



Uncovering the Secrets of Light

Hands-on experiments and demonstrations to see the surprising ways we use light in our lives. Students will also learn how engineers and scientists are exploring new ways in which the colorful world of light can impact our health, happiness and safety while saving energy and protecting the environment.

Activities (Have each activity checked off by an ERC student when you have completed it.)

1. Turning on an LED by connecting it correctly to a battery.
2. Optical Communication – Using LED flashes to remotely control electronic components such as televisions and to give music a ride on a light beam.
3. Observing the colors produced by different sources of light.
4. Light Saber – A discharge lamp that shows us that we are conductors just like wires and that can magically turn on a special kind of lamp without touching it.
5. USB Microscope – Using light to see small things, especially how displays work.
6. Pulse Width Modulation – Controlling light by turning it on and off. Bright light comes from having it on more than off.
7. Theremin – A musical instrument that is played without touching it.
8. Flat Panel Displays – What is polarized light and how do we use it to make TV and computer displays?
9. Magnetic Levitation – Using a light beam and a magnet to make a ball float in space
10. Coin Flipper – One magnet makes another magnet with the opposite pole so they can rapidly repel one another.
11. Color Mixing
12. Observing Audio Signals with the Mobile Studio.

Your Name: _____

Today's Date: _____



LED Circuit: Making Light with Electronics

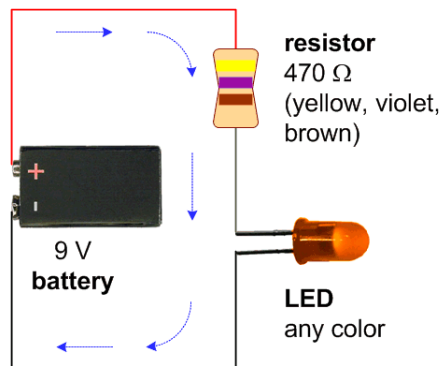
Components:

- LED (Light Emitting Diode)
 - Resistor
 - Wires
 - Battery
- We will now make a solid state light
 - Such a light could be used to send flashing signals
 - This is what traffic lights (red, yellow, green) are made from these days



The Light Emitting Diode is an electrical component. To operate it requires electricity to power it. For our experiment, we will get this electricity from a 9Volt battery

For this activity, you have a bag of parts and a protoboard. First, we will build a simple configuration that lights up an LED. The circuit we will build is discussed on an excellent website for projects. <http://www.robotroom.com>

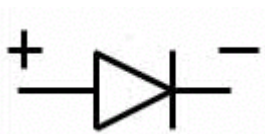


1. Using the protoboard, the LED and the current limiting resistor, build the circuit shown above. Include the wires you will use to connect to the 9V battery, but do not connect the battery.
2. Have your circuit checked. If it is OK, connect the battery to the battery wires. Your LED should light up.

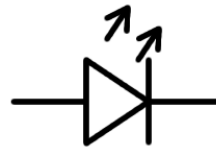


If your LED does not light up, remove it and insert it in the other direction. If it does not light up, you will need some help to troubleshoot your circuit.

- LEDs only permit current to flow in one direction because they are diodes. Diodes work like a flapper valve which only allows water to flow in one direction. There is a flapper valve in the bottom of the tank that feeds water to a toilet, for example. Incandescent bulbs are not diodes, but are just resistors that get sufficiently hot to give off light. This makes them quite inefficient. To see that an incandescent bulb can also work with a 9V battery and in both directions, use one of the 12V bulbs provided with pigtail wires attached. Since the alternating current (AC) power provided to these bulbs has voltages that alternate between +12V and -12V 60 time per second, this shows that an incandescent bulb will stay on essentially all of the time. If they were diodes they would only be on when the current flows in the right direction. The circuit symbol for a diode and an LED are quite similar.



Diode:



LED:

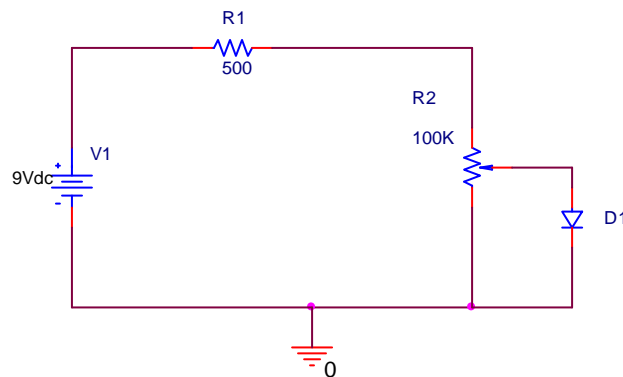
Note that the current flows to the right in both cases. The small arrows on the LED indicate that light is emitted when the diode is on.

- Also, you can add a second LED to your circuit. First try connecting them in parallel and then in series. Do they both light up? Is one brighter than the other? Describe what you did and what you observed.

If you look over the descriptions of LEDs on Wikipedia http://en.wikipedia.org/wiki/Light-emitting_diode you will find that it generally takes a higher voltage to turn on LEDs at the blue end of the visible light spectrum than at the red end of the spectrum. This is because the blue end is higher energy than the red end. Thus, when you connect two diodes in parallel, the lower energy LED should be brighter, sometimes to the point of keeping the other one off completely.

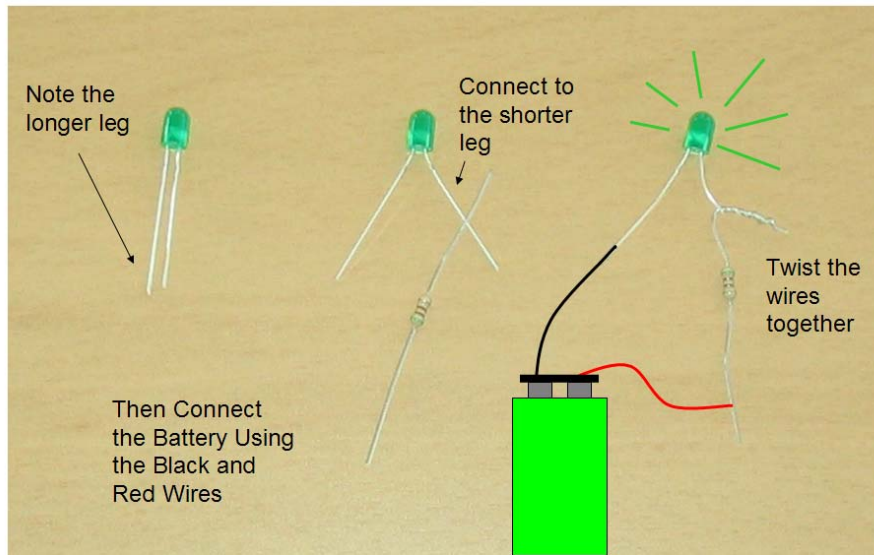
We will now modify the circuit slightly. First, return to the circuit configuration with only one LED.

- Now we will add a potentiometer to the circuit so that the intensity of the light can be controlled. Disconnect the diode from the resistor, place the diode across one half of the potentiometer and then connect things as shown below. Your LED should light up again. If not, turn the knob and it should. This configuration shows us one way to control the intensity of the light from the LED. Unfortunately, it is not a very efficient way of doing this, just simple and inexpensive.



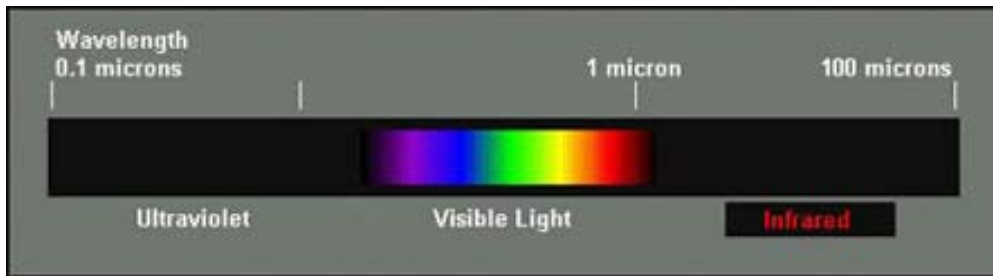
Note: The parts distributed to you during the day are yours to keep. We need the protoboard returned to us, but you will still be able to make the LED light up at home by following the instructions found below.

First, connect the LED and the resistor, by twisting the wires together.



To light the LED, touch the metal ends of the black and red wires to the resistor and diode. This should cause the light to turn on. Again, if the LED does not turn on, try connecting the wires in the other direction.

Optical Signals: Using light to control the operation of televisions, etc. and to send music through the air.



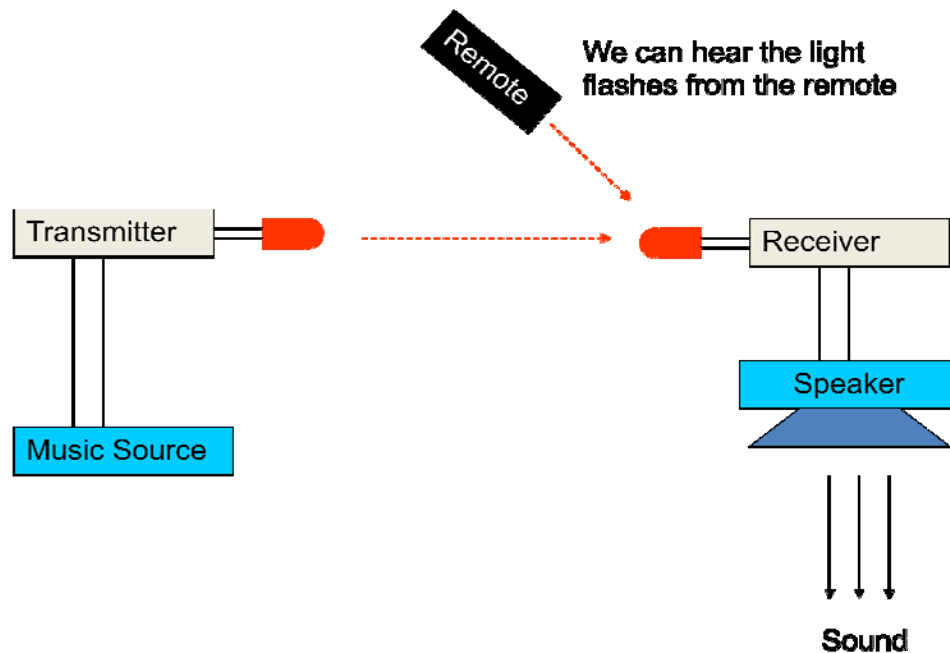
Infrared Light – What is Infrared Light? It is light beyond red that is not visible to us. IR is given off by hot things. (There is also ultraviolet light that is beyond blue. UV light gives us sun tans.) What do we know about IR light?

- Cannot be seen by humans
- Can be seen by digital camera
- Remote control sends IR light flashes to TV or any other device it is to control



Pushing a button on a remote control causes a particular sequence of light flashes to be sent to the TV or other device that is being controlled. The flashes are like a secret code that only the TV can understand and that we cannot see.

1. Using any available remote control device and a video camera, aim the remote at the camera and observe the light flashes. Can you tell the difference between the flashes sent by different buttons? (Usually not – only the main flash can be seen. The individual flashes occur too fast to be seen by humans but the TV can tell the difference.)
2. Using the same remote control device, aim the remote at the receiver circuit for the audio transmitter and receiver combination (diagram on the next page). The device that receives the IR signal is a photo diode (it looks like an LED). You should be able to hear the pulses of light given off by the remote. Can you describe what they sound like?



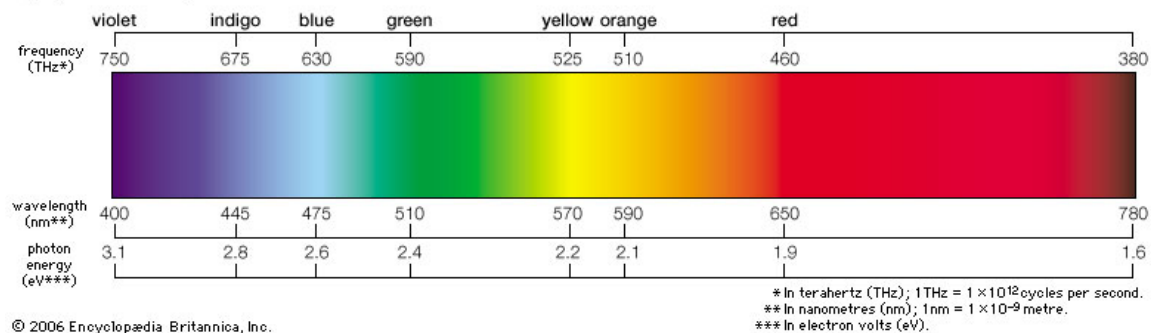
3. In the last step, you have tested the receiver. If you detected the sound produced by the remote, your receiver is working. Now you are to set up the music source and transmitter. Using a music source like an iPod or the audio output from the computer, connect the input cable for the transmitter to the music source. Making sure that the LED on the transmitter is pointing directly at the photo diode receiver (looks like an LED), turn on the music signal from the music source. You should be able to hear the music from the speaker connected to the receiver.
 - a. Block the light from the transmitter to the receiver. The sound from the speaker should stop.
 - b. Move the transmitter and receiver apart. The sound should become weaker.
 - c. Aim the transmitter so it does not send a signal to the receiver. The sound should go away.
 - d. Use the optical fiber to direct the light from the transmitter to the receiver. That is, place one end of the fiber by the transmitter LED and the other end by the photodetector. You should be able to hear the music again.
 - e. Re-align the transmitter and receiver and cover the entire experiment (transmitter and receiver) with some kind of material that blocks the background light from the room or turn the room lights off. The sound should become stronger. This is because the photo diode senses the increase in light due to the signal from the transmitter. If the room is too bright, it has a hard time seeing the light.

Other Sources of Light: Observing the colors that make up light

Light is made up of all the colors of the rainbow from blue to red. To be able to see the individual colors that make up sunlight, for example, we can use a simple device called a spectroscope. In the picture below, the spectroscope looks like a very small telescope. However, unlike a telescope, it has a small slit at one end that separates the colors into a display that looks like the visible spectrum below.

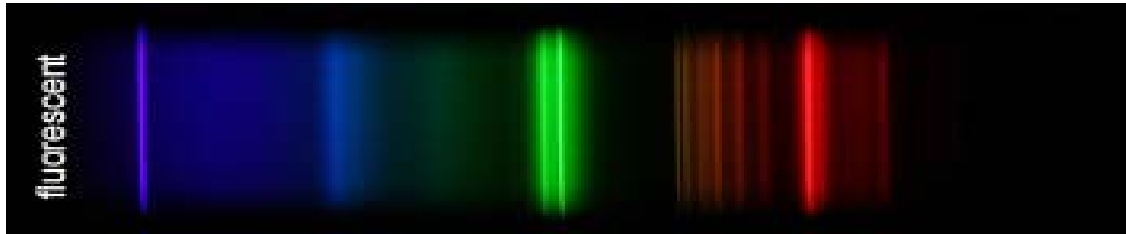


Light, the visible spectrum

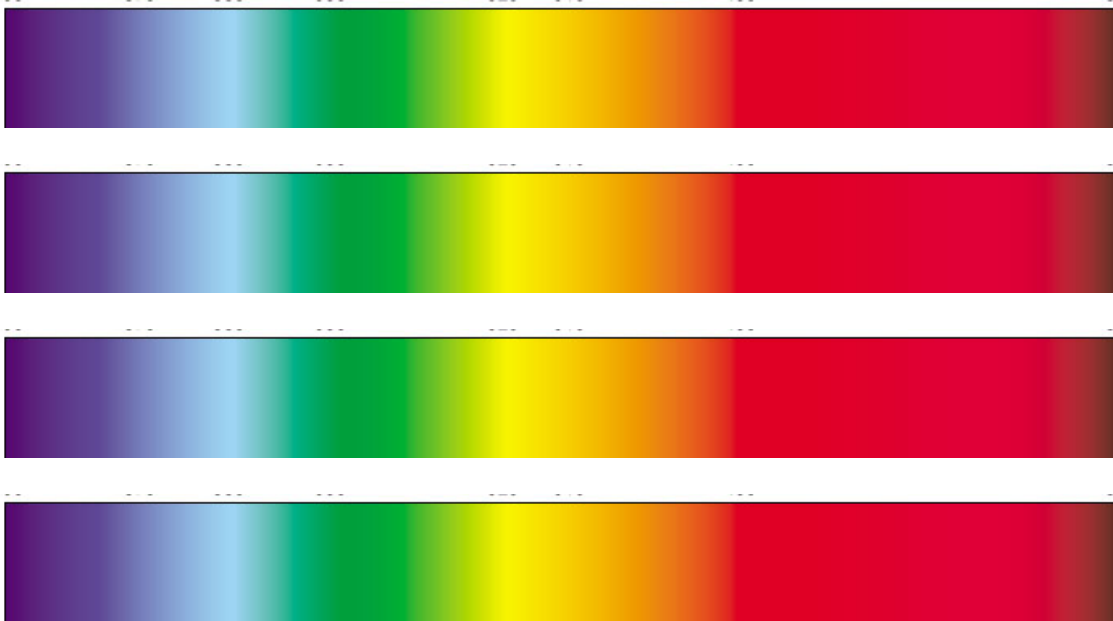


1. Before we use the spectroscope to look at the kind of light sources made by humans, we should first look at the light from the sun. Go to the nearest window and look out the window through the spectroscope. You should observe something like the picture above (just the colors, without all of the numbers).

2. Next, observe several artificial light sources – fluorescent lamps, the light from a computer monitor, light from an LED. Note that the light you observe will look different than sunlight because there are bright lines that stand out in the spectrum. An example is shown below, where a type of fluorescent lamp is seen to have many bright lines. The lamps in the classroom will probably not produce this same pattern.



Observe at least two different light sources in the classroom and then (if you have time) show where you observe the brightest lines by sketching them on the spectra below. If possible, it is a good idea to turn off most other light sources in the room and to have both members of your group observe the light pattern before you sketch it.

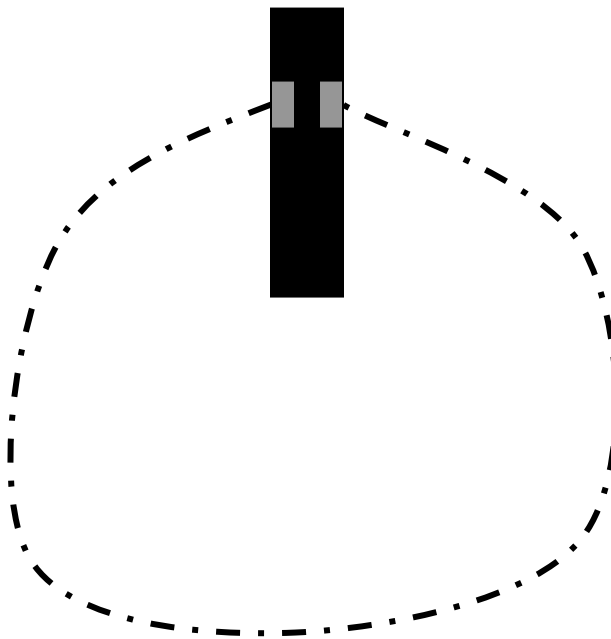


Light Saber – A discharge lamp that looks like the light saber from Star Wars

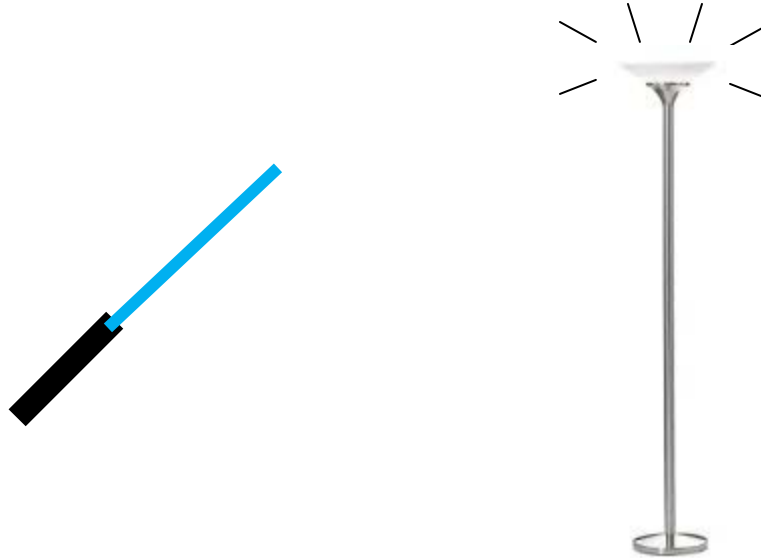
In this device, a light beam is caused to move up a glass tube when the person holding the handle connects the two metal contacts with their thumb or finger



To make this more interesting, and to show that we are all good electrical conductors, each group of six will all hold hands and form a circle with the people at the end each making contact with one of the metal contacts. The length of the light beam is determined by how good the contact is, so having many people in the loop will probably make the beam rather short.



Each student should, thus, try to turn the beam on by themselves and then see if it is longer or shorter. The red beam is neon and the blue beam is argon. Once the beam is as bright as possible, it can be observed through the spectroscope.



Bring the light saber close to the floor lamp without touching it. About one meter of separation is good. Turn on the light saber and you should also see the floor lamp turn on. This happens because the lamp is electrically very noisy and the floor lamp is a touch lamp. Touch lamps turn on when you touch them because you are acting like an antenna and you pick up electrical noise from the air. To act like an antenna, you must be a conductor, but we have already shown that we are conductors by holding hands and turning the light saber on.

Extra Activity – To see what kind of a conductor you are, use the DMM to measure your resistance. Hold the tips of the mini-grabber connectors between your thumb and index finger on each hand. Write down the value of the resistance of the members of your group.

USB Microscope – Using a smart lighting, computer-based microscope to see small things.



The USB Microscope is capable of seeing some very small images with and without the illumination provided by an array of several LEDs. When using the microscope, try images using room light alone or light from the object being imaged in addition to light from the array. It should be possible to appreciate the smart nature of the imaging control since you will be able to see the device adjust for the light source. For each of the imaging activities below, describe how you set it up and what you observe.

1. Begin with a classic imaging exercise and observe both sides of the US penny and count the number of images you can find for Lincoln.
2. Next, observe one of the clear LEDs you have been using in your circuits. You should look at it from the side (as in the image above) and from the top (if the LED is on, the light would be shining directly into the microscope). Your goal should be to better understand the internal structure of a standard LED. This should be done with the LED off. However, once you have completed this, power up your LED and see if you can observe it using only the light produced by the LED. You will have to make it very, very dim or it will wash out the image. This requires the use of the potentiometer or the PWM setup. Note – this is difficult to do, so do not spend a lot of

time working on it. Your goal should be to get an idea of where the light is emitted from the LED.

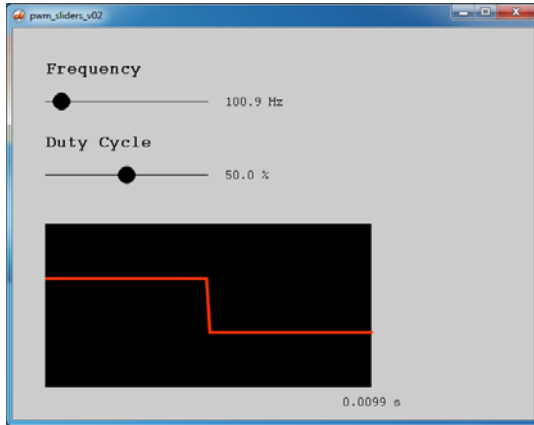
3. Using the LED array, observe the spinning top with the diffraction gratings on its surface (these produce the rainbow colors).
4. Using a display device (the LDC display on your computer, the display on your cell phone or MP3 player, etc.) try to expand the image sufficiently to see the individual pixels in an image. Look at a region that displays as white, red, green and blue if possible.
5. Observe some part of the Mobile Studio circuit board.
6. Observe some part of your body – hair and skin can both be interesting.
7. Once you have completed the tasks above, try imaging something else. Use your imagination.

Some of the objects imaged:



Examples of images taken with this USB microscope can be found at <http://hibp.ecse.rpi.edu/~connor/SmartPowerandLight/Dino%20Images/>

Pulse Width Modulation – How we fool our eyes into seeing different brightness while turning an LED on with exactly the same intensity. Also, how to mix colors to make a new color.



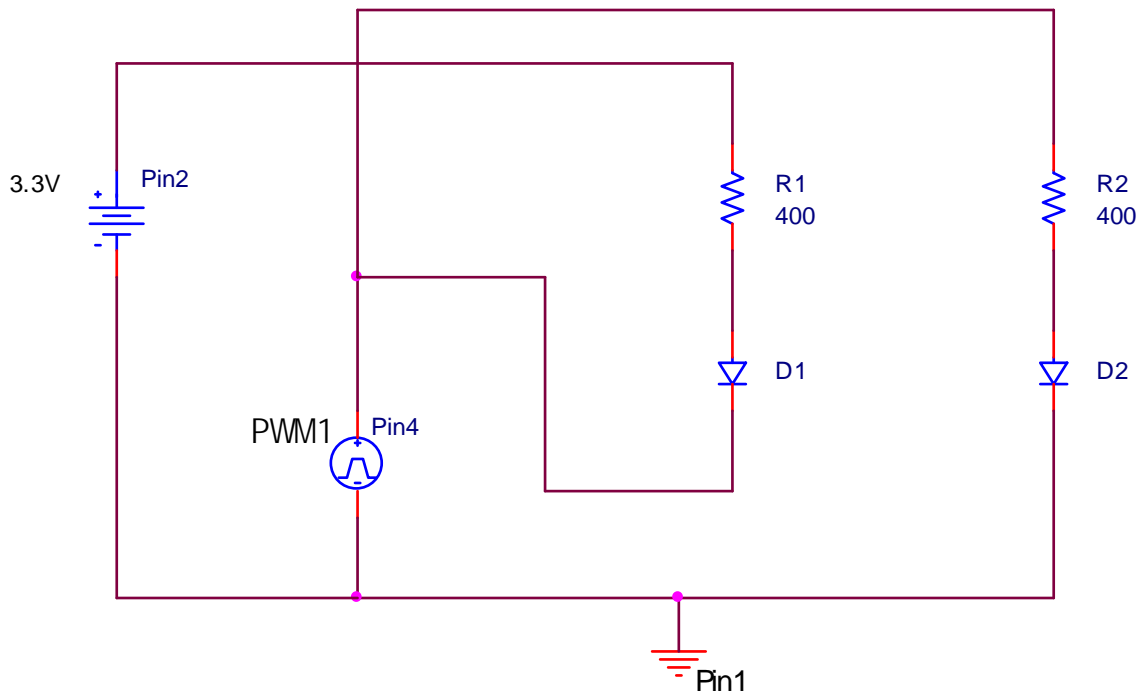
In this activity we see how we can flash an LED on and off to make it look bright and dim. The light is pulsed. The longer the on pulse and the shorter the off pulse, the brighter the light. Try different pulse widths to see this effect.

Also, if the light flashes more than 30 times per second (30Hz) we cannot see the light flash. Our eyes do not respond fast enough. To see the light flash, slow it down to 10Hz or less (1Hz is best) and you will see the light does indeed flash. Also, you will see that the two LEDs flash alternately so that when one gets brighter the other gets dimmer.

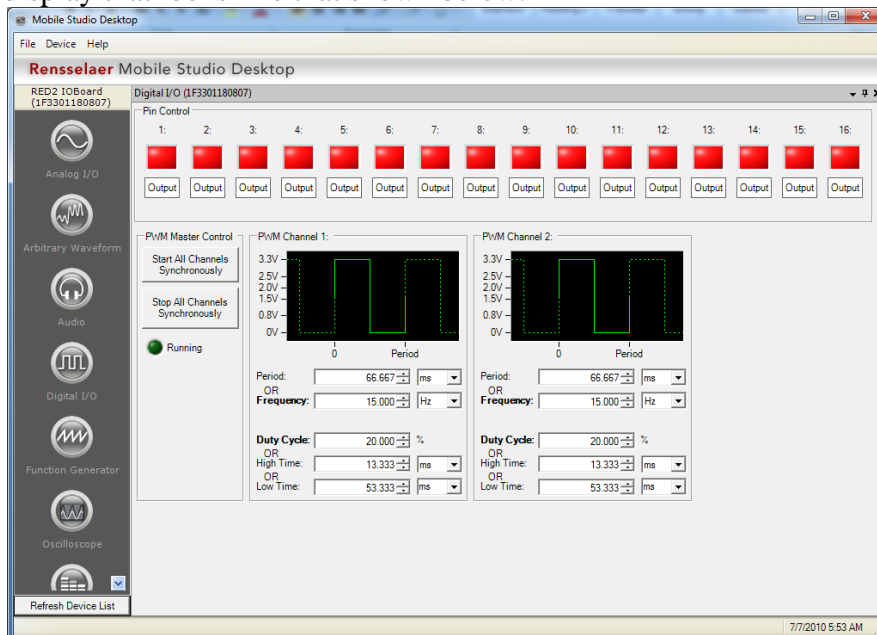
Movies and television images appear to move smoothly because they flash faster than we can see.

If the PWM Slider executable is not already installed on your computer, download it from <http://mobilestudio.rpi.edu/Downloads.aspx> You will find it at the bottom of the page.

Build the two LED circuit on your protoboard rather than connecting the LEDs directly to the Mobile Studio Board as shown above. You will need two LEDs and two current limiting resistors (the ones you used in earlier activities). You will also need 4 jumper wires. In this circuit, D2 will turn on whenever the PWM1 voltage is high and D1 will turn on whenever the PWM1 voltage is low. Thus, the LEDs will alternate being on and will have complementary duty cycles. When the duty cycle for PWM1 is large, the duty cycle experienced by D1 will be small.



1. Verify the information provided above by trying different frequencies and duty cycles. You should be able to observe that this is an effective way of mixing colors.
2. Once you have explored the various operating conditions with the PWM Slider executable, repeat using the Mobile Studio Desktop. That is, close the PWM, open the Mobile Studio Desktop and click on the Digital I/O option. You should see a display that looks like that shown below.



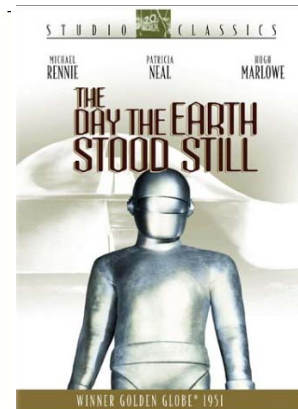


- Click on 'Start All Channels' and then adjust the parameters of the pulse width modulation. You will have much more precise control of conditions this way so you should be able to better determine how fast you can see the LEDs flash, for example.
3. If you have time, you can connect an LED with its current limiting resistor to one of the digital I/O pins and to the digital ground. Then you can turn the LED on and off with by clicking the corresponding button (green is on).

Note that in this activity, the ground is the digital ground, which is the first pin next to the earphone jack on the digital side of the board. This is labeled on the RED2 board but not on the plastic cover. It is best not to mix the digital and analog grounds on the Mobile Studio Board.



The Theremin – Maybe the strangest musical instrument ever made

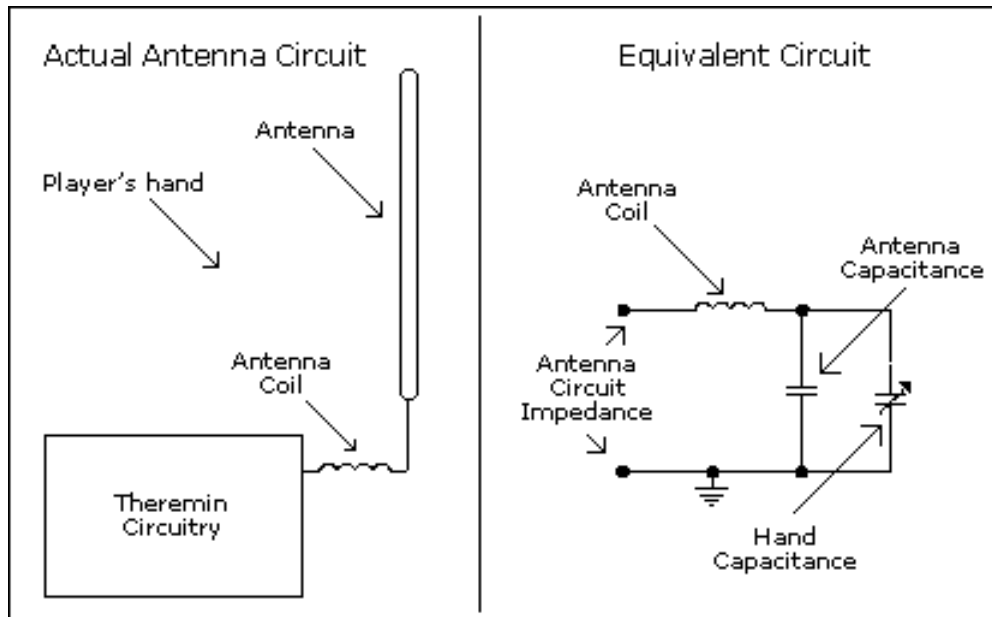


In this activity we learn how sensors, like airport metal detectors, can sense that we are nearby. You can control the volume and pitch of this musical instrument by bringing your hands close to two metal electrodes. When you do this, you become part of the electrical circuit (a capacitor, actually), which changes the way it operates. In an airport metal detector, any metallic object you have will change the inductance of the circuit, but otherwise the effect is the same.

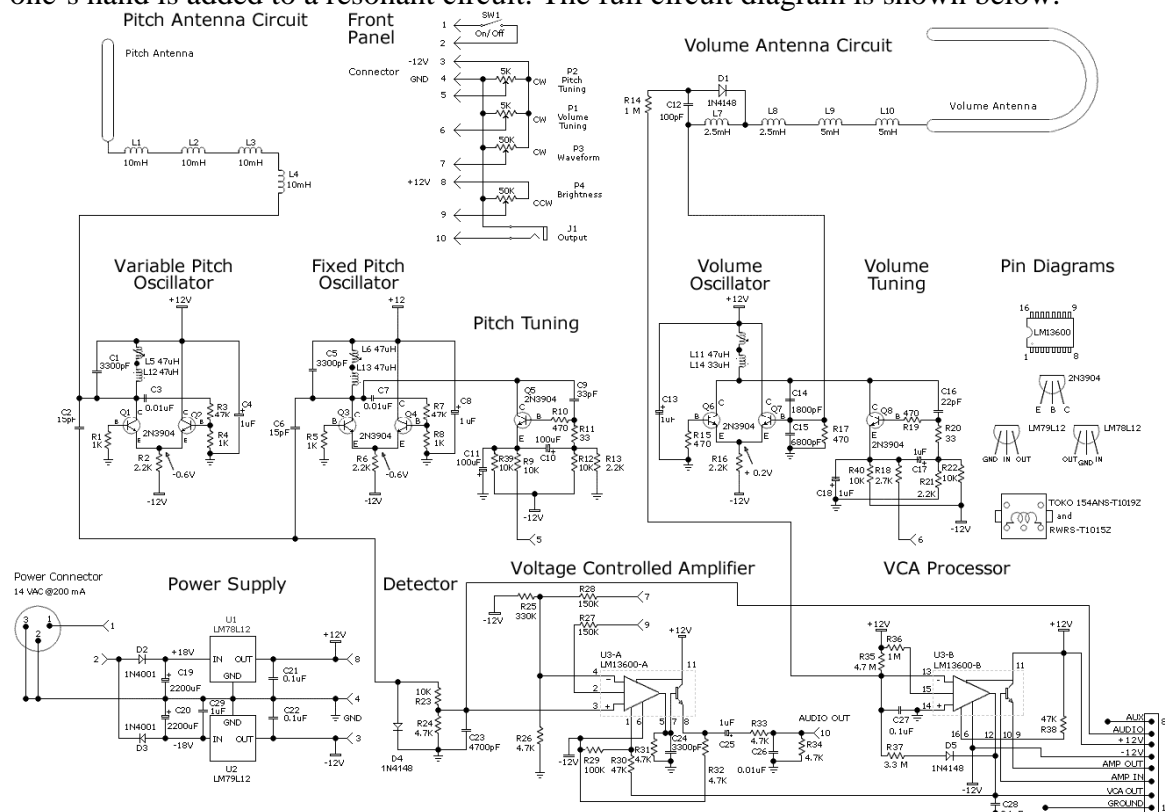
This instrument works by creating a beat frequency between two pitches that are too high for us to hear. (They are a little less than 300,000Hz) The difference in pitch is very small, so we can easily hear it.

Instruments similar to this are used by many music groups. It is also used in science fiction movies to make weird and scary noises.

1. The left electrode is volume control and the right electrode is pitch control. Your first task is to explore the sounds you can make with this device, how close you must be to the electrodes, etc. Basically, just have fun with it and then write down a description of your experience.
2. This device works by adding capacitance to the circuit by placing our hands near the electrodes. Any two conductors make a capacitor. In this case, our hands are one of the conductors and the electrodes are the other. Given the expression shown on the next page for the frequency of the oscillators in the circuit, can you determine how much we have to change C to increase this frequency by 1000Hz so we can hear a tone of 1000Hz?
3. Go online and look for information on the Theremin. Definitely look at YouTube to watch a video or two of people playing this interesting instrument.



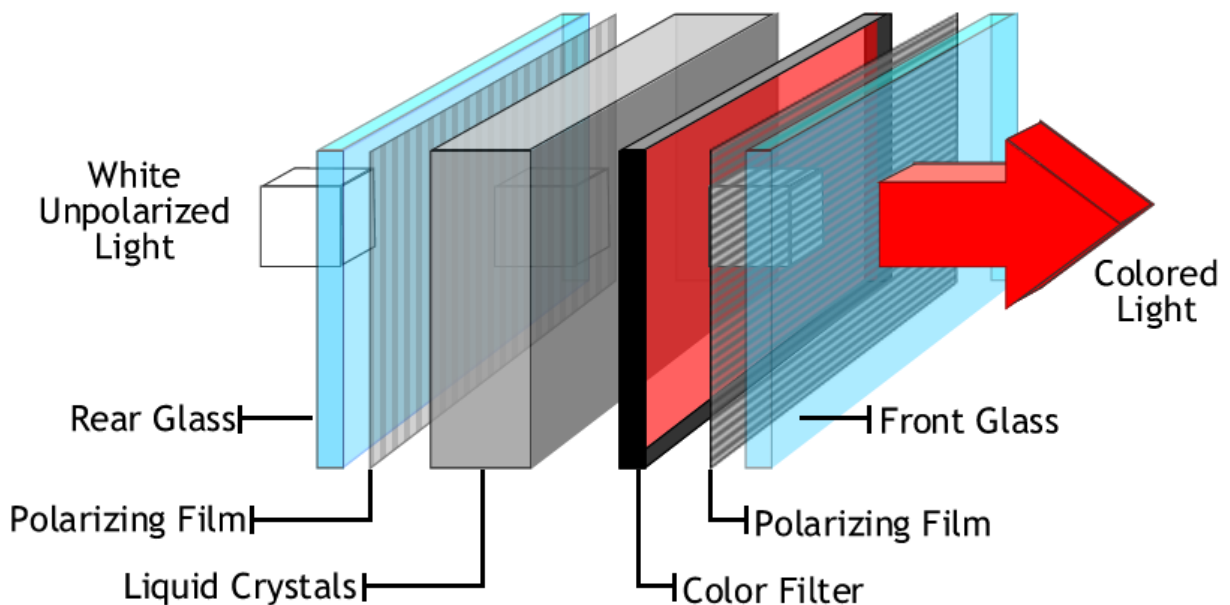
Shown above is the basic idea behind the Theremin, where the capacitance from one's hand is added to a resonant circuit. The full circuit diagram is shown below.



The circuit resonates at a frequency given by

$$f = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{(94\mu H)(3300pF)}} = 286kHz$$

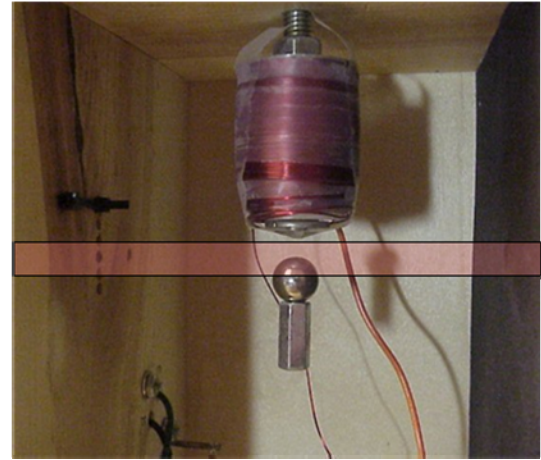
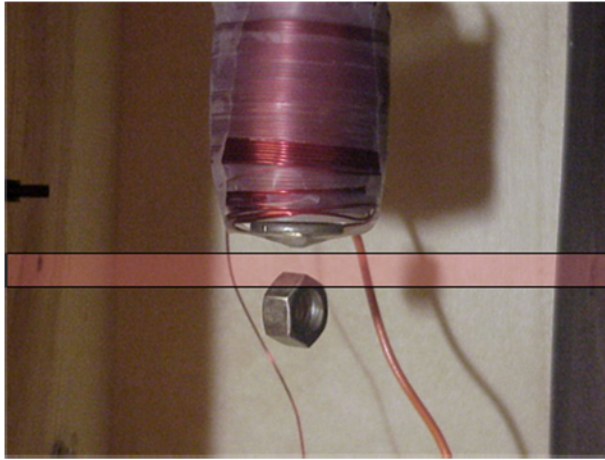
Flat Panel Displays – How polarized light allows us to make Liquid Crystal Displays Work.



LCD displays use light polarizers like the ones we use for sunglasses and 3D displays to turn small dots of colored light on and off. To see that there is a polarizer in such a display, place a polarizing filter over a flat panel display and rotate it until the image goes away. Also use two filters to see the same effect.

Describe what you observe when you place the polarizing filter over the LCD display on the computer you are using. You will have to rotate the filter. Discuss the operation of LCD displays in your group and with one of the ERC students.

Magnetic Levitation – Using a light beam and magnet to make a ball float in space



- Close up photos showing levitation of washer and ball bearing with magnet attached. Some preferred orientation is necessary for stability.

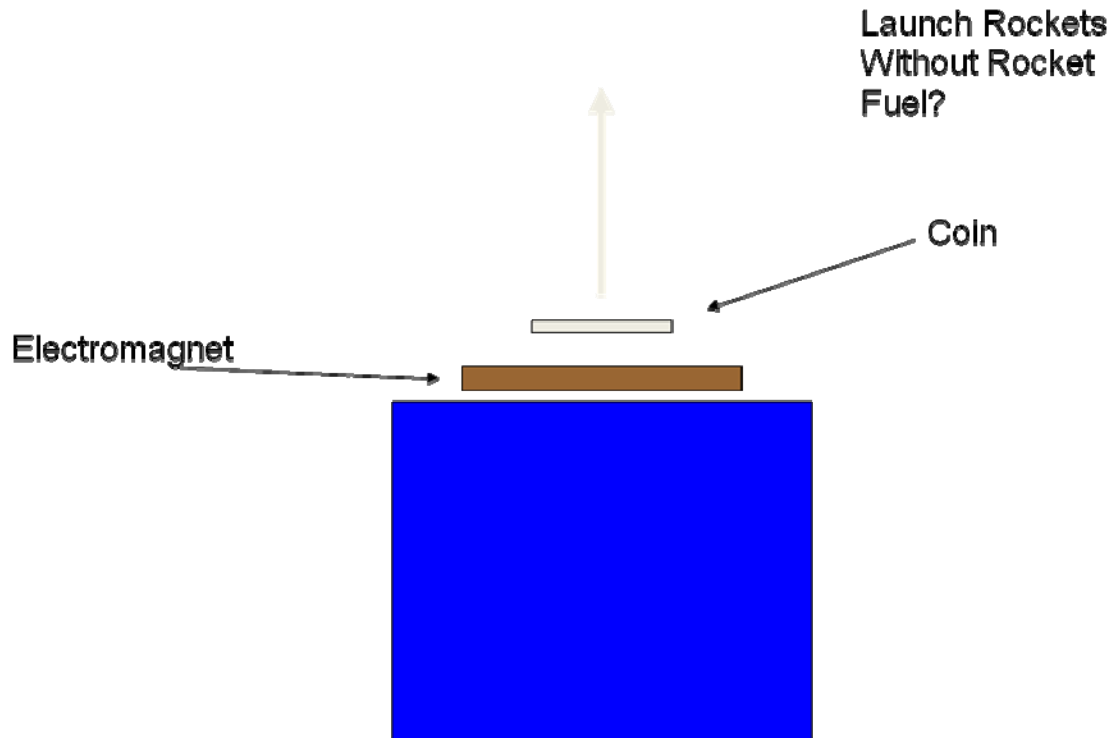
An invisible (IR) light beam 'sees' where the object is and tells the magnet how powerful it has to be to hold it in place.

In this activity, you should try to get the magnet to levitate the ball. Remember that you have to keep your fingers out of the beam of light, otherwise you will block the light sensor and the system cannot work. This is an example of a smart system that can do a job for us without us doing anything, at least once the ball is floating. The light beam is IR so we cannot see it, but we can definitely feel the magnet once the light beam tells it to turn on.

1. How much of the IR beam do you think you blocked when you succeeded in getting the ball to levitate?
2. Use another light source to see if you can interfere with the IR beam. Be sure not to block the beam, only try to increase the background light signal in some way.
3. Using any other magnet (permanent magnet, electromagnet), try to suspend a magnetic object below it without touching the object. Is it possible to do this if you cannot independently control the strength of the magnet?
4. This is an example of negative feedback. Can you identify at least one other example of negative feedback in some every day device? You may want to look online for some ideas.

Activity #10

Coin Flipper – Using one electromagnet to repel another



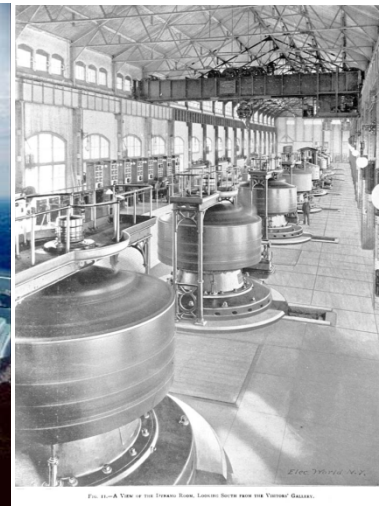
In the maglev activity, we saw that a magnet can put a force on a ball that pulls the two objects together. There is a second kind of magnetic force that pushes things apart. The second force happens when one electromagnetic makes currents flow in another conductor (called eddy currents). The current in the second object also forms an electromagnet, but with its poles pointed in the opposite direction. Since north poles repel north poles and south poles repel south poles, the two magnets will repel one another. There is sufficient force produced to launch objects at high speed. In this case, we launch coins and similar disk shaped objects. Also required for this force is that the disk be a very good conductor but not magnetic. If it is magnetic, it will be both attracted and repelled and little will happen.

We can measure the speed of the coin using light, but that is not yet included in this activity.

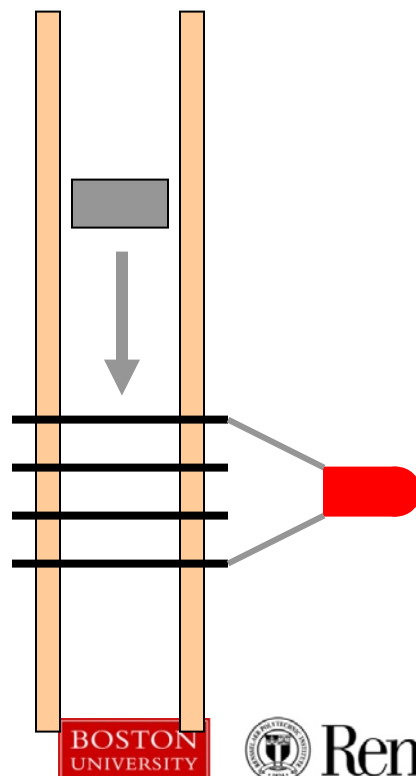
1. Try several different coins and other conducting objects. Which ones were launched the best (fastest, farthest, etc)? Which ones did not move much at all?
2. Launch a ping pong ball using a copper ring. Obviously, it is the ring that is being launched and it transfers its momentum to the ball by pushing on it.

Using Light to Show Motion – Moving Magnet Makes Light

If we drop a strong magnet down a pipe and wrap a coil of wire around the pipe, we will be able to generate electricity. This is the same principle used by the big electrical generators at places like Niagara Falls. (The water going over the falls causes the magnets to move).



Drop the magnet down the plastic pipe and watch the LEDs light up as the magnet passes by.



Magnetic Braking

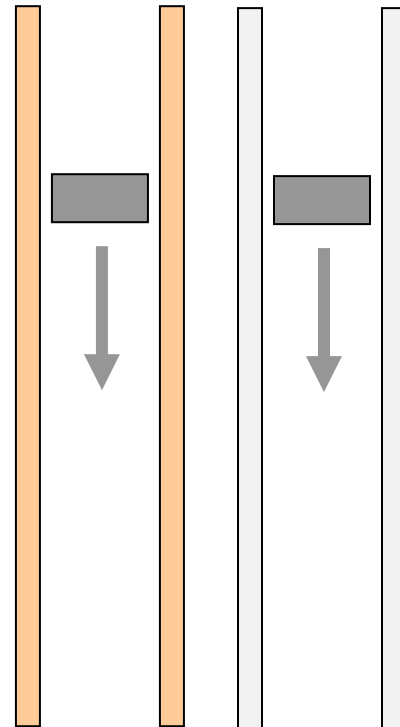
We have seen with the coin flipper and the magnet dropping through a copper coil, that a changing magnetic field can produce a current in a nearby conductor. For the coin flipper, the changing field occurs because the current that produces the field changes rapidly with time. The permanent magnet dropping through the coil has a changing field because the magnet itself is moving. In this exercise, we will observe the differences when we drop a magnet down a plastic pipe and a copper pipe. One will go rapidly and one will be quite slow.

1. Drop the magnet down the plastic pipe and measure the time it takes to fall from one end of the pipe to the other. There is a good online stopwatch to make this measurement at <http://www.online-stopwatch.com/full-screen-stopwatch/>. Calculate the time to drop and then compare it to your measurement. Drop it on the carpet to avoid making noise or damaging anything. From basic Physics:

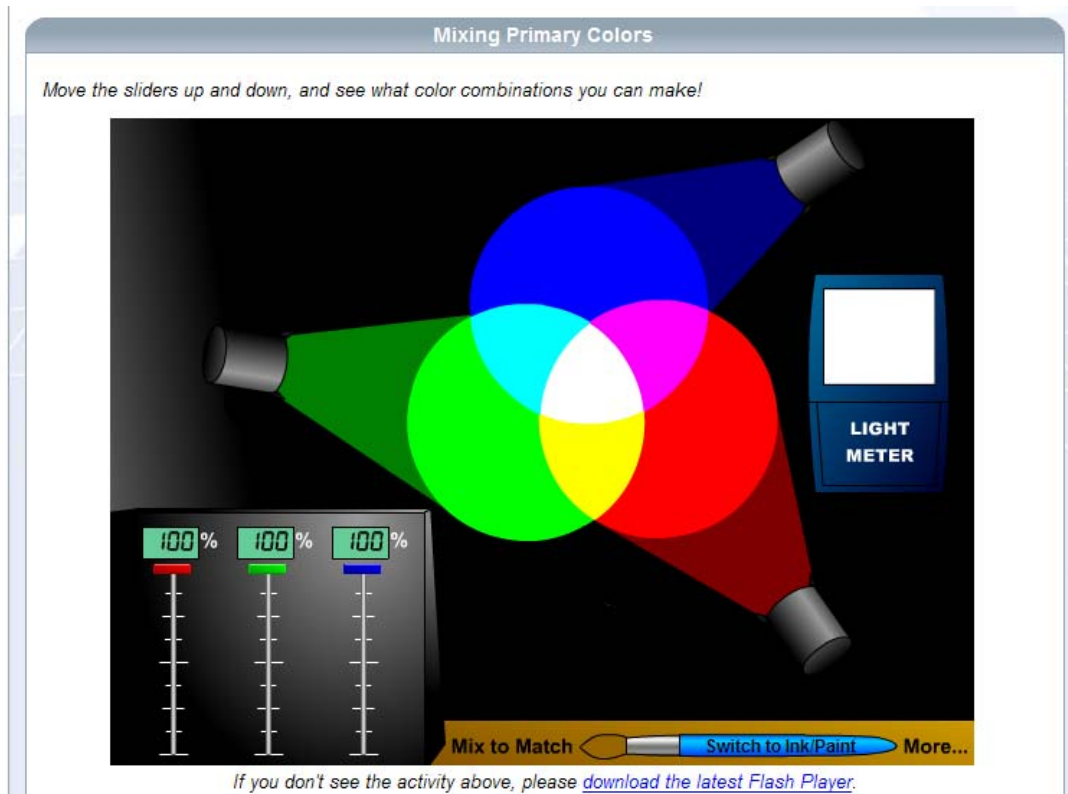
$$h = \frac{at^2}{2} = \frac{gt^2}{2} \quad \text{or} \quad t = \sqrt{\frac{2h}{g}} \quad g = 9.8 \text{ m/s}^2$$

2. Now drop the magnet down the copper pipe and measure the time.
3. Also try sliding the magnet on the copper plate.
Describe what you observe.
4. Now describe how you might use this effect to make a brake for a car or truck.

Copper pipe with strong magnet falling through it
Plastic pipe with the same strong magnet



Mixing Colors – White light is made by mixing red, green and blue light. To see this, go to the web site <http://www.omsr.edu/tech/colormix.php> where the following figure is found:



1. Once at this web site, the slider controls at the lower left hand corner can be used to increase or decrease the amount of red, green or blue light in the figure. With all three at their maximum intensity, they combine to make white light. Use the slider controls to see what colors you can make with red plus green, red plus blue, blue plus green, and all three.
2. Compare your experience mixing colors using this tool with what you were able to do with two LEDs and Pulse Width Modulation.



Observing Audio Signals with the Mobile Studio

If there is time, you can see how sounds look when they are observed as electrical signals. We have already looked at signals in the audio range, but now we want to start with something that is a recognizable sound. For this exercise, you will need a cable that connects from the audio (earphone) jack on the computer to the Mobile Studio Board. This has a standard plug on one end and three wires on the other. Connect one of the plastic coated wires to channel one on the scope (pin 1) and the other to channel two (pin 4). The uncoated wire is the ground so connect it to one of the ground points (pin 2). Now set up the Oscilloscope in the Mobile Studio to measure signals from A1 SE and A2 SE. Set the time per division to be 1ms. This you should change later on, but this is a good place to start. Start the measurement. If the signal is too large or too small, change the loudness of the signal from the computer and the voltage scale on the Mobile Studio until you see the signal clearly.

1. Observe the signals on the two channels (the two stereo channels for the audio) as the musical piece changes. You will note that it is not possible to hear the signal and measure it at the same time since the audio output from the computer is sent to the Mobile Studio.
2. The designers of the Mobile Studio (Don Millard and Jason Coutermarsh) realized that we would like to be able to hear signals while we measure them. Thus, they added another feature. Click on Audio, make sure it is enabled, then use either earphones in the earphone jack or a speaker connected as we did previously to hear the signal. You will have to be sure that the audio source is selected to be ADC1 and ADC 2 for the two channels.
3. Finally, download the smaller of the two files found at <http://hibp.ecse.rpi.edu/~connor/SmartPowerandLight/Audio/> which is a recording of the sounds produced by the TVBGone remote control which can shut off any TV sold in North America. Once you get that working, you can download the longer file, which has the complete signal from the remote. Now you can listen to this signal and watch it on the Mobile Studio. What kind of a structure do you see to the signal? Can you see how it is able to send coded messages to electronic devices like TV sets?

As usual, please write down your observations while you do this experiment.



Other Information

Example of IR remote image in digital camera



YouTube Resources

Showing the IR light from a remote.

<http://youtube.com/watch?v=Lf769YVZ7ME>

http://youtube.com/watch?v=U_UE3s9edVo

http://youtube.com/watch?v=WUF8_3uPNNU

What is Infrared? (from NASA)

<http://youtube.com/watch?v=2--0q0XIQJ0>

Examples of LED Circuits

<http://youtube.com/watch?v=eqId7g7SC10>

http://youtube.com/watch?v=Q4Oz_BXcbz0&feature=related

Light Displays

http://youtube.com/watch?v=9hjtd_eEmA (42000 holiday lights)

<http://youtube.com/watch?v=KZZC2NFukZA> (CN Tower in Toronto)

LED Traffic Lights

<http://youtube.com/watch?v=yAAbsy15OLo>

LED Light Bulbs

<http://youtube.com/watch?v=XTIgDq2a-1A&feature=related>

Interactive LED Coffee Table

<http://youtube.com/watch?v=IkmpIXd9Q90&feature=related>