Physics Demonstrations
The Society of Physics Students

Joshua Kaggie
Alexis Olsen
Joseph Ulmer

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Over the course of the last few semesters students from the Society of Physics Society (SPS) have given tours to Scout groups. This has been written so that demonstrators to learn more about the demonstrations. This manual begins by introducing what a tour is, how a tour is set up, and where to meet a visiting group. The remainder of the manual covers explanations of the demonstrations. The demonstrations are grouped into the following categories: liquid nitrogen, electromagnetism, waves and light, and energy. The explanations should be simple enough for scouts to understand.
1 Introduction

For several semesters, the Society of Physics Students (SPS) has been giving tours of the physics department. These tours are led by students in the physics department who are interested in educating the community about physics, and exciting them about science. During a tour, a student shows visitors around the department and then shows them physics demonstrations. Besides grabbing the visitors’ attentions, these demonstrations are designed to explain basic physical principles and possibly recruit future physicists.

This has been written for you, the student demonstrator. We hope that it will make it easy for you to learn and enjoy the demonstrations.

This manual covers how to do the demonstrations and how to explain them. The explanations given here are intended to be simple enough for middle school children to understand. Therefore, the explanations are fairly simple and avoid math and some of the complex ideas inherent in electricity, magnetism, and optics. When one of these complex ideas is necessary for an explanation, it is simplified without being misleading.

We hope that this manual will help you to give effective yet fun demonstrations. Have fun with the children and they will have fun with you. They will also be more responsive to what you say and show them.

2 Preparation

The tours are set up through the physics department office. When a tour is set up the President of SPS should let you know when the tour group is coming. You should have plenty of time to prepare.

Before the visitors arrive be sure to do the following:

- Familiarize yourself with the demonstrations and their explanations.
- Practice each demonstration so that it can be presented effectively.
- Make sure that the Dewar (a large, gray, insulating jug) has enough liquid nitrogen in it. The Dewar will be filled as part of the tour.
- Set up the demonstrations in classroom 325. There is a plastic container filled with many demonstrations. You may have to sort through the container before visitors arrive. The instructions for setting up the demos are in the following pages.
- Also, check to make sure the demonstrations work.

3 The Tour

Usually you can meet the visitors in front of the physics main office. Sometimes they might come early and be waiting in the tour room. Once in a while the group may come a half hour late or not arrive at all, in which case, let the SPS President know.

You may show the visitors around the department. If there are no classes the children enjoy seeing the auditorium classrooms. If there are some researchers available they might even explain and show their research to your group. The department is aware that demonstrations occur.
3.1 Questions that Scouts must answer for a patch

In order for the scouts to receive the physics patch, they must answer a few questions about physics and different principles involved. Some Scouts will have this list of questions to answer and others will have simpler questions. Therefore, it is handy to have a list of answers available.

What is Astrophysics?
Astrophysics is the branch of astronomy that deals with the physics of the universe, including the physical properties (density, temperature and chemical composition) of astronomical objects such as stars and galaxies.

What is Cosmology?
Cosmology is the study of the Universe and humanity’s place in it. In recent times, physics has come to play a central role in shaping the understanding of the Universe through scientific observation, experiments, and theorizing.

What is condensed matter physics?
Condensed matter physics is the study of the macroscopic physical properties of matter. In particular, when the number of particles is large and interactions between particles are strong.

What is nuclear physics?
Nuclear physics is the study of the nucleus of the atom. It has three main aspects: studying protons and neutrons and their interactions, classifying the properties of nuclei, and advancing technology.

What is atomic physics?
Atomic physics is the study of atoms as a system comprised of electrons and the nucleus. It is primarily concerned with the arrangement of electrons around the nucleus and the processes by which these arrangements change.

What is the difference between theoretical and experimental physics?
The difference between theoretical and experimental physics is that theoretical physics involves understanding nature by using mathematical models and experimental physics deals with observing natural phenomena through experimentation.

How cold is Liquid Nitrogen?
Nitrogen is a liquid between 63 K and 77.2 K (-326°F and -320°F). Colder than that it will be a solid, and warmer than that it will become a gas. Most of the liquid nitrogen that you see will be boiling therefore it is near 77.2 K.
What is a laser?

A LASER (Light Amplification by Stimulated Emission of Radiation) is an optical source that emits photons in a coherent beam. A coherent beam means that the wavelength and frequency of the light emitted is the same for all the photons.

What is a nanometer?

A nanometer is really small. It is one-billionth of a meter.

4 Demonstrations

You do not have to show all demonstrations. Some groups will be quiet, noisy, inquisitive, or bored. Some groups will be large and others will be small. You may want to vary the demonstrations depending on the group and their interest.

4.1 Liquid Nitrogen

Nitrogen makes up 78% of the Earth’s atmosphere. Pure nitrogen is an unreactive colorless diatomic gas at room temperature. Liquid nitrogen exists between 63K and 77K. Because it is so cold, liquid nitrogen is used as a coolant for many things. It is also used to preserve biological samples and to freeze off warts.

Do not touch metals that have been frozen with liquid nitrogen. Do not touch glass or most solids that are currently submerged in liquid nitrogen. Do not spill large amounts on your shoes or clothes. Do not leave your skin in contact with liquid nitrogen for over 5 seconds.

If there is too much liquid nitrogen in the air, it can displace oxygen and cause asphyxiation. Make sure a door or window is open if over 3 liters of nitrogen are used within 15 minutes.

4.1.1 Shrinking balloons

In this demonstration you hold a balloon in liquid nitrogen until it shrinks. While it is in the liquid nitrogen it shrinks down to almost its empty size as if there were no air in it at all.

The reasoning for this is that air molecules slow down and stop hitting the sides of the balloon as frequently, creating a lower pressure. Because of this, as the air in the balloon gets colder, it shrinks in size until it looks as though there is nothing left in the balloon.

4.1.2 Smashing roses

To do this demonstration, you hold a rose or other flower in a cup of liquid nitrogen for a minute or so until it is frozen solid. Then you hit the flower against the edge of a desk or other hard material and the flower shatters into many pieces.

This effect is due to the freezing of water. As the flower sits in the liquid nitrogen, the water in it freezes solid making the flower very brittle. When the flower is smashed on the desk, it is the same thing as taking a flower-shaped ice cube and hitting it against the desk—it shatters.
4.1.3 Smashing racquetballs

This demonstration is essentially the same thing as the flower demonstration. You put a racquetball in the liquid nitrogen long enough that it loses its elasticity and freezes solid. It will feel as if it is made of stiff plastic at this point. Then you throw the ball against the wall and it breaks into many pieces.

The reason a racquetball bounces and stretches is because the rubber molecules it is made of can move and bend. When the ball gets cold, the molecules can’t move and so the ball becomes very brittle. So when the ball hits the wall, instead of bouncing, it breaks.

4.1.4 Pouring liquid nitrogen on your hand

To show the scouts the difference in temperature between liquid nitrogen and a person, you can dip your hand into a cup of liquid nitrogen. You can also pour it on your hand. As long as you do it quickly it will not hurt you and will boil the nitrogen instead.

This demonstration can be explained to the scouts with an analogy. Remind them how cold liquid nitrogen is and then how warm a person is and then tell them that when the nitrogen touches you, it feels as you would feel if you stuck your hand on the stove. A person is so much hotter than liquid nitrogen that the liquid nitrogen immediately boils away and doesn’t freeze your hand. However, if you left your hand in the cup for a while it would cool your hand down (similar to the racquetball) and then would cause damage.

4.1.5 Levitating a magnetic cube

For this demonstration you need to gather a few things from the box of demonstrations. You need the bottom of a Styrofoam cup, the superconducting disk (which is flat and black), and the small cube magnet. To do this demonstration you place the superconducting disk in the bottom of the
Styrofoam cup and then fill the cup with the liquid nitrogen. When the disk is covered in nitrogen for about thirty seconds, a brass colored magnetic cube can be placed on top of it and will levitate. Once the magnet is floating, try to make it spin so that the scouts can see that it is really floating above the super conducting disk.

Avoid terms such as “cross product” when explaining electricity and magnetism. A simple explanation is that magnets push on electrons, but the electrons don’t like being pushed so they push back. In this demonstration, the magnet above the disk pushes on the electrons in the disk, and so the electrons in the disk push back on the magnet. We tell the scouts that normally the electrons wouldn’t be able to push the magnet hard enough to make it float, but because of the super conducting disk they can. This is because the cold of the liquid nitrogen allows the electrons in the disk to push a lot harder than they normally could and so they make the magnet float.

4.2 Electricity and Magnetism

Electromagnetism is the study of electricity and magnetism. When explaining these experiments use simple terms and don’t use the term “cross product” or any mathematical equations. Make sure that the group understand the basics such as like charges repel and unlike charges attract.

Some groups will have already learned about electrons and protons, while others have not. You might want to explain atoms and electrons very briefly.

4.2.1 Dropping a magnet down a copper tube

Place a copper tube up right and then drop a magnet into the copper tube. The magnet should move slower in the copper pipe then it would normally take to fall.

This effect is due to the magnetic field created when the magnet is in the copper pipe. The magnetic field will cause the electrons to push against the magnet and create a drag force. A moving magnet creates Eddy currents which oppose the moving magnet.

4.2.2 Rolling a nonmagnetic and a magnetic ball down an aluminum ramp

Place a nonmagnetic and a magnetic ball on an aluminum ramp and let them roll down at the same time. The non magnetic ball should reach the bottom of the ramp before the magnetic ball.

This happens because a magnetic field is created between the aluminum ramp and the magnetic ball causing the ball to roll slower.

4.2.3 Using Ferro-fluid to show magnetic field lines

The Ferro-fluid is a brownish liquid inside of a clear container with a white cap. Remove the top of the container to see the ferro-fluid. Be careful not to spill the fluid as it will stain. Do not place a magnet over the fluid because the fluid will stick to the magnet.

A Ferro-fluid is a specific type of liquid which responds to a magnetic field. Ferro-fluids are composed of tiny magnetic particles suspended in a fluid. By moving a magnet over the ferro-fluid the magnetic field will appear.

The magnetic particles in the Ferro-fluid are so small that they will form along the magnetic field lines and create the effect.
4.2.4 Moving a magnet across a copper plate

The magnet will be hard to move across the plate and the children will be able to feel the magnet dragging behind.

This happens because the magnet and the copper plate have different charges and are attracted to each other. The negative and positive charges want to stay together so they are hard to move apart.

4.2.5 Shocking each other with the Van de Graff generator

The Van de Graff generator looks like a large silver ball with a clear plastic tube holding it up. Before turning it on, make sure that neither you nor the generator are near any outlets. Do not touch (nor stand on or near) any outlets, plugs, or even insulated cords while touching the generator. Do not put any metals near the generator. Keep the generator away from any electronics. Generally, credit cards in your pocket will be far enough away and not in any danger.

Turn on the Van de Graff generator and touch the silver ball. If you turn off the light then you can see sparks when you put your hand near the generator. You can ask for volunteers to touch it or make a chain. They may notice that they will only get shocked when someone new is added to the chain.

If the generator isn’t creating enough charge than the aluminum plates can be added to the top to create more. However, do not try this before testing the generators charge first. If the chain is long enough and the charge is low enough, you could have someone touch the door handle.

The Van de Graff generator creates an electric charge in the air. If a metal is put too close to the generator, then extreme capacitance can occur causing unsafe conditions. The charge in the air will discharge (or create current) through the easiest path. It is easier for current to go across the skin of a person than through the air. It is also easier for current to go to a second person instead of discharging in the air or through the soles of shoes.

4.2.6 Flying fur and pie tins with the Van de Graff generator

Place fur or pin tins upside down on the Van de Graff generator. The fur or pin tins should then begin to fly off the generator as the electric charge builds up on the sphere. You can also move your hand close to the fur and watch it move away from your hand.

This works because like charges repel and the sphere and the fur or pie tins will develop the same charge. The top pie pan will hold the other ones down until it builds enough charge to repel from the generator. The rest will then fly off one at a time.

4.3 Energy

There are many types of energy, such as heat, electromagnetic energy and kinetic energy. Sometimes one type of energy can be converted into other types of energy. Kinetic energy can move a magnet creating electromagnetic energy.

Kinetic energy is the energy of motion. Any moving object has kinetic energy relative to the speed and the mass of the object. There is vibrational, rotational, and translational kinetic energy.
4.3.1 The big sphere floats, the little one doesn’t

There is an extra large sphere in the demonstration kit. Grab the large sphere and a small sphere. Fill a container with water.

Ask the children which ball they think will sink or float. Will either of them float? Place the little one in the water and watch it sink. Place the large one in the water and watch it float.

The large ball has a lower density than water so it doesn’t sink, while the small ball has a higher density than water.

4.3.2 Two balls colliding can create heat and burn paper

Hit the two steel balls together with a piece of paper in between. It helps to have someone else hold the piece of paper. (Just watch out for any fingers!) After you smack them together a few times you will smell a burning smell and see brown and black spots and holes in the paper. This shows that the kinetic energy was converted to heat.

The law of conservation of energy is shown here. Inelastic collisions often lose most of their energy in heat.

The steel balls lose some of their energy in heat which is transferred through the paper. The heat of the paper causes it to burn, although it never catches fire. After you collide the balls together, you can see the black and brown spots and smell the burnt paper.

4.3.3 A Stirling engine powered by the heat of your hand

If you place the Stirling engine on a warm computer, warm water, or your hand, then you can see the rotors rotate.

Here’s an explanation taken from the web:

Every Stirling engine has a sealed cylinder with one part hot and the other cold. The working gas inside the engine (which is often air, helium, or hydrogen) is moved by a mechanism from the hot side to the cold side. When the gas is on the hot side it expands and pushes up on a piston. When it moves back to the cold side it contracts.

Similar processes make the radiometer turn. In fact, every engine runs on similar processes. This is an example of heat being converted into kinetic energy.

4.3.4 A gyroscope is difficult to rotate

Have someone hold the gyroscope (which looks like a bicycle wheel) and spin it. Make sure they hold it tight and not to get anything caught in it. Have that person try and rotate the gyroscope left or right and ask them how difficult it is. It will be more difficult to rotate if it is spinning faster.

Gyroscopes are used in bicycles, ships, airplanes, space shuttles, and even satellites. This effect is also seen in yo-yos and Frisbees.

An effect called precession counters your force at right angles. When the force is applied to the axle, the section at the top of the gyroscope will try to move to the left, and the section at the bottom of the gyroscope will try to move to the right, as shown. If the gyroscope is not spinning, then the wheel flops over, as shown in the video on the previous page. If the gyroscope is spinning,

\[\text{http://www.stirlingengine.com/faq/one?scope=public&faq_id=1#1}\]
think about what happens to these two sections of the gyroscope: Newton’s first law of motion states that a body in motion continues to move at a constant speed along a straight line unless acted upon by an unbalanced force. So the top point on the gyroscope is acted on by the force applied to the axle and begins to move toward the left. It continues trying to move leftward because of Newton’s first law of motion, but the gyro’s spinning rotates it.  

4.3.5 Energy is conserved when two airpucks collide

The airpucks are green saucers that must be turned on to work. There is a black switch underneath each airpuck. The airpucks will have to be charged in order to work. It’s best to place them on the floor.

Two colliding airpucks show conservation of energy. The energy from one is given to the other or split between the two. Some of the energy is lost in heat and friction, but it is close to frictionless due to the air lift.

4.3.6 Friction causes a top to invert

There are some small wooden tops about 3 inches long in the supply crate. They are semicircular spheres with a prong pointing out of the middle end.

Spin the wooden tops. If you get it right, the tops will invert so that the heavy end is on top of the small end. This almost defies logic!

The top wants to remove as much surface friction as possible so it inverts. If you could spin it perfectly up and down or if you spin it on a frictionless surface, then it will not invert. There is less friction on the sides than on the bottom so it moves towards its side. There is less friction on the small, light end than on the sides, so the top inverts.

4.4 Waves, Sound, and Light

Light is made up of photons, which are both particles and packets of energy. Light acts like a wave and like a particle. You can shine one photon through a slit and detect that single photon. If you shine multiple photons through a slit, you will see a diffraction pattern that is a result of the wavelike nature of light.

4.4.1 Different types of waves

Take the large spring and have someone grab the other end. Separate the two ends of the spring to different sides of the room. It will not contract fast enough to cause harm, but still make sure that it is held tight. You can show two different types of waves, longitudinal (compressed waves) and transverse.

Transverse is easy to show. Just move the spring up and down or left and right.

In order to show longitudinal have your helper and yourself grab part of the spring in front of you (while still holding tightly to the end of the spring,) and compress the spring between both of your hands. Release the part that you just grabbed and you’ll see longitudinal waves, ie. the compression of the spring at various points throughout the spring.

[^1: http://www.howstuffworks.com/gyroscope.htm, April 17, 2006.]
4.4.2 Singing rod

Grab the 60cm long metal rod (silver colored). Make sure the door is shut. (There might be rosin to lightly coat your fingertips.) Slide your fingers repeatedly along it. You can control the volume and the pitch by how tightly you grip, where you hold it, and how quickly you move your hands on it.

The explanation for this is that sound is generated by vibrating molecules. A vibrating object causes the surrounding air to vibrate. Our ears detect the vibrating air so we can hear the sound.

4.4.3 Singing bowl

Half fill the bronze bowl with water. Wet the palms of your hand and rub the two handles of the bronze bowl. Don’t use circular motion but rub it backwards and forwards. Make sure the door is shut and that you have paper towels available. The water will ripple only slightly at first but then water will begin to shoot up in continuous streams.

Your hands cause the handles to vibrate which in turn causes the bowl to vibrate at about 300 Hz creating standing waves in the water. The reason why the water spouts is similar to why diffraction patterns happen. Waves will reinforce each other at various points causing droplets to jump up. It is also the same principle that causes crystal glasses to make sound.

4.4.4 Light is absorbed into black paint causing a windmill (in a vacuum) to rotate

The windmill encased in a glass bulb is called a radiometer. It was created by William Crookes in 1875 when he was experimenting with vacuums.

The radiometer can be used either using a visible light source or a near-infrared source (such as the heat from your hands). When light hits the radiometer, it is absorbed by the dark parts of the radiometer and reflected by the bright parts of the radiometer. The dark parts heat up and then cool down when the radiometer turns away from the light source.

Remember that heat is the movement of molecules. The heat moving from one side of the vane to the other side of the vane causes some movement.

Two incorrect theories include that it’s due to the pressure of light and that the dark side releases a gas when light is present.

The radiometer will only work in a partial vacuum and not in a full vacuum. The radiometer turns different directions when it is heating up versus when it is cooling down.

4.4.5 Light can be polarized

The polarizing filter either looks like a black plastic sheet or a small square sheet framed in cardboard. There are other filters in the demonstration container. When looking through a polarizing filter light looks dimmer but no other light effects occur.

Use a filter and shine light through it, the light becomes polarized. Shine laser light through, then depending on how it’s rotated, you can make the light darker or brighter.

The easiest explanation is that light works like waves. Imagine a wave that moves up and down and a wave that moves left and right. Most light that we experience is moving in all sorts of directions. When you sort out the light that is moving just up and down (just one direction in general) then you create what’s called polarized light.

A polarizing filter is similar to a slit that just lets light up and down through (or any direction). The chemical properties of the filter let light through that’s a certain direction.
4.4.6  **Polarized light is rotated in Karo syrup showing different intensities**

Shine the laser light through the tube filled with Karo syrup. You will notice that there are different intensities of light throughout the Karo syrup. It is easier to see with the light off.

The Karo syrup acts like a polarizing filter. It also rotates the polarization of the light (the direction of the wave) as the light moves through it, showing different intensities at different spots.

4.4.7  **Different colors can be seen from polarized white light in Karo syrup**

Shine a white light source such as a flashlight through the polarizing filter and then through the Karo syrup. You should see different colors throughout the Karo syrup. It may help if you turn off any other lights.

White light is made up of all the different colors of the rainbow. Each color has a different wavelength (different size of wave). Each wavelength gets rotated slightly more or less frequently than other wavelengths. When one color becomes dim, then you can see other colors in that spot.

4.4.8  **A diffraction pattern occurs when light goes through something small**

Shine the laser light on some hair or through a diffraction grating. If you are far enough from the wall or screen that it’s shown on, you will see a diffraction pattern - a pattern wider than the initial laser light with bright and dark spots.

Light works like a wave. Picture a two water waves hitting each other. When crests from both the waves hit each other, there will be extra large crests. When troughs from both waves hit each other, there will be deeper troughs. When a crest and a trough hits the same spot, they will cancel each other out.

4.4.9  **A mirage that you can’t touch**

There are two black coated hemispheres. Place something small like a penny or figurine inside at the very center. The object will now look like it’s someplace that it’s not and still look very real. You can shine a light on it and look at it from different angles and it will still look real unless you put an object that was too big.

Light rays can be bent. The most common bending of light rays is glasses or a magnifying glass. The light rays coming from the object are bent so that the look like they are originating from the top of the device instead of the center.

5  **Conclusion**

We would like to thank you for reading and using this manual. We hope that it makes it easier for you to learn to do scout tours. We also encourage you to have fun with the scouts. Treat the tours as an opportunity to teach the visitors and get them interested in science and you will enjoy the tours. The visitors will also be much more responsive if you are enjoying yourself. We would like to further thank you for taking some of your time to show the scouts around the department and for getting them interested in science at a young age.