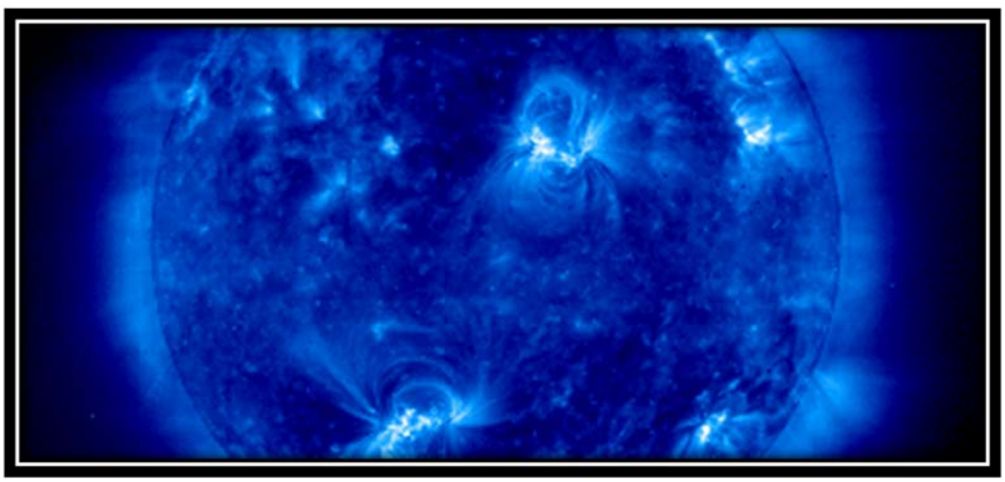
# LIGHT 2

Students learn about intensity, polarization, frequency, refraction, diffraction, and reflection as they build an electric eye, optical cameras, reflector telescopes, compound microscopes, spectrometers, burglar alarms, optical light benches, battery-free radios, laser microscopes, laser shows, and so much more.



Created by Aurora Lipper, Supercharged Science

**www.SuperchargedScience.com**

This curriculum is aligned with the National Standards and STEM for Science.

# TABLE OF CONTENTS

# Introduction

Greetings and welcome to the study of light. This unit was created by a mechanical engineer, university instructor, airplane pilot, astronomer, robot-builder and real rocket scientist… me! I have the happy opportunity to teach you everything I know about electricity over the next set of lessons. I promise to give you my best stuff so you can take it and run with it… or fly!

To get the most out of these labs, there are really only a couple of things to keep in mind. Since we are all here to have fun and learn something new, this shouldn't be too hard.

One of the best things you can do as the student is to cultivate your curiosity about things. *Why did that move? How did that spin? What's really going on here?*

This unit on light is chock full of demonstrations and experiments for two big reasons. First, they're fun. But more importantly, the reason we do experiments in science is to hone your observational skills. Science experiments really speak for themselves much better than I can ever put into words or show you on a video. And I'm going to hit you with a lot of these science demonstrations and experiments to help you develop your observing techniques.

Scientists not only learn to observe what's going on in the experiment, but they also learn how to observe what their experiment is telling them, which is found by looking at your data. It's not enough to invent some new kind of experiment if you don't know how it will perform when the conditions change a bit, like on Mars. We're going to learn how to predict what we think will happen, design experiments that will test this idea, and look over the results we got to figure out where to go from there. Science is a process, it's a way of thinking, and we're going to get plenty of practice at it.

Good luck with this unit on the magic of light!

# For the Parent/Teacher:
# **Educational Goals for Light 2**

Scientist are still trying to make heads or tails of this thing called light, and near as they can tell, it sometimes interacts like a particle (like a marble) and other times like a wave (like on the ocean), and you really can't separate the two because they actually complement each other.

Energy can take one of two forms: matter and light (called electromagnetic radiation). Light is energy in the form of either a particle or a wave that can travel through space and some kinds of matter, like glass. We're going to investigate the wild world of the photon that has baffled scientists for over a century. Low electromagnetic radiation (called radio waves) can have wavelengths longer than a football field, while high-energy gamma rays can destroy living tissue.

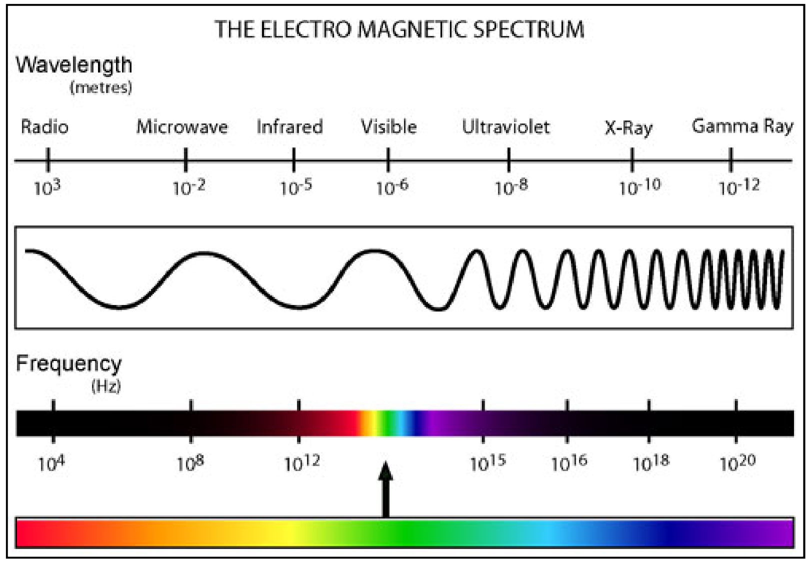
**Here are the scientific concepts:**

- Low-frequency electromagnetic waves are called radio waves, which are *not* the same as sound waves.
- Light you can see (visible light like a rainbow) makes up only a tiny bit of the entire electromagnetic spectrum.
- Light has wavelength (frequency, or color), intensity (brightness), polarization (direction), and phase (time shift).
- Visible light is a small band within a very broad electromagnetic spectrum.
- For an object to be seen, light emitted by or scattered from it must enter the eye.
- Light travels in straight lines except when the medium it travels through changes.
- How simple lenses are used in a magnifying glass, the eye, camera, telescope, and microscope.
- White light is a mixture of many wavelengths (colors), and that retinal cells react differently with different wavelengths.
- Light interacts with matter by transmission (including refraction), absorption, or scattering (including reflection).
- The angle of reflection of a light beam is equal to the angle of incidence.

**By the end of the labs in this unit, students will be able to:**

- Design and build both a refractor and reflector telescope using lenses.
- Know how to demonstrate how compound microscopes work.
- Understand how to determine how to measure the speed of light.
- Differentiate observation from inference (interpretation) and know scientists' explanations come partly from what they observe and partly from how they interpret their observations.
- Measure and estimate the weight, length and volume of objects.
- Formulate and justify predictions based on cause-and-effect relationships.
- Conduct multiple trials to test a prediction and draw conclusions about the relationships between predictions and results.
- Construct and interpret graphs from measurements.
- Follow a set of written instructions for a scientific investigation.

# What We're Going to Learn in Studying Light




Visible light that enters your eye is seen as a color of the rainbow. However, visible light only makes up a tiny bit of the entire electromagnetic spectrum. White light is a mixture of many wavelengths or colors, and your retinal cells react differently with different wavelengths.

Photons with the lowest amounts of energy and longest wavelengths (some are the size of football fields) are **radio waves**. The next step up is **microwaves,** which have more energy than radio waves. **IR** has slightly more energy, and **visible light** (the rainbow you can see with your eyes) has more energy and shorter wavelengths. Ultraviolet (UV) light has more energy than visible, and X-rays have even more energy than **UV**, and finally the deadly **gamma rays** have the most amount of energy.

Radio waves are low-energy, long wavelength forms of energy. Radio waves are *not* the same thing as sound waves. Think about this: You can't hear the stuff coming off a radio station antenna – you need a way to transform the light waves into sound waves (which is exactly what your radio does). The sounds from a scream are vibrating air molecules, while radio waves are actually light beams moving much, *much* faster.

Microwaves are the next step up in frequency above radio waves. Did you know that microwaves emit microwaves? Your microwave oven heats your dinner by aiming very specific light energy at your food. The microwaves excite the water molecule (which is present is nearly all foods), and this energy makes the water molecules jiggle around faster (called *heat*). The energy from the microwaves gets pumped into your food to heat it up.

Infrared light is a smaller wavelength than microwaves, but it also packs in more energy. When you press the button on your remote control to your TV, you're using infrared light (IR) to control your TV. Infrared light has a bit more energy than microwave light, but it's still invisible to our eyes. However, snakes can detect IR and see the redder hues that we can't. Every warm body gives off light in the IR, so snakes use this to find mice in the cool dark night.

Are you getting the picture that different detectors are sensitive to different colors? Your eyeballs are sensitive to specific colors in the 400-700 nm (nanometer) range, which is how long one wavelength is. A nanometer is extremely tiny! The frequency of red light is around 430 trillion Hz (Hertz, which is one wave cycle per second). If you were to count the number of waves passing a certain point in one second, you'd count 430 trillion waves. If you counted 750 trillion waves, the light would be violet. Different colors have different frequencies.

Light interacts with matter by passing through it, bouncing off it, or anything in between. Sometimes light even gets absorbed, either with or without being re-emitted at a different energy and wavelength.

# Master Materials List for All Labs

This is a brief list of the materials that you will need to do *all* of the activities, experiments and projects in each section. The set of materials listed below is just for one lab group. If you have a class of ten lab groups, you'll need to get ten sets of the materials listed below. For ten lab groups, an easy way to keep track of your materials is to give each group a number from one to ten, and make up ten separate lab kits using small plastic tubs or baskets. Put one number on each item and fill each tub with the materials listed below. Label the tubs with the section name, like *Light Study Kit* and you will have an easy way to keep track of the materials and build accountability into the program for the kids. Copy these lists and stick them in the bin for easy tracking. Feel free to reuse items between lessons and unit sections. Most materials are reusable year after year.

- 2 metersticks
- 3 clothespins
- 5 UV beads
- 9V Battery
- AA battery case with batteries
- bar of Ivory Soap
- brass fasteners
- bright light source
- buzzer (3-6V)
- camera (one for entire class)
- cardboard tube (at least 10 inches long)
- CdS Cell
- clear plastic bag
- hard clear plastic objects, like disposable utensils, clear plastic cups, CD cases, etc.
- hot glue gun
- index cards
- large paper clips
- laser (red key-chain laser)
- LED
- masking tape
- metal frying pan or cookie sheet
- microwave (one for entire class)
- old CD
- overhead projector film
- piece of fabric
- plastic baggie
- plastic sheet
- plate
- pliers
- pond water sample
- popsicle sticks
- razor
- remote control (one for entire class)
- rubber band
- scissors
- scrap of cardboard
- small mirrors (mosaic-type work well)
- sun block
- sunglasses
- tape (double-sided)
- tape (the 3/4″ glossy clear kind)
- three alligator clip leads
- three alligator wires
- trash bag (white or black, or both)
- two double-convex lenses two pairs of polarized sunglasses
- white wall
- wooden cutting board

# Lab Safety

**Goggles:** These should be worn when working with chemicals, heat, fire, or projectiles. These protect your eyes from chemical splatter, explosions, and tiny fast-moving objects aimed at the eyes. If you wear glasses, you can find goggles that fit over them. Don't substitute eyeglasses for goggles, because of the lack of side protection. Eyeglasses don't provide this important side eye protection.

**Clean up Messes:** Your lab area should be neat, organized, and spotless before you start, during your experiment, and when you leave. Scientists waste more time hunting for lost papers, pieces of an experiment, and trying to reposition sensitive equipment… all of which could have easily been avoided had they been taught organizational skills from the start.

**Dispose of Poisons:** If a poisonous substance was used, created, or produced during your experiment, you must follow the proper handling procedures for disposal. You'll find details for this in the experiments as needed.

**Special Notes on Batteries:** Do not use alkaline batteries with your experiments. Find the super-cheap kind of batteries (usually labeled "Heavy Duty" or "Super Heavy Duty") because these types of batteries have a carbon-zinc core, which does not contain the acid that alkaline batteries have. This means when you wire up circuits incorrectly (which you should expect to do because you are learning), the circuits will not overheat or leak. If you use alkaline batteries (like Energizer and Duracell) and your students short a circuit, their wires and components will get super-hot and leak acid, which is very dangerous.

**No Eating or Drinking in the Lab:** All foods and drinks are banned from your classroom during science experimentation. When you eat or drink, you run the very real risk of ingesting part of your experiment. For electricity and magnetism labs, always wash your hands after the lab is over to rinse off the lead from the electrical components.

**No Horse Play:** When you goof around, accidents happen, which means chemicals spill, circuits short, and all kinds of hazards can occur that you weren't expecting. Never throw anything to another person and be careful where you put your hands – it could be in the middle of a sensitive experiment, especially with magnetism and electricity. You don't want to run the risk of getting shocked or electrified when it's not part of your experiment.

**Fire:** If you think there's a fire in the room (even if you're not sure), let your teacher know right away. If they are not around (they always should be), smother the fire with a fire blanket or use a fire extinguisher and send someone to find an adult. Stop, drop, and roll!

**Questions:** If you're not sure about something stop and ask, no matter what it's about. If you don't know how to properly handle a chemical, do part of an experiment, ask! If you're not comfortable doing part of the experiment, then don't do it.

# Lesson #1: Microwaving Soap

**Overview:** When you warm up leftovers, have you ever wondered why the microwave heats the food and not the plate? (Well, some plates, anyway.) It has to do with the way microwaves work. Microwaves generate high-energy electromagnetic waves that, when aimed at water molecules, make these molecules get super-excited and start bouncing around a lot. Which is why it's dangerous to heat anything not containing water in your microwave, as there's nowhere for that energy to go, since the electromagnetic radiation is tuned to excite water molecules.

**What to Learn:** Light you can see (visible light like a rainbow) makes up only a tiny bit of the entire electromagnetic spectrum. Microwaves emit "microwaves" that are lower frequency, lower energy waves than visible light, but are higher energy, higher frequency than radio waves. The soap in this experiment will show you how a bar of Ivory soap contains air, and that air contains water vapor which will get heated by the microwave radiation and expand.

**Materials**

- 3 Ivory soap bars
- microwave (not a new or expensive one)
- plate

**Experiment**

1. Open the microwave.
2. Unwrap the bar of Ivory soap and place it on the plate (be sure it's glass or ceramic).
3. Set the time for 2-3 minutes.
4. Watch it very closely and remove it when it reaches its maximum volume (when it stops expanding).
5. NOTE: the soap may be hot after the experiment, so please be careful! Allow it to cool for a few minutes prior to touching it.
6. You can even use the soap after you're done.
7. After you have done your experiment once, design an experiment to test a question you have about Ivory soap. This experiment should be designed to answer a specific question, and you'll make a guess (called a hypothesis) as to how things will turn out. After making a guess, perform the experiment and write down what you observed happen. In the last column of your data table, you'll write what you conclude. The first one has been done as an example for you. The question that the sample is answering is: *How does soap bar volume affect how much it puffs up?* You can test all sorts of questions, from what happens if you put more than one bar of soap in, or what if you use lower power for longer, or what if you chill the bar in the freezer overnight first? The questions are endless. Have fun!

# Microwaving Soap Data Table

| Hypothesis | Experiment | Observation | Conclusion |
|---|---|---|---|
| *Half a bar of soap will only puff just as big as a whole bar.* | *Put half a bar of soap in microwave for 2.5 minutes and a whole bar in for 2.5 minutes and compare.* | *When compared, the half bar puffed up <u>more</u> than the whole bar!* | *There might be less mass to move out of the way, so the bar puffs up more easily. Needs more testing. Maybe test a quarter of a bar next?* |
| | | | |
| | | | |
| | | | |

**Reading**

Microwaves generate high-energy electromagnetic waves that, when aimed at water molecules, make these molecules get super-excited and start bouncing around a lot.

We see this happen when we heat water in a pot on the stove. When you add energy to the pot (by turning on the stove), the water molecules start vibrating and moving around faster and faster the more heat you add. Eventually, when the pot of water boils, the top layer of molecules are so excited they vibrate free and float up as steam.

When you add more energy to the water molecule, either by using your stove top or your nearest microwave, you cause those water molecules to vibrate faster. We detect these faster vibrations by measuring an increase in the temperature of the water molecules (or in the food containing water). Which is why it's dangerous to heat anything not containing water in your microwave, as there's nowhere for that energy to go, since the electromagnetic radiation is tuned to excite water molecules.

This following experiment is a quick example of this principle using a naked bar of Ivory soap. The trick is to use Ivory, which contains an unusually high amount of air. Since air contains water moisture, Ivory also has water hidden inside the bar of soap. The microwave will excite the water molecules and your kids will never look at the soap the same way again.

**Note:** Scientists refer to 'light' as the visible part of the electromagnetic spectrum, where radio and microwaves are lower energy and frequency than light (and the height of the wave can be the size of a football field). Gamma rays and X-rays are higher energy and frequency than light (these tend to pass through mirrors rather than bounce off them).

**Exercises**

1. What is it in your food (and the soap) that is actually heated by the microwave?

2. How does a microwave heat things?

# Lesson #2: Infrared Light

**Overview:** Infra-red light is in the part of the electromagnetic spectrum that isn't usually visible to human eyes, but using this nifty trick, you will easily be able to see the IR signal from your TV remote, remote-controller for an RC car, and more!

**What to Learn:** When you press the button on your remote control to your TV, you're using infrared light (IR) to control your TV. Infrared light is invisible to our eyes. However, snakes can detect IR and see the redder hues that we can't. Every warm body gives off light in the IR, so snakes use this to find mice in the cool night.

**Materials :**

*You will need these items:*

- remote control for TV or stereo
- camera (video or still camera)

*This is just a suggested list of objects. Feel free to find your own!*

- metal frying pan or cookie sheet
- plastic sheet
- plastic baggie
- trash bag (white or black, or both)
- wooden cutting board

**Experiment**

1. Grab a remote control and verify that it is indeed working.  Turn the device on and off using the remote.
2. Grab a sheet of plastic, like a cutting board, and place it between your remote and the device. Does it turn on when you aim the beam at it? Does the plastic block the beam?
3. Open up a trash bag and place one side of the bag between your remote and the device. Did that block the beam, or did the remote turn on the device?
4. What else can you try? How about a clear bag?
5. A clear bag filled with water?
6. A sheet of paper?
7. What about a metal pan? Find something that's not coated with Teflon. Does infrared go through metal?
8. What if you point it at a white wall behind you, pretending the white wall is a mirror and aiming it so it will reflect it back to the device?
9. Complete the table.
10. Now let's make the invisible infrared light *visible*. Take your camera (either still or video camera will work) and turn it on. Put it on a mode where you can see through the view screen. Aim the infrared camera right at the emitter for the remote (usually near the top) and press a button. Point the remote right at the camera and watch through the camera. Our eyes normally can't see the infrared light, but the camera can!

11. The camera can also see the otherwise dark end of the remote! If your camera has a special night vision mode, where it's especially sensitive to infrared light? If so, try it!

# Infrared Data Table

| **Item/Object Tested** | **Guess FIRST!** ***Will the Infrared Light Pass Through?*** | **What Happened?** *(Did it pass through or not?)* |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

**Reading**

Different detectors are sensitive to different colors. Your eyeballs are sensitive to specific colors in the 400-700 nm (nanometer) range which is how long one wavelength is. A nanometer is extremely tiny!

The frequency of red light is around 430 trillion Hz (Hertz, which is one wave cycle per second). If you were to count the number of waves passing a certain point in one second, you'd count 430 trillion waves. If you counted 750 trillion waves, the light would be violet. Different colors have different frequencies.

Light energy (also called *electromagnetic radiation)* with the lowest amounts of energy and longest wavelengths (1mm to 1km) are **radio waves**. These are emitted by radio galaxies like quasars, supernova leftovers, and the radio tower at the top of the hill. Radio waves from space with a wavelength greater than 100 meters are reflected back into space by our atmosphere. Radio waves are detected in space by the COBE satellite, the VLA in New Mexico, and the Arecibo Observatory in South America.

The next step down in wave size is **microwaves,** which have more energy than radio waves but are a shorter wavelength. These are the ones inside your microwave that excite the water molecules inside your food so that your food heats up.

**Infrared (IR)** has slightly more energy and an even smaller wavelength (700 nanometers, or nm to 1mm), and you can feel this light as warmth on your skin when you step into the sun. There's a lot of infrared radiation in space around the star-forming clouds and objects with a temperature above 1000°C. SOFIA and the Infrared Observatory both detect infrared from various stars in space.

**Visible light or optical light waves** are the visible rainbow you can see with your eyes after a rainy day. These wavelengths have more energy and shorter wavelengths (300 to 700 nm) than infrared. The Hubble Space Telescope and Earth-bound optical telescopes look at stars, galaxies, and planets.

Ultraviolet (UV) light has more energy and shorter wavelengths (10nm to 390nm) than visible light, and you'll find hot stars emit largely in this region of the spectrum. The ozone layer protects us from most of the UV, but not all. That's why you get a sunburn if you don't wear sun block, and why colors fade in sunlight. SkyLab, Astrotelescope and SOHO all search for UV. SOHO looks directly at the sun's corona to get amazing images in UV.

**X-rays** have even more energy and short wavelengths (0.01nm to 10 nm) than UV light, and you'll find these are emitted by active black holes, supernova remnants, and very hot stars (we're talking 1 million to 100 million° C). Fortunately for us, these are quickly absorbed in the upper atmosphere and most never make it to the surface of Earth. X-rays generated on earth are emitted by electrons outside the nucleus of an atom. ROSAT looked at cluster galaxies to detect X-ray sources.

Deadly **gamma rays** have the most amount of energy and the shortest frequency (less than 0.01 nm), and you'll find these in areas of superflares from pulsars, supernovas, and radioactive atoms. Gamma rays are like X-rays, in that they both can go through thick materials, and would rather go through your detector than into it to be detected. Gamma rays on Earth are generated inside the nucleus of an atom. The Compton Observatory looked at quasars to detect gamma rays.

**Exercises**

1. Look over your data table. What *kinds* of objects (plastic, metal, natural, etc.) allow infrared light to pass through them?

2. Why does the camera work in making the infrared light visible?

# Lesson #3: Ultraviolet Light

**Overview:** Stars, including our sun, produce all kinds of wavelengths of light, including UV (ultra-violet). That's the wavelength that gives you sunburns. We're going to find out the best way to protect you from the harmful rays.

**What to Learn:** The UV beads we're going to use in our experiment are made from a chemical that reacts with light. It takes the UV light from the sun and then re-emits it in a different wavelength that's visible to us.

**Materials**

- 5 UV beads (these change colors when exposed to the sun)
- tape (double-sided is easier)
- sun block
- sunglasses (ask the kids to bring a pair)
- sunny day
- water
- piece of fabric
- clear plastic bag

**Experiment**

1. Place a piece of tape on the data table, and stick your beads to the tape, one in each box.
2. Walk outside with your data table and record your observations.

## UV Light Data Table 1

| Bead | Color Inside | Color When in Sunlight | How Long Did It Take to Return to Indoor Color? *(measure in seconds)* |
|---|---|---|---|
| 1 | | | |
| 2 | | | |
| 3 | | | |
| 4 | | | |
| 5 | | | |

3. Walk back indoors and cover the beads, blocking out all light. Peek at them every minute or two to find out when they've returned to their unexposed color.
4. Now prepare your second round of testing by doing the following *before* exposing the beads to the sun:
    a. Place a bead inside a baggie.
    b. Place a second bead inside a baggie filled with water.

c. Smear a clean baggie with sun block and place a third bead inside.
d. Place a pair of sunglasses over a fourth bead.
e. Place a fifth bead under a piece of fabric.

5. Walk your five beads outside and record your observations in the data table.

## UV Light Data Table 2

| Bead | Color Inside | Color When in Sunlight |
|---|---|---|
| 1: Baggie | | |
| 2: Baggie + Water | | |
| 3: Sun block | | |
| 4: Sunglasses | | |
| 5: Fabric | | |

6. Bring your beads back inside and return them to their unexposed color.
7. Prepare your third round of testing by exposing your beads to some of the following:
    f. a fluorescent lamp
    g. an incandescent lamp
    h. flashlight
    i. glow stick
    j. computer screen
    k. reflected sunlight using a mirror
    l. candle flame (please be careful with this!)
    m. any other light source you have access to
8. Record your observations in the data table.

## UV Light Data Table 3

| Light Source | Color Inside | Color When Exposed | How Long Did It Take to Change Color when Exposed? |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

**Reading**

Stars, including our sun, produce all kinds of wavelengths of light, even UV. The UV beads we're going to use in our experiment are made from a chemical that reacts with light. It takes the UV light from the sun and then re-emits it in a different wavelength that's visible to us.

When a particle of UV light smacks into an atom, it collides with an electron and makes the electron jump to a higher, more energetic state that is a bit further from the center of the atom than it's comfortable being. That's how energy gets absorbed by an atom. The amount of energy an electron has determines how far from the atom it has to be. The electron prefers being in its lower state, so it relaxes and jumps back down, transferring a blip of energy away as it does. This blip of energy is the light we see emitted from the UV beads. This process continues as long as we see a color coming from the UV beads.

UV sensitive materials have a pigment inside that changes color when exposed to UV light from either the sun or lights that emit in the 350nm – 300nm wavelength. (UVA is high-energy: 400-320nm, and UVB is low energy: 320-280nm). If you have fluorescent black lights, use them. (Do regular incandescent bulbs work? If not, you know they emit light outside the range of the beads!)

When light hits the pigment molecule, it absorbs the energy and actually expands asymmetrically (one end of the molecule expands more than the other). Different expansion amounts will give you a different color. Although it's a bit more complicated than that, you now have the basic idea. Your beads will change colors thousands of times before they wear out, so enjoy these super-inexpensive UV detectors.

A note about sun block: You can test different SPF levels of sun block, but here's the main idea behind the ratings: the number for SPF is the number of minutes it takes to get the same sun exposure than if you weren't wearing any for one minute. For example, SPF 30 will give you the same sun exposure after 30 minutes that you would normally get if you weren't wearing any after just one minute.

**Exercises**

1. What kinds of light sources didn't work with the UV beads?

2. Did your sun block really block out the UV rays?

3. Which was the best protection against UV rays?

# Lesson #4: Crystal Radio

**Overview:** Radio waves are a special type of electromagnetic waves that have low frequency and long wavelengths, and we use special equipment in order to "hear" them. A crystal radio is among the simplest of radio receivers, since there's no battery or power source, and nearly no moving parts. The source of power comes directly from the radio waves themselves.

**What to Learn:** Low-frequency electromagnetic waves are called radio waves, which are *not* the same as sound waves. By using electromagnetism principles, we can convert the radio waves into sound waves you can hear.

**Materials**

- toilet paper tube
- popsicle stick
- small square of sandpaper
- magnet wire (Radio Shack part #278-1345)
- germanium diode: 1N34A (NWebTronics or try GSST)
- 4.7k-ohm resistor (Radio Shack part #271-1330)
- Alligator clip test leads (Radio Shack part #278-1157)
- 100'stranded insulated wire (for the antenna)
- scrap of cardboard
- brass fasteners (3-4)
- telephone handset OR get a crystal earphone from GSST
- wire strippers
- hot glue gun

**Experiment**

1. Cut a piece of wire about 8 inches in length.
2. Remove about ½ inch to an inch of the plastic insulation from each end of your cut wire.
3. Remove about ½ inch to an inch of the plastic insulation from your 100' spool of antenna wire.
4. Next you'll make the tuner. Get the popsicle stick, a fastener, and the end of your antenna wire.
5. Insert the popsicle stick into the brass fastener and connect your antenna wire to the fastener by pinching the fastener ends together and wrapping the wire around the fastener. Fold the fastener ends down on the popsicle stick and put this entire piece aside.
6. Begin wrapping the magnet wire around the cardboard tube, making sure that none of the magnet wires overlap. You can wrap around and then slide the windings down so that they are close to each other, but not overlapping. You can put a bit of tape on the wire as you go so that it doesn't unwind and spring up as you're winding. This will take a bit of time to do properly. You'll want about 200 windings with no overlapping. Leave about a 6-inch loose tail at the end of your wire. Be sure to tape the last few windings to secure them to your tube.
7. Use hot glue to attach your wrapped cardboard tube to the cardboard base.
8. Find your germanium diode and connect the side with NO markings to the magnet wire tail that is on the wire-wrapped cardboard coil. Twist the wires together. Use a brass fastener to attach this connection to the cardboard.

9. Attach the marked end of the diode to a resistor (either end) and to one of the wires from your earphone. Attach these to the base with a brass fastener.
10. The third connection has four wires. Take the piece of 8-inch wire and attach it to the resistor, the other unattached side of the wire-wrapped cardboard coil's magnet wire, and the wire to the earphone. Attach these to the base with a fastener.
11. Make sure that the brass fasteners don't touch by covering them with tape. This both insulates them and stabilizes them so that they don't move.
12. Take your sandpaper scrap and use it to sand right on top of the coil, rubbing back and forth VERY gently. This removes the insulation from the very top of the wires. This is where you'll tune the radio.
13. Use a grounding source for your radio by touching the exposed, unattached tip of the 8-inch wire to something metal that's grounded in your house. Some examples are lamps with metal parts, metal faucets, metal refrigerators, etc. DO NOT plug in the end to an electrical circuit.
14. To attach the antenna, untwist the entire coil. You'll use the end of the popsicle stick with the fastener on the end to move along the top of the coil in order to tune the radio.

**Troubleshooting:** Some large buildings can block radio waves, so try going outside and see if that helps. Also, you might not have a good grounding source, so try another object. Finally, double check all connections to be sure the wires are all connected properly.

15. Be sure to run your experiment a few times before taking actual data, to be sure you've got everything running smoothly.
16. You will be varying the antenna length (start long and snip it shorter as you record your data trials) and measuring strength of the signal using the scoring below:

- 1 – No Signal: You can't hear any signal at all.
- 2 – Inaudible Sound: You can barely hear a signal, but can't make out any words.
- 3 – Weak Signal: You can hear a few words here and there, but nothing that makes sense.
- 4 – Medium Signal: You can hear most words, but it still sounds scratchy.
- 5 – Strong Signal: You can clearly hear words or songs.

# Crystal Radio Data Table

| Trial # | Antenna Length (Feet) | Signal Strength (Min = 1, Max = 5) |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |
| 4 | | |
| 5 | | |
| 6 | | |
| 7 | | |
| 8 | | |

**Reading**

Radio waves are actually low frequency, long wavelength electromagnetic waves. They are not the same thing as sound waves. Crystal radios turn radio waves directly into a signal that our ears can detect. Transmitters are radio stations that emit radio waves. We also need a tuning coil, detector, antenna, and earphones to hear the waves. Today we will use a cardboard tube wrapped in magnet wire as our tuning coil and a geranium diode as our detector.

Your crystal radio will detect in the AM band that have been traveling from stations (transmitters) thousands of miles away. After working with the electromagnetic spectrum where we played with frequency and wavelengths of light, you'll find that you've got all the basics for picking up AM radio stations using simple equipment from Radio Shack.

The radio is made up of a tuning coil (magnet wire wrapped around a toilet paper tube), a detector (germanium diode) and crystal earphones, and an antenna wire.

One of the biggest challenges with detecting low-power radio waves is that there is no amplifier on the radio to boost the signal strength. You'll soon figure out that you need to find the quietest spot in your house away from any transmitters (and loud noises) that might interfere with the reception when you build one of these. You'll also have to figure out the best antenna length to produce the clearest, strongest radio signal in your crystal radio.

Power from the radio comes from the radio waves themselves, so we won't need batteries or any other outside power source. We will also need an electrical ground so that the current will make a complete circuit for our radio.

**Exercises**

1. What are radio waves?

2. Name some of the parts needed for any radio that we also used in this radio.

3. What serves as the tuning coil for the crystal radio?

4. Why do you need a ground for the radio?

# Lesson #5: Polarization

**Overview:** This experiment uses a special filter to investigate the vibrating patterns of visible light to discover otherwise invisible stress fractures in objects.

**What to Learn:** Students will learn that light not only has a wavelength (which is also called frequency, or color) and intensity (brightness), but it also has a direction known as its polarization. Folks who spend a lot of time outdoors in the bright sun, like snow boarders and fishermen, use polarized lenses to "cut the glare" by reducing the light that gets reflected off water and ice.

**Materials**

- two pairs of polarized sunglasses
- tape (the 3/4″ glossy clear kind works best)
- window
- hard clear plastic objects, like disposable utensils, clear plastic cups, CD cases, etc.

**Experiment**

1. Open the glasses and line them up so that the lenses are facing each other.
2. Look through the glasses at a window.
3. Rotate one pair of glasses 90 degrees. The lenses should completely block the light at 90 degrees.
4. When the glasses are sitting on the table facing each other, they are aligned at zero degrees. At this point, they allow some light to pass through, but not all light.
5. Complete the table:

## Polarization Data Table #1

| Flashlight beam shining by itself | Flashlight shining through two parallel polarizing filters | Flashlight shining through two filters at 90˚ to each other |
|---|---|---|
| | | |

6. For the second experiment, you'll be using two polarized filters. Lenses from old polarized sunglasses work well. You can confirm they are polarized with the rotating test (step #5 above).

7. Hold up two polarizers parallel to each other so you can see light streaming through both.
8. Have your lab partner hold an object up in between the polarizers.
9. Rotate the polarizing filters until you see some beautiful patterns and colors emerge. You can bend and flex the object to see different colors.
10. What other items can you look at through the filters?

## Polarization Data Table #2

| **Object between the polarizers** (clear, hard plastic items) | **Draw the image you see:** |
|---|---|
| | |
| | |
| | |
| | |
| | |

**Reading**

The wavelength of light is its frequency or color. Intensity of light is how bright or dim it appears, phase is its time shift, and polarization is its direction. Polarized glasses filter out any light that's not coming from a certain direction. It allows some of the light to go through, but not all. So polarized lenses are light filters. Because it varies in brightness depending on its stage, astronomers use polarizing filters to look at the moon. They can use rotating polarizing filters to adjust the amount of light entering the eye.

White light, like from the sun, vibrates in all directions. Polarizers are special kinds of filters that block out all light except for the ones that are vibrating in the vertical plane.

Polarization has to do with the direction of the light.  Think of a white picket fence – the kind that has space between each board.  The light can pass through the gaps in the fence but is blocked by the boards.  That's exactly what a polarizer does. It filters the light depending on its direction.

When you have two polarizers, you can rotate one of the "fences" a quarter turn so that virtually *no* light can get through – only little bits here and there where the gaps line up. Most of the way is blocked, though, which is what happens when you rotate the two pairs of sunglasses. Your sunglasses are polarizing filters, meaning that they only let light of a certain direction in. The view through the sunglasses is a bit dimmer, as less photons reach your eyeball.

You use the "filter" principle in the kitchen. When you cook pasta, you use a filter (a strainer) to get the pasta out of the water. That's what the sunglasses are doing – they are filtering out certain types of light. Rotating the lenses 90° to block out all light is like trying to strain your pasta with two strainers that don't have their holes lined up, so it's more like a mixing bowl. Nothing is allowed to pass through.

Astronomers use polarizing filters to look at the moon. Ever notice how bright the moon is during a full moon, and how dim it is near new moon? Using a rotating polarizing filter, astronomer can adjust the amount of light that enters into their eye so they can see more detail on the surface without being blinded with too much light.

**Stress Fractures:** White light contains all the colors of the rainbow. When the white light hits the clear plastic object, it refracts the light into colors, and only the waves in the vertical direction make it through the second polarizer. When you squeeze or bend the plastic, you're changing the speed at which the light travels through the plastic, which changes the wavelength and also the color you see. You'll notice higher-stressed areas have lots of color changes and lower-stressed areas are only a couple of colors.

## Exercises

1. Why do you need two polarizers to block the light completely?

2. How can you tell if your sunglasses are polarized if you only have one pair?

# Lesson #6: Spectrometers

**Overview:** Spectrometers (spectroscopes) are used in chemistry and astronomy to measure light. In astronomy, we can find out about distant stars without ever traveling to them, because we can split the incoming light from the stars into their colors (or energies) and "read" what they are made up of (what gases they are burning) and thus determine their what they are made of.

**What to Learn:** In this experiment, you'll make a simple cardboard spectrometer that will be able to detect all kinds of interesting things!

**SPECIAL NOTE: This instrument is NOT for looking at the Sun. Do NOT look directly at the Sun. But you can point the tube at a sheet of paper that has the Sun's reflected light on it.**

**Materials:**

Easy Spectrometer

- Old CD
- Razor
- Index card
- Cardboard tube at least 10 inches long

Advanced Spectrometer (Calibrated)

- Cardboard box (ours is 10″ x 5″ x 5″, but anything close to this will work fine)
- Diffraction grating
- 2 razor blades (with adult help)
- Masking tape
- Ruler
- Photocopy of a ruler (or sketch a line with 1 through 10 cm markings on it, about 4cm wide)

Easy Spectrometer:

1. A CD has a diffraction grating built into it. We're going to use a CD instead of a diffraction grating for this experiment.
2. Cut a clean slit less than 1 mm wide in an index card or spare piece of cardboard.
3. Tape it to one end of the tube.
4. Align your tube with the slit horizontally, and on the top of the tube at the far end cut a viewing slot about one inch long and ½ inch wide.
5. Cut a second slot into the tube at a 45-degree angle from the vertical away from the viewing slot.
6. Insert the CD into this slot so that it reflects light coming through the slit into your eye (viewing slot).
7. Aim the 1 mm slit at a light source such as a fluorescent light, neon sign, sunset, light bulb, computer screen, television, night light, candle, fireplace… any light source you can find EXCEPT THE SUN.
8. Look through the open hole at the light reflected off the compact disk (look for a rainbow in most cases) inside the cardboard tube.
9. Complete the data table.

Advanced Spectrometer (Calibrated)

1. Using a small box, measure 4.5 cm from the edge of the box. Starting here, cut a hole for the double-razor slit that is 1.5 cm wide 3 cm long.
2. From the other edge (on the same side), cut a hole to hold your scale that is 11 cm wide and 4 cm tall.
3. Print out the scale and attach it to the edge of the box.
4. Very carefully line up the two razors, edge-to-edge, to make a slit and secure into place with tape.
5. On the opposite side of the box, measure over 3 cm and cut a hole for the diffraction grating that is 4 cm wide and 3 cm tall.
6. Tape your diffraction grating over the hole.
7. Aim the razor slit at a light source such as a fluorescent light, neon sign, sunset, light bulb, computer screen, television, night light, candle, fireplace… any light source you can find. Put the diffraction grating up to your eye and look at the inner scale. Move the spectrometer around until you can get the rainbow to be on the scale inside the box.

**How to Calibrate the Spectrometer with the Scale**

8. Inside your box is a scale in centimeters. Point your slit to a fluorescent bulb, and you'll see three lines appear (a blue, a green, and a yellow-orange line). The lines you see in the fluorescent bulb are due to mercury superimposed on a rainbow continuous spectrum due to the coating. Each of the lines you see is due to a particular electron transition in the visible region of Hg (mercury).
    1. **blue line (435 nm)**
    2. **green line (546 nm)**,
    3. **yellow orange line (579 nm)**

    If you look at a sodium vapor street light you'll see a yellow line (actually 2 closely spaced) at 589 nm.

9. Line the razor slits along the length of the fluorescent tube to get the most intense lines. Move the box laterally (the lines will move due to parallax shift).
10. Take scale readings at the extreme of these movements and take the average for the scale reading. For instance, if the blue line averages to the 8.8 cm value, this corresponds to the 435 nm wavelength. Do this for the other 2 lines.
11. On graph paper, plot the cm (the ruler scale values) on the vertical axis and the wavelength (run this from 400-700 nm) on the horizontal axis.
12. Draw the best straight lines through the 3 points (4 lines if you use the Na (sodium) street lamp). You've just calibrated the spectrometer!
13. Line the razor slits up with another light source. Notice which lines appear and where they are on your scale. Find the value on your graph paper. For example, if you see a line appear at 5.5 cm, use your finger to follow along to the 5.5 cm until you hit the best-fit line, and then read the corresponding value on the wavelength axis. You now have the wavelength for the line you've just seen!

**Notes on Calibration and Construction:** If you swap out different diffraction gratings, you will have to re-calibrate. If you make a new spectrometer, you will have to re-calibrate to the Hg (mercury) lines for each new spectrometer. If you do remake the box, use a scale that is translucent so you can see the numbers. If you use a clear plastic ruler, it may let in too much light from the outside making it difficult to read the emission line.

# Spectrometer Data Table

| Light Source | Draw what you see: | Wavelength<br>*For Advanced Spectrometers Only!* |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

**Reading**

Diffraction gratings are found in insect (including butterfly) wings, bird feathers, and plant leaves. While I don't recommend using living things for this experiment, I do suggest using an old CD. That's how we're going to build the *Easy Spectrometer.*

CDs are like a mirror with circular tracks that are very close together. The light is spread into a spectrum when it hits the tracks, and each color bends a little more than the last. To see the rainbow spectrum, you've got to adjust the CD and the position of your eye so the angles line up correctly (actually, the angles are perpendicular).

You're looking for a spectrum (think of a rainbow). –Depending on what you look at (neon signs, chandeliers, incandescent bulbs, fluorescent bulbs, halogen lights, etc.), you'll see different colors of the rainbow.

For the *Advanced Spectrometer,* we're actually going to calibrate it by plotting information on a graph and using a diffraction grating to make it more precise. It's much more like the instrument that scientists use in their labs.

Scientist use spectroscopes (spectrometers) to collect a small sample of light and test it to see what made the light. As the light passes through the diffraction grating, it gets split into different bands of light, and you'll see these as different wavelengths, or colors of light.

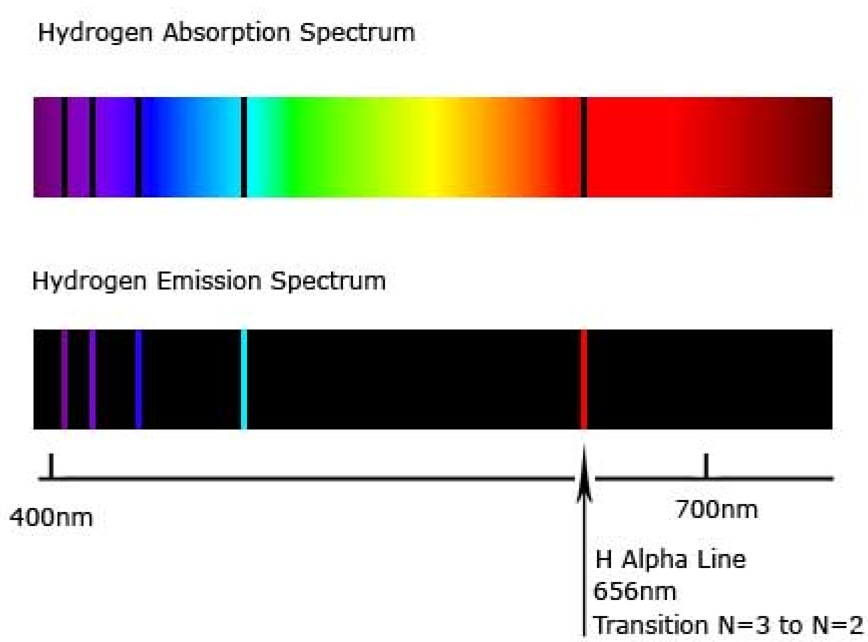
Scientists can figure out what fuel a star is burning, the age of the star, the composition of the star, how fast it's moving, and whether it's moving toward or away from Earth. For example, when hydrogen burns, it gives off light, but not in all the colors of the rainbow, only very specific colors in red and blue. It's like hydrogen's own personal fingerprint, or light signature.

While the spectrometers we're about to make aren't powerful enough to split starlight, they're perfect for using with the lights in your house, and even with an outdoor campfire. Next time you're out on the town after dark, bring this with you to peek different types of lights – you'll be amazed how different they really are.

**SPECIAL NOTE: This instrument is NOT for looking at the Sun. Do NOT look directly at the Sun.** But you can point the tube at a sheet of paper that has the Sun's reflected light on it.

**How to Tell Which Elements are Burning**

For example, if you were to view hydrogen burning with your spectroscope, you'd see the bottom appear in your spectrometer:



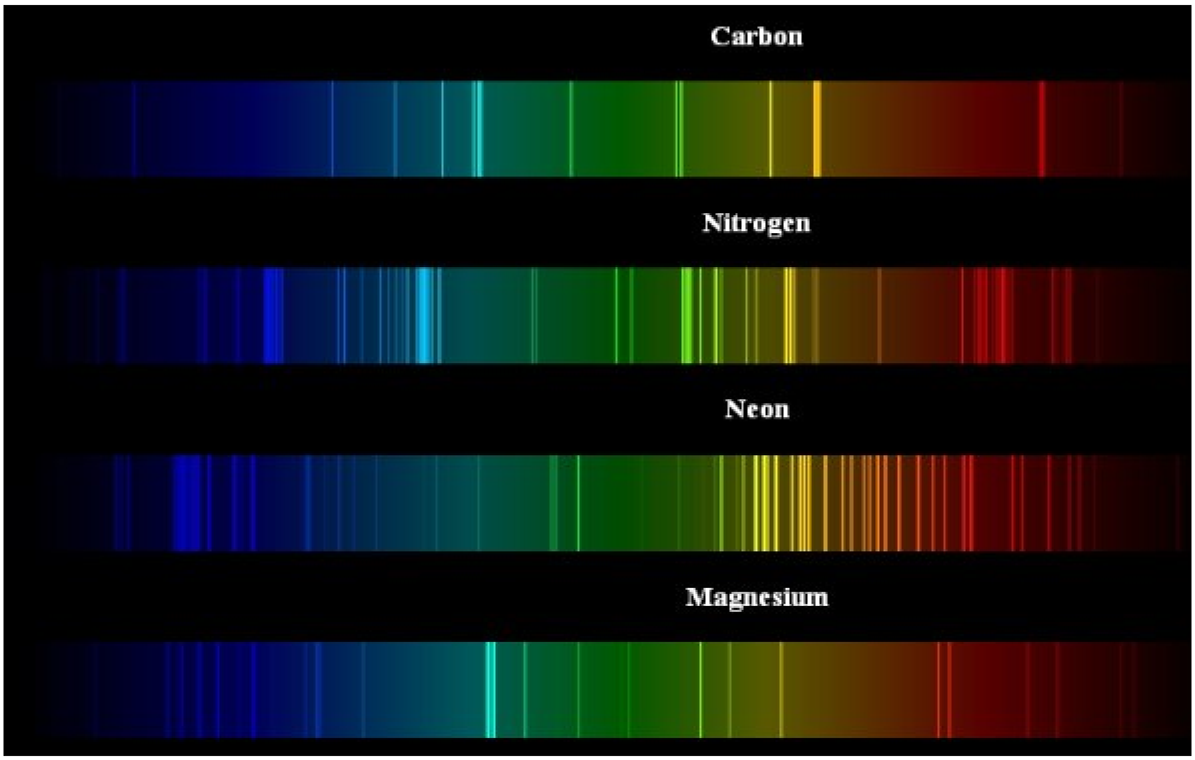

Notice how one fits into the other, like a puzzle. When you put the two together, you've got the entire spectrum.

**What's the difference between the two?** The upper picture (absorption spectrum of hydrogen) is what astronomers see when they use their spectrometers on distant stars when looking through the earth's atmosphere (a cloud of gas particles). The lower picture (emission spectrum of hydrogen) is what you'd see if you were looking directly at the source itself.

**Note - Do NOT use your spectrometer to look at the Sun!** When astronomers look at stars, they have computers look for them - they aren't putting their eye on the end of a tube.

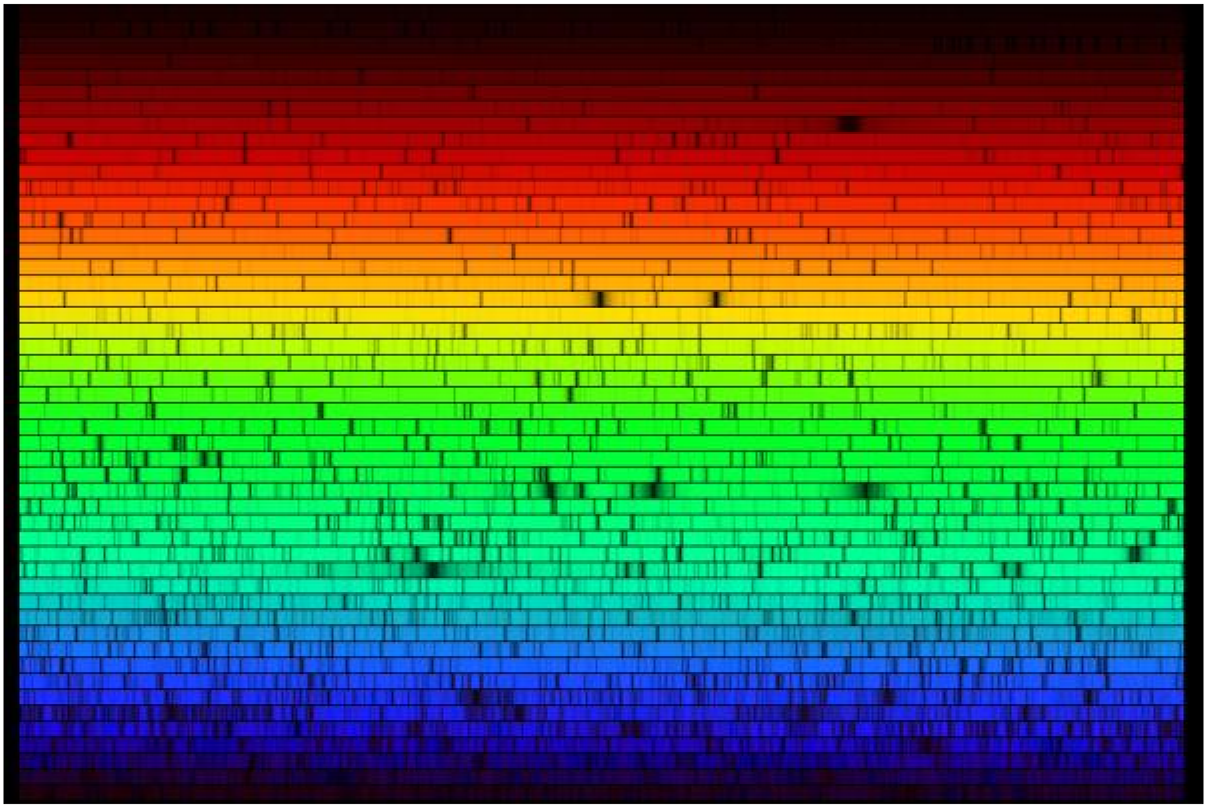
Each element has its own special 'signature', unique as a fingerprint, that it leaves behind when it burns. This is how we can tell what's on fire ***in*** a campfire.

For example, here's what you'd see for the following elements:




Just get the feel for how the signature changes depending on what you're looking at. For example, a green campfire is going to look a lot different from a regular campfire, as you're burning several elements in addition to just carbon. When you look at your campfire with your spectroscope, you're going to see ***all*** the signatures at the same time. Imagine superimposing all four sets of spectral lines above (carbon, neon, magnesium, and nitrogen) into one ***single*** spectrum... it's going to look like a mess! It takes a lot of hard work to untangle it and figure out which lines belong to which element. Thankfully, these days, computers are more than happy to chug away and figure most of it out for us.

Here's the giant rainbow of absorption lines astronomers see when they point their instruments at the Sun:



**Do you see all the black lines?** Those are called emission lines, and since astronomers have to look through a lot of atmosphere to view the Sun, there's a lot of the spectrum missing (shown by the black lines), especially corresponding to water vapor. The water absorbs certain wavelengths of light, which corresponds to the black lines.

**Questions to Answer**

1. Name three more light sources that you think might work with your spectroscope.

2. Why is there a slit at the end of the tube instead of leaving it open?

# Lesson #7: Electric Eye

**Overview:** Photoresistors are very inexpensive light detectors, and you'll find them in cameras, street lights, clock radios, robotics, and more. We're going to play with one and find out how to detect light using a simple series circuit.

**What to Learn:** This is the first of many different burglar alarms we're going to make with our simple circuits and switches knowledge. Pay special attention to how this gets inserted in your circuit. Notice any similarities to the switch circuit? We're going to use the idea of wiring up components in *series* over the next couple of Burglar Alarm lessons.

**Materials**

- AA battery case with batteries
- one CdS cell
- three alligator wires
- LED
- Optional: Laser pointer or flashlight (or both)
- Optional: DMM (Digital Multimeter)

**Experiment**

1. Separate the wires of your CdS cell.
2. Light up your LED in a simple circuit. Don't put in the CdS cell yet – we want to be sure everything works before introducing a new electronic element.
3. Remove one of the alligator clips from an LED wire and replace it with a third alligator clip lead.
4. Attach each one of the two free ends of alligator wires to either end of the CdS cell. You should now have a complete circuit that looks a lot like a circle when you stretch it out.
5. Put your hand over the CdS light detector and the LED should go dark.
6. Shine a flashlight or laser pointer on the CdS cell (or just go outside in the sun) and the LED will light up. If you used the sun for a light source, you'll need to cup your hands around the LED because it's going to look dark or dim outdoors.
7. Optional: Using your DMM set to DC volts and "20," measure the voltage of the LED. How many volts does the LED receive? (Don't forget to write "V" after the number you read.)

   ______________________________________________

8. Set your DMM to "ohms" or the "Ω" symbol. Touch one probe to each side of the CdS cell. If this is too difficult, then attach an alligator wire to a probe and the other end to one of the wires on the CdS cell. Do this for both sides. Make sure your dial is set to measure resistance. What do you read? (Don't forget to write "Ω" or "ohms" after the number you write down.)

   ______________________________________________

9. Fill in the data table. Note that your values will not be the same as mine, since you have different lighting, different batteries, and a different size cell than I do. Feel free to go outside, hide it under the table, close the cell in a book, put it next to the window, etc… when taking your data. Be creative!

## CdS Photocell Data Table

| **Lighting Condition** | **CdS Cell Resistance** | **LED Voltage** |
|---|---|---|
| *CdS Cell completely covered up* | *7.1 MΩ (or 7,100,000 Ω)* | *0.5 volts* |
| *Laser pointer beam dead center on the cell* | *3.8 kΩ (or 3,800 Ω)* | *2.9 volts* |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

**Reading**

This is the first of many different burglar alarms we're going to make with our simple circuits and switches knowledge. This particular one is a good one to start with, since it's relatively simple to make and you probably have experience with the *buzz* you hear when you enter a store that's armed with one of these.

A *photoresistor* or *light dependent resistor* limits the amount of current that flows through it in proportion to the light it receives. This effect is called *photoconductivity*. The more light that falls on the resistor, the more electricity flows through the wire. Photoresistors are also called *photocells*.

**Exercises**

1. How is a CdS cell like a switch? How is it *not* like a switch?
2. When is the LED the brightest?
3. How could you use this as a burglar alarm?

# Lesson #8: Laser Burglar Alarm

**Overview:** This is a laser burglar alarm that will be able to turn on a buzzer by increasing the voltage in the circuit. This type of circuit is a light-actuated circuit. When a beam of light hits the sensor (the "eye"), a buzzer sounds. Use this to indicate when a door closes or drawer closes… your suspect will never know what got triggered.

**What to Learn:** For an object to be seen, light emitted by or scattered from it must enter the eye. In this case, we'll be using a detector as the "eye" to see the laser beam.

**Materials**

- red laser
- 9V Battery
- three alligator clip leads
- buzzer (3-6V)
- cdS Cell

**Experiment**

1. Take the darkest alligator clip lead that you have and attach it to the negative side of the 9-volt battery. (The larger lead is negative.)
2. Attach the other end of the alligator clip to the darker end of the buzzer.
3. Take another alligator clip and attach it to the other side of the buzzer.
4. Attach the other side of the second alligator clip to the CdS cell.
5. For the last set of connections, attach the CdS cell to the remaining alligator clip. Attach the other end to the positive lead of the 9-volt battery.
6. Shine the laser beam on to the CdS cell. Does the buzzer sound?
7. If the buzzer doesn't sound, double check all your connections. Make sure everything is connected in a giant loop.
8. To mount the alarm, disconnect everything first.
9. Hot glue the battery and buzzer to the cardboard.
10. DO NOT hot glue the CdS cell. Hot glue each of the alligator clips leading to the CdS cell instead. This will allow the cell to bend and adjust a bit to make sure the laser hits just where it should.
11. Connect everything back up in the circuit.
12. Now you can tape the alarm beside a door and attach the laser beam to the door itself. (To keep the laser beam on, wrap a rubber band around the on/off switch.)
13. When someone closes the door, the alarm should sound.  You can also mount the alarm so that the alarm sounds when the door is opened.
14. Draw a diagram of how your wires are connected in this circuit. Include all electrical components, like the battery, buzzer, and CdS cell:

**Reading**

This alarm uses a simple circuit where everything is hooked up in a series, making a complete circle. The CdS (cadmium sulfide cell) is a special kind of resistor called a photoresistor, which is sensitive to light.

A resistor limits the amount of current (electricity) that flows through it, and since this one is light-sensitive, it will allow different amounts of current through depending on how much light it "sees."

Photoresistors are very inexpensive light detectors, and you'll find them in cameras, street lights, clock radios, robotics, and more. We're going to play with one and find out how to detect light using a simple series circuit.

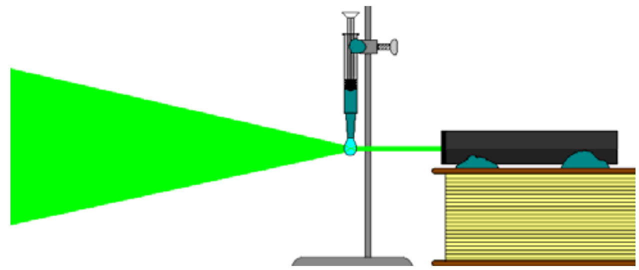
**Exercises**

1. How is this circuit different from the *Electric Eye* experiment we did previously?

2. Name three other light sources that work to activate your circuit.

# Lesson #9: Laser Microscope

**Overview:** Did you know that you can use a laser to see tiny paramecia in pond water? We're going to build a simple laser microscope that will shine through a single drop of water and project shadows on a wall or ceiling for us to study.



Here's how it works: By shining a laser though a drop of water, we can see the shadows of objects inside the water. It's like playing shadow puppets, only we're using a highly concentrated laser beam instead of a flashlight.

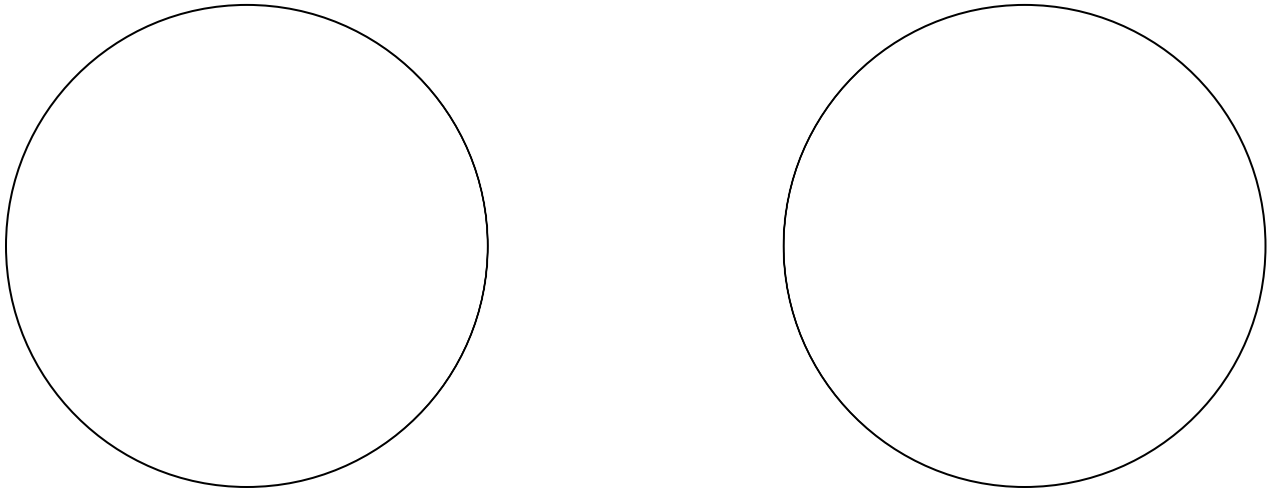
**What to Learn:** Light travels in straight lines except when the medium it travels through changes.

**Materials**

- red laser
- large paperclip
- rubber band
- stack of books
- white wall
- pond water sample (or make your own from a cup of water with dead grass that's been sitting for a week on the windowsill)
- pliers

**Experiment**

1. To bend the paperclip, open it up first. Then open one end, bringing that end up. You can make a loop in this end by using the pliers.
2. Attach the clip to the laser using the rubber band, wrapping it around several times.
3. Bend the wire so that when the laser is on, the beam goes through the loop.
4. Dip the loop (NOT the laser!) into the water. It should be small enough to hold a drop of water.
5. Turn down the lights so that you can see the images better.
6. Use a white surface, like a wall or ceiling, to direct your laser onto. Adjust the focus by moving the laser back and forth until you find the spot where things look clearest.
7. Draw what you see from two different water samples in the circles provided. Label each one!



**Reading**

Here's how it works: By shining a laser though a drop of water, we can see the shadows of objects inside the water. It's like playing shadow puppets, only we're using a highly concentrated laser beam instead of a flashlight.

If you're wondering how a narrow laser beam spreads out to cover a wall, it has to do with the shape of the water droplet. Water has surface tension, which makes the water want to curl into a ball shape. But because water's heavy, the ball stretches a little. This makes the water a tear-drop shape, which makes it act like a convex lens, which magnifies the light and spreads it out.

**Exercises**

1. Does this work with other clear liquids?

2. What kind of lens occurs if you change the amount of surface tension by using soapy water instead?

3. Does the temperature of the water matter? What about a piece of ice?

4. Does this work with a flashlight instead of a laser?

5. Do lasers hurt your eyes? How?

# Lesson #10: Optical Bench

**Overview:** Mirrors and filters and lenses, oh my! In this lesson, we'll learn a lot more about each of these items and how you can use them together to make an optical bench. An optical table gives you a solid surface to work on and nails down your parts so they don't move. Scientists use optical benches when they design microscopes, telescopes, and other optical equipment. We're going to make a quick and easy optical lab bench to work with your lenses. Well, technically our setup is called an optical rail, and the neat thing about it is that it comes with a handy measuring device so you can see where the focal points are for your lenses.

**What to Learn:** Lenses work to bend light in a certain direction, called refraction. Concave lenses work to make objects smaller and convex lenses make them larger. Light interacts with matter by transmission (including refraction), absorption, or scattering (including reflection).

**Materials**

- lenses (glass or plastic - magnifying lenses work also)
- two razor blades (new)
- index cards (about four)
- razor
- old piece of wood
- single hair from your head
- tape
- small binder clips
- aluminum foil
- clothespins (2-4)
- laser pointer
- popsicle sticks (tongue-depressor size)
- hot glue gun
- scissors and a sharp razor
- meter sticks (2)
- large candle (with adult supervision)
- bright light source (ideas for this are on the video)

**Experiment**

1. Use masking tape to fasten together the two meter sticks so that they're on top of each other. Be sure that you'll still be able to insert popsicle sticks between the two meter sticks in order to mount your lenses and filters.
2. Run a bead of glue along the tape you just added and attach a popsicle stick on each end of the now-attached meter sticks. These popsicle sticks will be your base, so be sure the numbers are at the top edge and easy to read.

3. To make the screen, grab a popsicle stick and a white index card. Place some glue along half of one long edge of the stick and attach it to the middle of the card. You can insert this new screen into the rail (between the two meter sticks) at one end.
4. Using a sharp knife, carefully cut out a small rectangle out of an index card. Remove the rectangle from the card.
5. Carefully place the two new razor blades side by side on the index card, facing each other atop the hole you just cut. They should be parallel and as close as you can get them without the razors actually touching. Secure them in place with tape.
6. Use a small bead of hot glue to attach another popsicle stick to the back of this index card which you've just taped the razors to. Insert the end of the stick into the optical bench. Tape around the meter sticks if it doesn't stand up straight.
7. To make an anti-slit, cut another rectangle in an index card with your razor blade.
8. Take a tiny piece of hair and tape it below the rectangular hole you just made. Stretch it across the middle of the hole and tape down the hair on the other side.
9. Flip over the card and glue a popsicle stick on the other side. Stand this up between the meter sticks in your optical rail (it doesn't really matter what order you put them in yet).
10. Place some hot glue on the side of another popsicle stick and attach this to a clothespin. Be sure the pin can still open and close. Press the stick down on the pin firmly until the glue dries.
11. To help with friction inside the clothespin, place a bead of hot glue inside on each jaw of the clothespin and hold it open until it dries. You can prop a popsicle stick inside and set aside while drying. This makes a higher friction surface to hold the lenses in place more securely. Alternately, you can wrap a rubber band around each jaw of the clothespin.
12. Insert a lens into the dry (or rubber banded) clothespin and insert the popsicle stick into the optical bench.
13. When making more clothespins for additional lenses, you can help prop them upright on the optical bench with small binder clips.
14. Now you've made your bench. Make sure all your items are about at the same height so that the light will hit everything evenly.
15. Turn out the lights and use a candle (with adult supervision) as your light source. Put it at one end of the optical bench. At the other end will be your screen. These items should be as close to the ends of the bench as possible so that your measurements are accurate.
16. Use the magnifying glass (a convex lens) in the middle, moving it back and forth until the image is focused on the screen.
17. Note how far away the magnifying glass is from the focused image. This is your focal point. Record the focal length on your data sheet.
18. Next, use two magnifying glasses. Move one at a time between the candle (or other light source) and your screen. Note where each focuses and record this data. Chances are they will not have the same focal point.
19. Then, put them close together and see where the focal point is when the magnifying glasses are held together like this. Note if your image size changes when both magnifying glasses are used. Also note if the image is more blurry or crisper.
20. Put your lenses in the optical bench and find the focal length for each individual one. Record this data on your table. You may want to record this on the edge of your lenses, or you can number them and put the number on the edge so that you can readily identity each lens.
21. *f* number is a ratio of focal length over diameter. Measure each individual lens diameter. Take the focal length data you recorded in the previous step and find the *f* number by dividing focal length by the diameter.
22. Next, mount your laser on the optical beam. Mount a slit opposite the beam.

23. Shine the beam through the slit toward a wall that's 6-10 feet away. You should see an interference pattern on the wall.
24. Complete the table:

## Optical Bench Data Table

| **Lens Type** | **Diameter** (inches or cm) | **Focal Length** *(inches or cm)* | ***f* number** *f* = focal length ÷ diameter |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |

**Reading**

**Concave lenses** are shaped like a "cave" and curve inward like a spoon. Light that shines through a concave lens bends to a point (converging beam). Ever notice how when you peep through the hole in a door (especially in a hotel), you can see the entire person standing on the doorstep? There's a concave lens in there making the person appear smaller.

You'll also find these types of lenses in "shoplifting mirrors." Store owners post these mirrors around help them see a larger area than a flat mirror shows, although the images tend to be a lot smaller.

If you have a pair of near-sighted glasses, chances are that the lenses are concave. Near-sighted folks need help seeing things that are far away, and the concave lenses increase the focal point to the right spot on their retina.

Concave lenses work to make things look smaller, so they're not as widely used as convex lenses. You'll find concave lenses inside camera lenses and binoculars to help clear weird optical problems that happen around the edges of a convex lens (called aberration).

**Convex lenses** bulge outward, bending the light out in a spray (diverging beam). A hand-held magnifying glass is a single concave lens with a handle. These lenses have been used as 'burning glasses' for hundreds of years – by placing a small piece of paper at its focal point and using the sun as a light source, you can focus the light energy so intensely that you reach the flash point of the paper (the paper auto-ignites around 450°F).

When you stack a large convex lens above a solar panel, the magnification effect makes it so you can get away with using a smaller photovoltaic cell to get the same amount of energy from the sun. You'll find convex lenses in telescopes, microscopes, binoculars, eyeglasses, and more.

**Mirrors:** What if you coat one side of the lens with a reflecting silver coating? You get a mirror!

In the video, you'll see me stick wooden skewers into a piece of foam to simulate how the light rays reflect off the surface of the mirror. Note that when the mirror (foam) is straight, the light rays are straight (which is what you see when you look in the bathroom mirror). The light bounces off the straight mirror and zips right back at you, remaining parallel. Now arch the foam. Notice how the light rays (skewers) come to a point (focal point). After the focal point, the rays invert, so the top skewer is now at the bottom and the bottom is now at the top. This is your flipped (inverted) image. This is what you'd see when you look into a concave mirror, like the inside of a metal spoon. You can see your face, but it's upside-down.

**Slits** A slit allows light from only one source to enter. If you have light from other sources, your light beam is more scattered and your images and lines become blurry. Thin slits can be easily made by placing the edges of two razor blades very close together and securing into place. We're going to **use an anti-slit using a piece of hair, but you can** substitute a thin needle.

**Filters:** There are hundreds to thousands of different types of filters that are used in photography, astronomy, and sunglasses. A filter can change the amount and type of light allowed through it. For example, if you put on red-tinted glasses, suddenly everything takes on a reddish hue. The red filter blocks the rest of the incoming wavelengths (colors) and only allows the red colors to get to your eyeball.

There are color filters for every wavelength, even IR (infra-red) and UV (ultra-violet). UV filters reduce the haziness in our atmosphere, and are used on most high-end camera lenses, while IR filters are heat-absorbing filters used with hot light sources (like near incandescent bulbs or in overhead projectors).

A neutral density (ND) filter is a grayish-colored filter that reduces the intensity of all colors equally. Photographers use these filters to get motion blur effects with slow shutter speeds, like a softened waterfall.

**Exercises**

1. Using only the shape, how can you tell the difference between a convex and a concave lens?

2. Which type of lens makes objects viewed through it appear smaller?

3. Which type of lens makes the objects viewed through it appear larger?

4. How do you get the *f* number?

# Lesson #11: Refractor and Reflector Telescopes

**Overview:** Telescopes aren't nearly as complicated as they seem. We're going to build two different kinds of telescopes: the refractor (which has only lenses) and the reflector (which has lenses and mirrors) telescopes.

**What to Learn:** Your lenses are curved pieces of glass or plastic designed to bend (refract) light. A simple lens is just one piece, and a compound lens is when you stack two or more together, like inside a camera. You can arrange your lenses in different ways to get different types of magnification.

***Do not use this telescope to look at the Sun!*** *This telescope is for looking at the moon, distant terrestrial objects, and flashlights with their light intensity stepped down and passed through a wax filter.*

**Materials**

- index card
- 3 clothespins
- popsicle sticks
- 2 meter sticks
- bright light source
- two double-convex lenses
- concave mirror
- small flat mirror (like a mosaic mirror)
- large paper clip
- black garbage bag
- rubber band
- wax paper
- masking tape
- hot glue gun
- scissors

**Experiment**

1. The video for these labs is longer than usual. You'll want to make sure to complete the optical bench experiment first which includes complete instructions for mounting lenses and mirrors to the rail.
2. To make a moon light source, stretch a section of a garbage bag over the head of the flashlight. You can cut out a crescent moon and line the cut section with wax paper on the inside. Attach the garbage bag to the flashlight with a rubber band with the wax paper on the inside.
3. Mount a double-convex lens to a clothespin as shown in the Optical Bench video. You need two of these for the refractor telescope. Make sure your two lenses magnify about the same amount.
4. Make an optical rail and mount one of the lenses near one end of the rail. You'll adjust it soon when you bring the moon shape into focus.
5. Place an index card near the middle of the optical rail. Don't attach it to the meter stick itself.
6. Place your flashlight about six feet away from the table so it shines through the lens and onto the index card.
7. Adjust the distance the lens is from the index card and bring the moon into focus.
8. At this point, if you have different-sized lenses, you can hold the second one near the first so you have two moons on the card. Do you notice the difference in brightness in moons? If your lenses are different sizes but magnify the lenses, the larger lens will make a brighter image because it's got more light-gathering ability. Remove the second lens - we were just demonstrating this concept with it.
9. Slide the optical rail around so that the moon on the index card is right over the meter stick.
10. Take the second lens and insert it into the rail on the *other side* of the index card.
11. Look through the second lens and bring the moon that shines through the card into focus.

12. As you still look through the second lens, remove the card and look through both lenses. Make any tiny adjustments, if needed. You're looking for the moon to be in focus and magnified. You just made a refractor telescope, exactly like Galileo did 400 years ago!
13. Draw a diagram of your telescope and include the following:
    a. Label the two lenses
    b. Label the light source
    c. Measure the distance between the light source and the first lens and draw it in your diagram
    d. Measure the distance between the first and second lens and draw it in your diagram
    e. Title your image – what kind of telescope is it?
    f. What is the magnification of your telescope? Add this to your drawing under the title.

14. Now, we're going to replace one of the lenses with a curved mirror to make a reflector telescope.
15. Mount the mirror at the far end of the optical rail. The light source is still at the opposite end.
16. Move the index card into position to catch the reflection of the moon. Adjust the mirror so that the moon is right over the rail and in focus. Make sure the index card is not attached to the optical rail.
17. Pick up your double-convex lens and place it on the opposite side of the card from the mirror and look through it to focus the image as we did before.
18. Uh-oh! Did you find a problem? That's right – your *head* got in the way of the light source, didn't it?
19. What if we use a tiny mirror to change the direction of the light and then we can focus it?
20. Open up the paperclip into an L-shape and hot glue or tape one side of the L to the back of your mirror.
21. The other end of the paperclip attaches to the popsicle stick so you can insert it into the optical rail.
22. Hold the popsicle stick and paper clip junction as you rotate the mirror into position. You need to flip it 90 degrees down and over at 45 degrees.
23. Insert the secondary mirror (the tiny one we just mounted on a popsicle stick) into the optical rail.
24. Adjust your rail so that the moon is right over the rail and at the edge of the index card.
25. Adjust the image of the moon by moving the mirror so that the moon is the same height as the tiny mirror.
26. When you've got it, remove the card and the image should be right on your card. Look right at the tiny mirror with your eye and see if you can spot the crescent moon.
27. Take your magnifier and hold it up to your eye to see if you can make that focused image even larger. The magnifier is your *eyepiece*. The curved mirror is your *primary mirror*. The tiny flat mirror is your *secondary mirror.*
28. Draw a diagram of your telescope and include the following:
    a. Label the two mirrors
    b. Label the lens (what kind is it?)
    c. Label the light source
    d. Measure the distance between the light source and the first (primary ) mirror and draw it in your diagram
    e. Measure the distance between the first and second mirrors and draw it in your diagram
    f. Measure the distance between the second mirror and your magnifier and draw it in your diagram
    g. Title your image – what kind of telescope is it?
    h. What is the magnification of your telescope? Add this to your drawing under the title.

**Reading**

The word *telescope* came about in 1611 when a Greek mathematician was presented with one of Galileo's instruments. Back then, a telescope was a couple of lenses spaced apart carefully in order to observe distant objects. The first known telescopes were used to look at objects in the distance on land, not the stars.

The earliest telescopes were refractor telescopes.  While Galileo is often credited with the first telescope, it was actually first constructed in 1608 individuals in the Netherlands.  Galileo was the first person to take the telescope and point it at the stars.

There are different types of astronomers, some of whom have never looked through a telescope. For example, radio astronomers use satellite dishes to "view" the sky while backyard astronomers use optical telescopes armed with cameras. Professional observational astronomers use computers and specialized camera equipment to look through their X-ray scopes and determine what's out there. And the kid down the street uses a new set of binoculars he got for his birthday. They are all doing astronomy, just in different ways.

Amateur astronomers usually have smaller telescopes, typically 4" to 20" in diameter. They generally don't get paid to do astronomy. They just do it for the love of it, and they are the ones you'll find on sidewalks and sharing views of the sky with the general public during local stargazing events. Many amateur astronomers have discovered new objects based on their raw knowledge of the sky.

Professional astronomers come in two varieties: observational and theoretical. Professional observational astronomers mostly use expensive scientific instruments to look through their massive telescopes for them. They spend a lot of time measuring things, taking data, and crunching the numbers. They are very good at designing and performing experiments that answer the big questions to which no one knows the answers.

Professional theoretical astronomers think up new ideas and new models for fitting the data so that it makes sense in the field of physics. They are great at asking the big questions in the first place. Albert Einstein was a theoretical astronomer, as he hated to do experiments of any kind. Instead, he preferred to sit back and *think* about what might happen in the laboratory of his mind.

# Lesson #12: Measuring Your Hair

**Overview:** Do you have thick or thin hair? Let's find out using a laser to measure the width of your hair and a little knowledge about diffraction properties of light. (Since were using lasers, make sure you're not pointing a laser at anyone, any animal, or at a reflective surface.)

**What to Learn:**

**Materials:**

- a strand of hair
- laser pointer
- tape
- calculator
- ruler
- paper
- clothespin

**Experiment:**

1. Tape the hair across the open end of the laser pointer (the side where the beam emits from)
2. Measure 1 meter (3.28 feet) from the wall and put your laser right at the 1 meter mark.
3. Clip the clothespin onto the laser so that it keeps the laser on.
4. Where the mark shows up on the wall, tape a sheet of paper.
5. Mark on the sheet of paper the distance between the first two black lines on either side of the center of the beam.
6. Use your ruler to measure (in centimeters) to measure the distance between the two marks you made on the paper. Convert your number from centimeters to meters (For me, 8 cm = 0.08 meters.)
7. Read the wavelength from your laser and write it down. It will be in "nm" for nanometers. My laser was 650 nm, which means 0.000 000 650 meters.
8. Calculate the hair width by multiplying the laser wavelength by the distance to the wall (1 meter), and divide that number by the distance between the dark lines. Multiply your answer by 2 to get your final answer. Here's the equation:

**Hair width = [(Laser Wavelength) x (Distance to Wall)] / [ (Distance between dark lines) x 0.5 ]**

In the sample from the video, the wavelength was 650 nm = 0.000 000 650 meters, the distance from the wall was 1 meter, and the distance between the dark lines was 8 cm = 0.08 m, giving a hair width of 0.000 0162 5meters, or 16.25 micrometers (or 0.000 629 921 26 inches).

# Measuring Your Hair Data Table

Laser Wavelength ($\lambda$): ________________________ (nm)     Distance to Wall: ________________________ (in meters)

| **Hair Owner Name and Hair Type** *(straight, curly…)* | **Distance Between Dark Lines** *(cm)* | **Calculated Hair Width** *($\mu m$)* |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |

**Reading**

This experiment works by scattering the laser light on the hair. The scattering creates a diffraction pattern that looks like a line of lightness with dark areas. By measuring the distance the laser and hair are from the wall and also how far away the dark spots are, you can calculate the hair width using a couple of simple equations.

When light passes by the hair, it diffracts, or bends. The light bends around the hair, and each side of the hair is hit with light that bends differently, so we say that there are two points of light (one on either side of the hair). When they expand out to the wall, they are actually cone-shaped and they begin to interfere with each other. When the light is "in phase", they constructively interfere (shown by bright spots of light), and when they are out of phase by 180 degrees, they destructively interfere, when by dark spots.

According to *Babinet's Principle,* the hair will be identical to t two slits spaced the same distance apart as the width of the hair (you'll learn more about this in college), and using the small angle approximation with your trigonometry equations, you can determine the formula for hair width to be:

**Hair width = [(Laser Wavelength) x (Distance to Wall)] / [ (Distance between dark lines) x 0.5 ]**

If you rotate the hair a little under the tape of the laser beam, you'll find that curly hair gives a wider range of measurements, meaning that it has a more oval cross section, and straight hair is more round. How do you think you could modify the experiment to measure the sizes of other small objects, like blood cells or pollen?

**Exercises**

1. Which light source gave the most interesting results?
2. What happens when you aim a laser beam through the diffraction grating?
3. How is a CD different and the same as a diffraction grating?
4. Why does the feather work?

# Lesson #13: Laser Maze

**Overview:** Did you know that the word LASER stands for Light Amplification by Stimulated Emission of Radiation? Most lasers fire a monochromatic (one color) narrow, focused beam of light, but more complex lasers emit a broad range of wavelengths at the same time. By using lenses and mirrors, you can bounce, shift, reflect, shatter, and split a laser beam. Since the laser beam is so narrow and focused, you'll be able to see several reflections before it fades away from scatter.

**What to Learn:** Light has a source and travels in a direction. The angle of reflection of a light beam is equal to the angle of incidence.

**Materials**

- laser (A key-chain laser works great. Do NOT use green lasers, which can only be used outdoors.)
- large paper clips
- brass fasteners
- index cards
- small mirrors (mosaic-type work well)
- hot glue gun (optional)
- tape
- dry ice (optional)

**Experiment**

1. Open each paperclip into an "L" shape.
2. Insert a brass fastener into one U-shape leg and punch it through the card.
3. Hot glue (or tape) one square mirror onto the other end of the L-bracket.
4. Your mirror should be able to rotate. Do this with each mirror.
5. Turn down the lights.
6. Turn on the laser and adjust the mirrors to aim the beam from one mirror on to the next.
7. Take your laser with you into a steamy bathroom (which has mirrors!) after a hot shower. The tiny droplets of water in the steam will illuminate your beam. (*Psst! Don't get the laser wet!)*
8. If you have carpet, shine your laser under the bed while stomping the floor with your hand. The small particles (dust bunnies?) float up so you can see the beam. Some parents aren't going to like this idea, sooo….
9. Have an adult drop a chunk of dry ice (using gloves!) into a bowl of water and use the fog to illuminate the beam. The drawback to this is that you need to keep adding more dry ice as it sublimates (goes from solid to gas) and replacing the water (when it gets too cold to produce fog).

10. Draw a diagram of your laser maze and label all the different parts. How many mirrors can you get it to reflect off of?

**Reading**

In 1917, Einstein figured out the basic principles for the LASER and MASER (a laser beam with wavelengths in the microwave part of the spectrum) by building on Max Planck's work on light. It wasn't until 1960, though when the first laser actually emitted light at Hughes Research Lab. Today, there are several different kinds of lasers, including gas lasers, chemical lasers, semiconductor lasers, and solid state lasers. Some of the most powerful lasers ever conceived are gamma ray lasers (which can replace hundreds of lasers with only one) and the space-based X-ray lasers (which use the energy from a nuclear explosion) – neither of these have been built yet!

Gas lasers pump different types of gases to get different laser colors such as the red HeNe (Helium-Neon laser), the high-powered $CO_2$ lasers that they can melt through metal, the blue-green argon-ion, the UV lasers that use nitrogen, and the metallic-gas combination such as He-Ag lasers (helium and silver) and Ne-Cu (neon and copper) which emit a deep violet beam.

But what about lasers used every day? The lasers we're going to be using are semiconductor lasers that use a small laser diode to emit a beam. They are the same lasers that are in the grocery store scanners, pen laser pointers and key chain lasers. Usually a class I or II laser, these pose minimal safety risk and are safe to use in our experiments.

**Exercises**

1. The word LASER is actually an acronym. What does it stand for?
2. What type of laser did we use in our experiment?
3. Why can't we see the laser beams without the help of steam, dirty carpet, etc.?

# Lesson #14: Laser Light Show

**Overview:** What happens when you shine a laser beam onto a spinning mirror? In the Laser Maze experiment (#30), the mirrors stayed put. What happens if you took one of those mirrors and moved it really fast?

**What to Learn:** Light is reflected from mirrors and other surfaces.

**Materials (per lab group)**

- AA battery pack with AA batteries
- 1.5-3V DC motor
- keychain laser pointer
- clothespin
- round mirror
- two alligator clip leads
- gear that fits onto the motor and has a flat side to attach to the mirror
- 5-minute epoxy (don't use hot glue – it's not strong enough and you'll have sharp mirrors flying off a high-speed motor)

**Experiment**

1. Insert the batteries into their case.
2. Make sure the wire leads do not touch each other!
3. Attach the alligator clips to the wires by grabbing the metal tip of the wires with the teeth of the matching alligator clip.
4. Use hot glue or epoxy to secure the gear onto the round mirror.
5. Press-fit the gear-mirror onto the shaft when the glue is dry.
6. Make the motor spin using the alligator clips and the battery case. Do this by attaching the remaining ends of the clips to the metal tabs on the back of the motor – one on each tab.
7. Turn down the lights and fire up the laser, aiming the beam onto the motor.
8. You can use the clothespin to keep the laser turned on. It also acts as a stand for the laser to free your hands even more.
9. Shine the reflection somewhere easy to see, like the ceiling.
   Once you've got this working, add a second mirror like you did in the Laser Maze experiment. Work with another lab group and put your setup next to each other so you can utilize their motor-mirror assembly with your laser.

# Laser Light Show Data Table

| **Motor Configuration**<br>*(Is the mirror spinning clockwise or counter-clockwise? Are you pulsing the motor on and off? Is the motor going fast or slow?)* | **What did the laser beam do (or look like) when reflected off the motor's mirror?** |
|---|---|
| | |
| | |
| | |
| | |
| | |
| | |
| | |

**Reading**

It turns out that a slightly off-set spinning mirror will make the laser dot on the wall spin in a circle. Or ellipse. Or oval. And the more mirrors you add, the more spiral-graphic-looking your projected laser dot gets.

This experiment works because of imperfections: The mirrors are mounted off-center, the motors wobble, the shafts do not spin true, and a hundred other reasons why our mechanics and optics are not dead-on straight. And that's exactly what we want – the wobbling mirrors and shaky motors make the pretty pictures on the wall! If everything were absolutely perfectly aligned, all you would see is a dot.

**Exercises**

1. How does the mirror turn a laser dot into an image?

2. What happens when you add a second motor? Third?

# Light 2 Evaluation

Student Worksheet

**Overview:** Today you're going to take two different tests: the quiz and the lab practical. You're going to take the written quiz first, and the lab practical at the end of this lab. The lab practical isn't a paper test – it's where you get to show your teacher that you know how to do something.

**Lab Test & Homework**

1. Your teacher will call you up so you can share how much you understand about advanced topics of light. Since science is so much more than just reading a book or circling the right answer, this is an important part of the test to find out what you really understand.
2. While you are waiting for your turn to show your teacher how much of this stuff you already know, you get to get started on your homework assignment. The assignment is due next week, and half the credit is for creativity and the other half is for content, so really let your imagination fly as you work through it.

   Here it is: Your classroom is going to be converted into an interactive science museum next week. You will be in charge of one of the stations. Your audience knows nothing about light waves or photons. Your job is to design and build an experiment that teaches the students in lower levels an important concept in light, like color, brightness, polarization, wavelength (frequency), or anything you feel is appropriate. You will get to explain to your students what's going on as you demonstrate your experiment. You can have them watch or actively do something at your station. You will be graded based on content and creativity, so really let your mind go wild. (Hint: If you were the audience, what would *you* want to learn about most?)

# Light 2 Quiz

Name____________________________________________________

1. How does a microwave heat things?
2. Why does the camera work in making the infrared light visible?
3. Why do you need two polarizers to block the light completely?
4. How can you tell if your sunglasses are polarized if you only have one pair?
5. How is a CdS cell like a switch? How is it *not* like a switch?
6. Do lasers hurt your eyes? How?
7. How can you tell the difference between a convex and a concave lens?
8. Which type of lens makes objects viewed through it appear smaller?
9. How do you find the *f* number of a lens?
10. The word LASER is actually an acronym. What does it stand for?

# Light 2 Lab Practical

Student Worksheet

**This is your chance to show how much you have picked up on important key concepts, and if there are any holes. You also will be working on a homework assignment as you do this test individually with a teacher.**

**Materials:**

- metal spoon that is shiny enough to see yourself in
- two magnifying lenses
- one concave mirror (optional)
- one flat mirror

**Lab Practical:**

1. Design and build an experiment that demonstrates how lenses and mirrors are used in two different kinds of telescopes.

2. Hand the student a spoon and ask them on which side they will appear right side up and on which they will appear upside down when they look at themselves in it. Also ask them to tell you which side is a concave mirror and which is convex mirror.

# Answers to Exercises and Quizzes

**Lesson #1: Microwaving Soap**
1. What is it in your food (and the soap) that is actually heated by the microwave? (water molecules)
2. How does a microwave heat things? (using electromagnetic waves to heat water molecules)
3. Touch the soap after it has been allowed to cool for a few minutes and record your observations. (the soap should be more brittle and flakes easily)

**Lesson #2: Infrared Light**
1. What kinds of objects allow infrared light to pass through them? (Check data.)
2. Why does the camera work in making the infrared light visible? (The camera is a viewer that lets us see this special frequency of light. Light is technically what we call *electromagnetic radiation.* Radio waves, infrared, microwaves, X-rays, and gamma rays are all *electromagnetic radiation*. If you could see the radio waves, then you could see radio towers as they transmit. They would appear to light up. If you could see all forms of light, then not only could you see the radio towers, but also your cell phone, the doctor's X-ray cameras, and your car radio would all be lit up as they operated. It's all made out of the same stuff, just not all of it is visible to our eyes.)

**Lesson #3: Ultraviolet Light**
1. What kinds of light sources didn't work with the UV beads? (Check data.)
2. Did your sun block really block out the UV rays? (Check data.)
3. Which was the best protection against UV rays? (Check data.)

**Lesson #4 Crystal Radio**
1. What are radio waves? (low-energy, low-frequency, long-wavelength electromagnetic waves)
2. Name some of the parts needed for any radio that we also used in this radio. (tuning coil, detector, antenna, earphone)
3. What serves as the tuning coil for the crystal radio? (the cardboard tube wrapped in magnet wire)
4. Why do you need a ground for the radio? (Grounding completes the circuit and makes the radio work.)

**Lesson #5: Polarization**
1. Why do you need two polarizers to block the light completely? (Polarizers block all light expect waves vibrating in the vertical plane. When you have two polarizers, you can rotate one so that you block both the vertical and the horizontal planes, so virtually no light passes through. )
2. How can you tell if your sunglasses are polarized if you only have one pair? (Looking through one of the lenses at a LCD display [which is also polarized], you'll see the light get dimmer and brighter as you rotate the sunglass lens.)

**Lesson #6: Spectrometers**
1. Name three more light sources that you think might work with your spectroscope. (answers will vary)
2. Why is there a slit at the end of the tube instead of leaving it open? (The light that strikes the end of the tube gets mostly reflected away, and only a tiny amount of light gets inside the tube to the diffraction grating. If you had too much light, you wouldn't be able to see the spectrum.)

**Lesson #7: Electric Eye**

1. How is a CdS cell like a switch? How is it *not* like a switch? (The flow of current is controlled by the amount of light that falls on the detector. It's unlike a switch in that it never really stops the current completely.)
2. When is the LED the brightest? (in full sun)
3. How could you use this as a burglar alarm?

**Lesson #8: Laser Burglar Alarm**

1. How is this circuit different from the *Electric Eye* experiment we did previously? (The first circuit is the same as the electric eye circuit: the buzzer sounds when the light hits the sensor. The second circuit, if you chose to make it, works in the opposite way in that the laser keeps the buzzer from sounding.)
2. Name three other light sources that work to activate your circuit. (Sunlight, strong flashlight, and a car headlight.)

**Lesson #9: Laser Microscope**

1. Does this work with other clear liquids? (Yes, but each liquid has its own *index of refraction*, which means it will bend more or less than with the water depending on its optical density.)
2. What kind of lens occurs if you change the amount of surface tension by using soapy water instead? (Soapy water kills the surface tension of the water, so you will not be able to use it as a magnifier. The light will pass virtually straight through since there's no curvature of the surface.)
3. Does the temperature of the water matter? What about a piece of ice? (Yes, water is most dense at 4°C.)
4. Does this work with a flashlight instead of a laser? (No, because the light source is not concentrated enough.)
5. Do lasers hurt your eyes? How? (Magnifying lenses, telescopes, and microscopes use this idea to make objects appear different sizes by bending the light. You'll often see warnings about never pointing telescopes, magnifying lenses, or lasers into eyes. When you concentrate the sun's energy to a single point, the leaf burns. This is exactly what happens at the back of your eye with focused sunlight and laser beams. Never look at intense light with your naked eyes.)

**Lesson #10: Optical Bench**

1. How can you tell the difference between a convex and a concave lens? (Concave lenses are shaped like a "cave" and curve inward. Convex lenses curve outward.)
2. Which type of lens makes objects viewed through it appear smaller? (concave)
3. Which type of lens makes the objects viewed through it appear larger? (convex)
4. How do you get the *f* number? (It's the ratio of focal length over diameter.)

**Lesson #12: Measuring Your Hair**

1. Which light source gave the most interesting results? (Answers vary.)
2. What happens when you aim a laser beam through the diffraction grating? (The light diffracts into a pattern.)
3. How is a CD different and the same as a diffraction grating? (The tracks on a DC act like a diffraction grating. When you shine sunlight on a CD, it will separate the white light into its colors. The track separation on a CD is about 1.6 micrometers, or 625 racks per mm. Diffraction gratings are typically 500-1,000 lines per mm.)
4. Why does the feather work? (The feather is like having a lot of hairs stacked together, like the lines of a diffraction grating, with space in between for the light to pass through like a slit.)

**Lesson #13: Laser Maze**

1. The word LASER is actually an acronym. What does it stand for? (Light Amplification by Simulated Emission of Radiation)
2. What type of laser did we use in our experiment? (semiconductor laser)
3. Why can't we see the laser beams without the help of steam, dirty carpet, etc.? (Our eyes are tuned for green light, not red.)

**Lesson #14: Laser Light Show**

1. How does the mirror turn a laser dot into an image? (Refer to Background Reading.)
2. What happens when you add a second motor? Third? (You increase the wobble and get spiral-graphic images.)

# Vocabulary for the Unit

The three primary **colors of light** are red, blue, and green. Red and green light mixed together make yellow light. Prisms unmix light into its colors (wavelengths).

**Concave lenses** work to make objects smaller (door peep hole), and are curved inward like a cave.

**Convex lenses** make them larger (magnifying lenses), and have a "bump" in the middle you can feel with your fingers.

The amount of **energy** a photon has determines whether it's a particle or a wave. Photons with the lowest amounts of energy and longest wavelengths (some are the size of football fields) are **radio waves**. The next step up are **microwaves,** which have more energy than radio waves. **IR** has slightly more energy, and **visible light** (the rainbow you can see with your eyes) has more energy and shorter wavelengths. Ultraviolet (UV) light has more energy than visible, and X-rays have even more energy than **UV**, and finally the deadly **gamma rays** have the most amount of energy.

**Filters** can be used to block certain wavelengths.

**Intensity**, or brightness, is the amount of photons (packets of light) you have in a certain amount of space. A flashlight has less intensity than a car headlight.

**LASER** stands for Light Amplification by Stimulated Emission of Radiation. Most lasers are monochromatic (one color). Lasers are concentrated beams of light, and are illuminated by small particles (like smoke and dust).

**Lenses** work to bend light in a certain direction (refraction). A lens is a curved piece of glass or plastic that changes the speed of the light. Lenses have the same effect on lasers as on light beams.

**Light** can be defined by four things: intensity (how bright), frequency (or wavelength), polarization (the direction of the electric field), and phase (time shift).

Objects can either be a **light source** (like the sun) or **reflect light** (like the moon).

Light can change speeds, but the maximum **light speed** is through a vacuum (186,000 miles per second). Light changes speeds when it passes through a different material (like water, glass, or fog).

Depending on the **optical density** of the material, light will bend by different amounts. Glass is optically denser than water. Water is more optically dense than air.

When two beams of light are out of phase with each other, it's like playing a *G* and *A* on the piano. This is called **phase shift**.

Blue and UV light eject electrons from metal plates, but red light does not (**photoelectric** effect).

**Polarization** has to do with the direction of the electric field. Your sunglasses are polarizing filters, meaning that they only let light of a certain direction in.

When a beam of light hits a window, it bends and changes speed (**refraction**). Technically, the wavelength (color) changes but the frequency stays the same. In order for this to happen, the speed of light must also change.

Razor-edge **slits** create interference patterns. Slits are skinny holes that allow light to pass through. Scientists use slits to filter out all other light sources except the one they want to use in their experiment.

When you change the **wavelength**, you change the color of the light. The wavelength ($\lambda$) equals the speed of light (c) divided by the frequency ($\nu$), or $\boldsymbol{\lambda = c / \nu}$.