studied in class, interest is aroused. This being done, the instructor can lead into the current lab experiment.

A list of the demonstrations follows. They are instructive and economical, usually done with available materials and items. In some demonstrations, students can participate, adding to the attention-getting. Enjoy.

- **Skewed Balloon (And it doesn't burst!)**
- **Problem in Data Analysis (There's a dollar missing)**
- **Mixed Liquids Become More Dense**
- **Problem in Math Analysis (Can $2 = 1$?)**
- **Apparent Weightlessness (Where's the water?)**
- **Different Distances of Fall (Listen to the sound)**
- **Problem in Kinematics**
- **Which Way Does the Bubble Go? (Mass and inertia)**
- **Newton's Cradle (In-and-out)**
- **Pendulum and Peg**
- **Bucket Swing (What keeps the water in the pail?)**
- **Two Ball Bounce (Energy transfer)**
- **The Slinky Slinky® (Why doesn't it fall?)**
- **Which Way Does the Yo-yo Roll? (Torque - rotational motion)**
- **Candle Seesaw (Torque - equilibrium)**
- **Too Weak to Pick It Up? (Center of gravity - equilibrium)**
- **Stack Them Up (Center of mass - equilibrium)**
- **Cylinder Derby (Rotational motion - moment of inertia)**
- **Egg Spin (Rigid-body rotation)**

- **Transverse and Longitudinal Waves (Vibrating and singing rod)**
- **Musical Straws (Make your own kind of music)**
- **Singing Wine Glass (Resonance)**
- **Whirly Tube (Bloogle resonator)**
- **Burning Dollar Bill (Money to burn)**
- **Drinking Bird Engine (Perpetual motion?)**
- **Salt and Ice (Melting and freezing)**
- **Take the Heat (Specific heat)**
- **Poke a Hole (And no leaks)**
- **Electrostatics in Action (Levitation)**
- **Magnetism through the Hand**
- **Is Money Magnetic? (2 demos)**
- **Eating Magnetic Iron for Breakfast (2 demos)**
- **Which Rod is Magnetic?**
- **Now You See It, Now You Don't**
- **Mirror Right-left Reversal and Nonreversal (2 demos)**
- **Spherical Mirrors (Upside down and right-side up)**

Instructor Demonstrations

EXPERIMENT 1. THE SCIENTIFIC METHOD AND THOUGHT

Skewed Balloon (And it doesn't burst)

The purpose of the demonstration is to get the students to think and apply the scientific method (or scientific thinking) in forming explanations and drawing conclusions. The demonstration consists of pushing a wooden (bamboo) skewer completely through an inflated balloon without it collapsing (• Fig D1).

Items needed

- Latex rubber balloons (12-in. size)
- Bamboo skewers (12-in. long, found in the grilling or cooking section)
- Cooking oil (small amount)

Procedure

1. Blow up balloon to nearly full size and let air out so about 2/3 in size (about 9 inches). Tie a knot in the end to keep the balloon inflated. Note the thick areas of the inflated balloon near the tied knot and opposite end.
2. Fully rub cooking oil on the length of the skewer with the fingers. (You can do this openly or surreptitiously, depending on how difficult you want to make the demo explanation.)
3. Place the sharp end of the skewer on the thick end of the balloon near the tie aiming toward the opposite thick end. Use gentle pressure (twisting may help) and puncture the balloon.
4. Push the skewer steadily toward the opposite end until the tip of the skewer touches the thick end portion of the balloon. Keep pushing until the skewer tip penetrates through the rubber a couple inches. The skewed balloon should remain inflated. (A little air may be lost.)
5. Ask the students to explain. You may want to repeat the demonstration showing the oil coating of the skewer if you didn't do it before.

Explanation

Latex rubber is made up of long-chain polymer molecules. When the balloon is punctured, the long chains form a seal around the skewer. The cooking oil acts as a lubricant for the puncture.

EXPERIMENT 2. EXPERIMENTAL UNCERTAINTY (ERROR) AND DATA ANALYSIS

Problem in Data Analysis (There's something missing)

Procedure

To illustrate a problem in data analysis, have the students consider the following:

A student wants to buy a new cell phone for \$97 and borrows \$50 from each of two friends. He buys the phone and gets \$3 back. He gives each friend \$1 and keeps the other \$1.

Now he owes his two friends \$49 apiece. But \$49 plus \$49 is \$98; and when you add the \$1 he kept, you get \$99. Where is the missing dollar?

Explanation.

The data was manipulated and the wrong figures added. The student now has a \$97 cell phone plus \$1 cash. That totals \$98, which indeed is what he owes to his friends.

EXPERIMENT 3. MEASUREMENT INSTRUMENTS (MASS, VOLUME, AND DENSITY)

Mixed Liquids Become More Dense

The purpose of this demonstration is to show the students how unexpected results may occur in an experiment from unexpected sources. 500 mL of methyl alcohol ($\rho_{\text{al}} = 0.790 \text{ g/cm}^3$) and 500 mL of water ($\rho_{\text{w}} = 1.000 \text{ g/cm}^3$) are weighed (in grams), from which the density of a mixture may be theoretically determined. The liquids are mixed, and the mixture's weight and volume measured. Using experimental measurements, the density of the mixture is calculated and found to be greater than theoretically predicted.

Items Needed

- Two 500 mL graduated cylinders
- One 1000 ml graduated cylinder

- 500 mL each of methyl alcohol 95-100 % or 190-200 proof) and distilled water (Note: Also works with ethyl alcohol, but methyl has bigger effect.)
- Eye dropper
- Electronic scale with tare

Procedure

1. Place one 500 mL cylinder on scale and tare.
2. Add 500 mL of methyl alcohol. (Use eye dropper to get accurate meniscus.)
3. Record mass in grams.
4. Repeat with other cylinder and 500 mL of water.
5. Place 1000 mL cylinder on scale and tare.
6. Carefully pour alcohol and water into larger cylinder.
7. Record mass and *note* and record the volume of the mixture.
8. Compute the density of mixture from experimental values and compare with theoretical value. (Recall that 1 mL and 1 cm³ are equal volumes.) The experimental density should be greater because the combined volume of the liquids is less than 1000 mL! What is going on? (Note: 500 mL of the liquids gives about a 3% reduction in volume. Smaller volumes may be used, but the effect is more difficult to see.)

(Note: to speed things up, the densities of methyl alcohol and water may be used to calculate the masses in the 500 mL volumes.)

Explanation

The result should make the student aware that something hidden is going on here. Conservation of mass applies, but why the decrease in volume? This arises because both liquids are polar, with polar molecules having slightly electric positive and negative ends. As such, they form particular intermolecular lattices on the basis of charge and hydrogen bonding. The lattices create spaces between the molecules.

When polar liquids are mixed, it is possible that the lattices pack together more closely, taking up less space. The mixture of two liquids can therefore take up less volume than the two liquids

separately. (Lattice formation comes into play in the freezing of water. Because of the lattice structure of ice, it is less dense than liquid water and floats.)

(Mixture results for alcohols: methyl, 960 – 965 mL. ethyl, 980 – 985 mL)

EXPERIMENT 4. SIMPLE PENDULUM PARAMETERS

Problem in Math Analysis (Can $2 = 1$?)

In this experiment, there is some mathematical analysis. Emphasize to the students that an equation is a balanced statement, numerically equal on each side of the equal sign. And as long as the same operation is done to each side of the equation (addition, multiplication, etc.), it is still balanced.

Procedure

Let:

$$x = y$$

Multiply by x :

$$x^2 = xy$$

Multiply by y^2 :

$$x^2 - y^2 = xy - y^2$$

Factor:

$$(x + y)(x - y) = y(x - y)$$

Divide both sides by $(x - y)$:

$$(x + y) = y$$

But, $x = y$, so

$$(y + y) = y$$

and

$$2y = y$$

Then, cancelling the y 's:

$$2 = 1!$$

Explanation

Dividing by $(x - y)$ is dividing by zero, which is undefined.

EXPERIMENT 5. UNIFORMLY ACCELERATED MOTION

Apparent Weightlessness (Where's the water?)

Water flows freely out of two holes in a plastic cup filled with water. Yet, when the cup is dropped, the water ceases to flow.

Items needed

Styrofoam or paper cups. (Poke holes near the bottom of the cup on opposite sides with a pencil or other pointed object. It is helpful to prepare several cups, so the demo may be repeated.)

Procedure

1. Fill the cup with water until continuous, thin streams of water come from the holes.
Using your fingers to cover the holes, carefully stand on a chair or lab table.
2. Hold the cup out and allow streams of water to flow from the holes. Then, quickly drop the cup and note what happens to the streams while the cup is falling. (This is best done over a sink or waste basket for obvious reasons.)
3. During the fall, the streams cease to flow. Ask the students why.

Explanation

As the cup falls due to gravity, the water inside the cup accelerates at the same rate and does not come out the holes.

Different Distances of Fall (Listen to the sound)

The purpose of this demonstration is to illustrate how uniformly accelerated motion gives rise to different distances of fall. This is done by observing the time differences of sounds from spaced weights that are dropped and hit a pan.

Items Needed

- Cotton string

- Magic marker
- Weights (15 - 20)*
- Pan (metal pie pan or cookie tray)
- Scissors or knife (to cut string)
- A couple small strips of (duct) tape

*Weights may be small metal nuts, or better yet, split-shot fishing sinkers. The latter may be applied more accurately and easily held at a marked location.

Preparation

Cut two 3-meter lengths of string. Make a “zero” mark about 3-cm from one end of each.

- String A: from the zero mark, make marks at 10 cm, 40 cm, 90 cm, 1.6 m, and 2.5 m from the mark and attach weights at these marks.
- String B: from the zero mark, make marks at 20 cm, 40 cm, 60 cm, 80 cm, 1.0 m, 1.2 m, 1.4 m, and 1.6 m and attach weights to these marks.

Procedure

1. Attach the zero mark of String A to the pan with tape and place on the floor. Stretch out the string and have someone hold the other end while (carefully) standing on a stool or lab table. When still and vertical, drop the string and observe the differences in the sound made with the weights hitting the pan. (You may do this again to better observe the times between sounds. It is helpful to have students write down what they observe.)
2. Repeat procedure 1 using String B.
3. Have the students explain the differences in the sounds in terms of the motions of the weights.

(Note: You may initially show the weight distances to the students and ask them to predict what will occur.)

Explanation

If you label the weights from the bottom as y_1, y_2 , etc., String A’s weights are positioned so that there are equal time intervals between the weights hitting the pan. This may be seen from $y_i = \frac{1}{2}gt^2$, with $t_1, t_2 = 2t_1, t_3 = 3t_1$, etc. That is, $y_1 = \frac{1}{2}gt_1^2 = 10$ cm, $y_2 = \frac{1}{2}g(2t_1)^2 = 4y_1 = 4(10$ cm),

$y_3 = \frac{1}{2}g(3t_1)^2 = 9y_1 = 9(10 \text{ cm}) = 90 \text{ cm}$, etc. This spacing gives about a 0.143 s interval between hits for uniformly accelerated motion.

The weights of string B are evenly spaced and do not give equal time intervals as can be shown using $t_i = \sqrt{\frac{2y_i}{g}}$. The times get progressively smaller.

EXPERIMENT 6. THE ADDITION AND RESOLUTION OF VECTORS: THE FORCE TABLE

Problem in Kinematics (Can 1 = 2?)

This is similar to the Problem in Math Analysis demonstration in Experiment 4 but involves kinematics. In applying kinematic equations, it is important that we know certain restrictions, as the following shows.

A student trying to solve a problem with constant acceleration wants to find the velocity, v . The student is given that $v_0 = 0$ but is not given the acceleration a . Looking at the list of kinematic equations, he decides to use $v = at$ and $x = \frac{1}{2}at^2$ (with $x_0 = 0$ and $v_0 = 0$) so that the unknown a can be eliminated. Then equating the a 's in each equation,

$$\frac{v}{t} = \frac{2x}{t^2}$$

But x is not known, so he decides to use $x = vt$ to eliminate it, and

$$\frac{v}{t} = \frac{2vt}{t^2}$$

Simplifying,

$$v = 2v \quad \text{or} \quad 1 = 2!$$

What's wrong?

Explanation

The equation $v = at$ applies only to *nonaccelerated* motion and hence does not apply to the problem.

EXPERIMENT 7. NEWTON'S SECOND LAW: THE ATWOOD MACHINE

Which Way Does The Bubble Go? (Mass and inertia)

The action (or inaction) of inertia may be demonstrated using a small level. When the level is given a push, which way will the horizontal bubble go?

Item needed

Small level with horizontal tube

Procedure

1. With the level resting on a table, prepare to give it a push. Ask the students which way the bubble will go when the push (a force) is applied, and the level is accelerated.
2. Give the level a gentle push. The bubble goes toward the front of the level or in the direction of the motion. Many students will guess otherwise. Ask for an explanation.

Explanation

Students guess that the bubble will move toward the back of the level because we are used to observing the bubble instead of the liquid. The bubble is chiefly air, which little mass or inertia, and readily moves. Newton's first law explains the correct answer that the bubble moves towards the front of the level. Because of inertia, the liquid resists motion and "piles up" toward the rear of the level, forcing the bubble forward. Think about giving a stationary pan of water on a table or push. What happens to the water?

EXPERIMENT 8. CONSERVATION OF LINEAR MOMENTUM

Newton's Cradle (In-and-out)

A novelty item known as Newton's cradle consists of five suspended identical metal balls. When one ball swings in, after multiple collisions, one ball swings out at the other end of the row of balls. When two balls swing in, two swing out; when three swing in, three swing out, and so on—always the same number out as in (even when five swing in).

Note that the initial potential energy (mgh) is conserved – the final height(s) of the outgoing balls is essentially the same as the initial release height(s). This means that kinetic energy is conserved during the collision process. The collisions are therefore elastic – conservation of momentum and

kinetic energy. This fact is used in the experiment demonstration, which asks students if two balls swing in with a velocity v , why doesn't one ball swing out with a velocity of $2v$?

Item needed

Newton's cradle

Explanation

The collisions along the horizontal row of balls are approximately elastic. If two balls swing in and one ball swings out with twice the velocity that wouldn't violate the conservation of momentum: $(2m)v = m(2v)$. However, another condition applies for elastic collisions—the conservation of kinetic energy. Let's check to see if this condition is upheld for this case.

If K_i is before and K_f is after,

$$\begin{aligned}K_i &= K_f \\ \frac{1}{2}(2m)v^2 &\stackrel{?}{=} \frac{1}{2}m(2v)^2 \\ mv^2 &\neq 2mv^2\end{aligned}$$

Hence, the kinetic energy would *not* be conserved if this happened, and the equation tells us that this situation violates established physical principles and does not occur. Note that there's a big violation—more energy out than in.

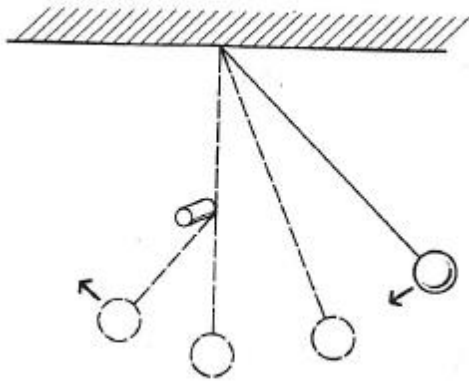
EXPERIMENT 9. PROJECTILE MOTION: THE BALLISTIC PENDULUM

Pendulum and Peg (Conservation of energy)

A pendulum and peg is used to demonstrate the conservation of mechanical energy.

Items needed

Pendulum and peg setup as shown below. (A pendulum suspended from the top of a doorway and a broom handle across the doorway works nicely.)



Procedure

Point out to the students how the pendulum bob rises to the same height on both sides of the swing when allowed to swing freely. Ask the students what will happen if the string of the swinging pendulum hits a peg, interrupting the swing. Interrupt the swing of the pendulum with the peg and demonstrate that the pendulum bob still rises to the same height.

Explanation

The kinetic energy gained on the downward swing is converted to potential energy as the bob rises after hitting the peg. With mechanical energy conserved, the bob rises to the same final height (with negligible energy lost in the string-peg collision).

EXPERIMENT 10. CENTRIPETAL FORCE

Bucket Swing (What keeps the water in the pail?)

This demonstration illustrates the concept of centripetal force and acceleration. A bucket of water is swung in a vertical circle with the water staying in the bucket at the top of the swing.

Items needed

- Small bucket or pail with handle
- Water

Procedure

1. Fill bucket to about $\frac{3}{4}$ full (to prevent splashing) with water.

2. Make sure you have plenty of free space, and swing the bucket back and forth increasing arcs to gain momentum. Finally, swing the bucket in one or more complete vertical circles, noting the water does not fall out at the top of the swing.

Explanation

Due to gravity, the water would certainly fall out of the upside-down bucket if it were stopped at the top of the swing. Even when the moving bucket is at the top of the swing, the water still falls with an acceleration g . It “stays” in the bucket as long as the inward force on the bucket supplies a centripetal acceleration of at least g . Swinging too slowly to achieve this acceleration may be a wet experience.

Sideline: The centripetal force of our orbiting Moon is supplied by gravity, and the Moon is accelerating or “falling” toward the Earth. Without this centripetal force, the Moon would fly off tangentially from its orbit.

EXPERIMENT 12. WORK AND ENERGY

Two Ball Bounce (Energy transfer)

Energy loss and energy transfer is demonstrated by dropping balls.

Items needed

- Basketball and tennis ball or racquetball
- Meter stick

Procedure

1. Individually drop each ball from shoulder height and observe the height each time the balls bounce back, which will be to an increasingly shorter height. Energy is lost. Where did it go? The fraction of initial potential energy (PE) lost may be approximated by the ratio of the final height (h_f) to the initial height (h_i); that is, final PE/initial PE = $mgh_f/mgh_i = h_f/h_i$.
2. Place the smaller ball on top of the basketball and drop them simultaneously from shoulder height. (A small plastic or rubber ring may be placed on top of the basketball to balance the smaller ball.) After hitting the floor, the basketball rebounds to a lesser height than when dropped alone, and the smaller ball bounces much higher. Why the difference in heights? (The initial and final potential energies of the balls may again be approximated from the heights.)

Explanation

When dropped individually, potential energy is converted into kinetic energy, and upon hitting the floor ($h = 0$), some of the kinetic energy is transferred to the floor and converted to sound and heat.

When the two balls are dropped together and the basketball collides with the floor, some energy is transferred to the floor as before. As the basketball rebounds with the remainder of its energy, it transfers some energy to the smaller ball. Having less rebound energy than when dropped alone, the basketball rebounds to a lesser height. The energy transferred to the smaller ball causes it to rebound to a much greater height. This is because the smaller ball weighs much less than the basketball and bounces much higher with the additional energy.

