

Optical Art Projects in Physical Science/Physics

J. Mark Schober, John Burroughs School, St. Louis.

Physics provides the tools for all visual art and music. Artistic expression requires the creative and skillful use of those tools. While our students are familiar with crayons to clay, the possibilities of polarization, diffraction and three-dimensional viewing may add some new tools to their palette.

You, of course, will determine how these activities may be useful in your teaching. However, here are some possibilities:

Use an art project as the basis for an inquiry activity.

1. Students can be introduced to the colorful images possible with polarizers and then set upon the task of determining how many layers of tape will produce a certain color and how the orientation of the polarizers and tape affects the color.
2. Students can be introduced to what diffraction gratings do to light. In the diffraction patterns they can determine how colors of light mix and how color filters affect light.
3. Students have seen 3-D movies, laser shows, video games, virtual reality devices, and Magic Eye™-type images. Creating images that can be viewed three dimensionally delves into geometry and perception.

Use the art project as a summary exercise.

1. In all three of these media, manipulating the images to create a desired effect requires an understanding of the physics involved. Having students create a project and then asking how they could change what they have created reinforces the connections between variables that the students have learned.
2. I assign students to do two things: First, use these new art media with a twist, possibly combining different effects. Then provide an explanation of the physics.

Special materials and sources:

Polarizing filters: Small filters can also be obtained by collecting old polarized sunglasses. Some 3-D movies use glasses with polarizing filters. The filters can be removed and put into slide mounts for student use. Edmund scientific offers 7.5" x 7.5" polarizers (#V37-350) for \$10.15 each. They also have a package of 20 two-inch square polarizers (#V41-168) for \$18.30.

Cellophane tape: Cellophane tape is hard to find in the age of magic tape (which doesn't work). I took a pair of polarizers to several stores until I found "Crystal Clear" by Moore Push-Pin company at an art store.

Diffraction grating film: Edmund scientific has a package of 15 diffraction grating slides (#V01-307) for \$15.50 or you can get two sheets of 12" x 6" diffraction grating film (#V40-267) for \$9.00 that you can cut and mount as needed.

You will find my explanations to be sufficient for many applications, although not rigorous or mathematical. If nothing else, I hope you will find my diagrams interesting.

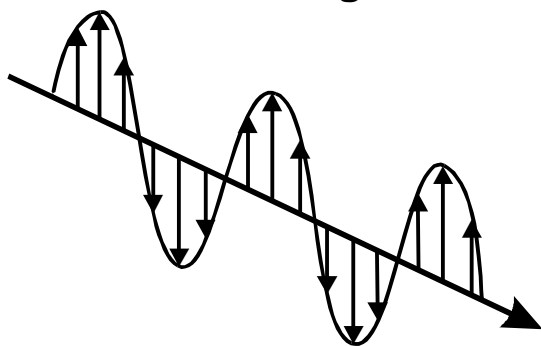
If you would like an electronic copy of this packet, send me an e-mail. You can edit the file if you have Microsoft Word 97. Other word processors may read the text but not the graphics. The graphics were created using Corel Draw 7.

Science Science

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NSTA Boston 1999. J. Mark Schober, John Burroughs School, St. Louis MO 63124. mschober@jburroughs.org

The Wave Model of Light



For the discussion of polarization and diffraction, it is helpful to have a mental picture of the wave nature of light. The diagram above could be used to represent the electric field of an electromagnetic wave. (The magnetic field wave is rotated 90° from the electric field but omitted from the diagram since it is not essential to this discussion.) The wave propagates in the direction of the large arrow at the speed of light. The length of the small arrows represents the electric field strength. Diffraction patterns show that light can add in intensity or cancel out, providing evidence for the wave model of light. Polarization provides evidence that light behaves as a transverse wave and not a longitudinal wave.

Polarization

The wave model of light suggests that the electric field of the wave is planar. Generally, light is randomly polarized which means that the plane of the electric field is different from wave to wave. Polarized light consists of many waves vibrating in parallel planes. Light can be polarized when passing through some crystals (such as calcite) or Polaroid material. Waves not aligned with the transmission axis are absorbed, while those aligned with the transmission axis are transmitted. In the diagrams below, the polarizer and analyzer are identical pieces of Polaroid material whose transmission axis is indicated by the dashed arrow.

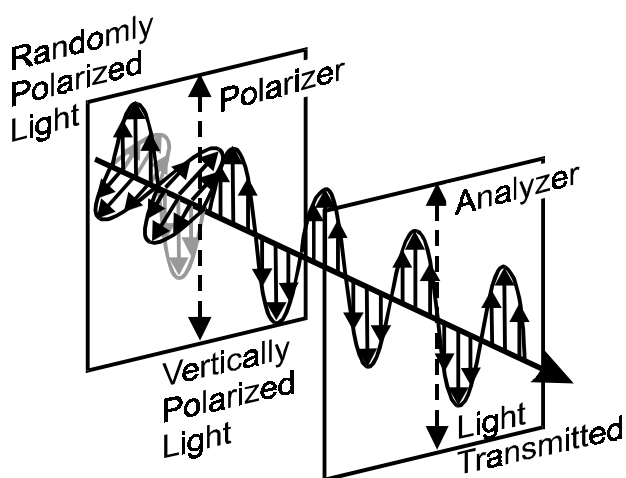


Figure 1.

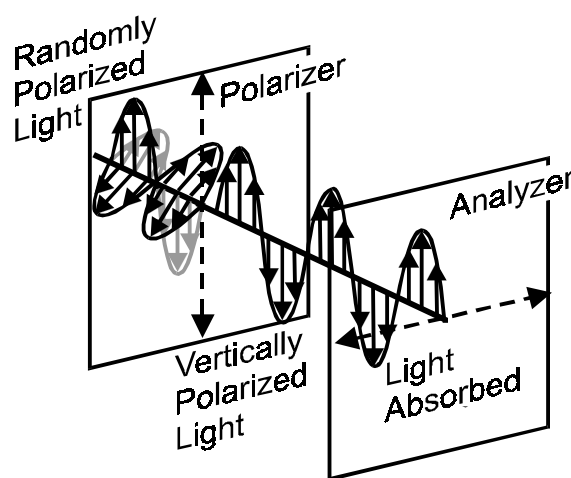
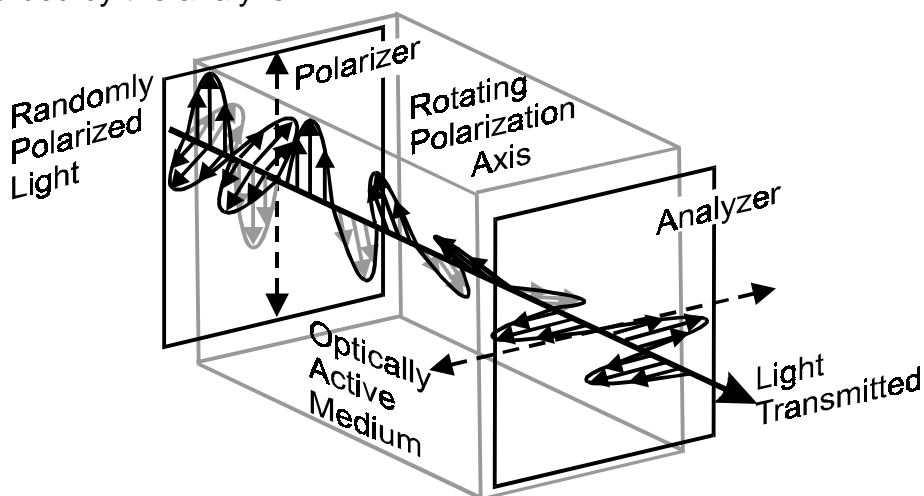


Figure 2.

In Figure 1, the transmission axes are aligned, and therefore transmission occurs. In Figure 2, the transmission axes are perpendicular and therefore light transmitted by the polarizer is absorbed by the analyzer.



Some materials are “optically active” or birefringent, both of which cause the polarization plane of the electric field to rotate¹ while traveling through the material. In other words, placing a piece of optically active material between two polarizers with perpendicularly oriented transmission axes will allow light to be transmitted.

Optically active materials tend to be organic substances. For example, dextrose (corn syrup) is named for the fact that it rotates the polarization of light in a right-handed twist (clockwise). Most clear brittle plastics, cellophane plastic wrappers and celluloid tape are birefringent.

In the experiment described above, a fascinating result is that color is visible. The amount of rotation in an optically active material depends on color (wavelength). Shorter wavelengths tend to rotate more than long wavelengths do². The result is that some colors are rotated enough to be transmitted, while others are rotated enough to be absorbed. We therefore see some colors but not others.

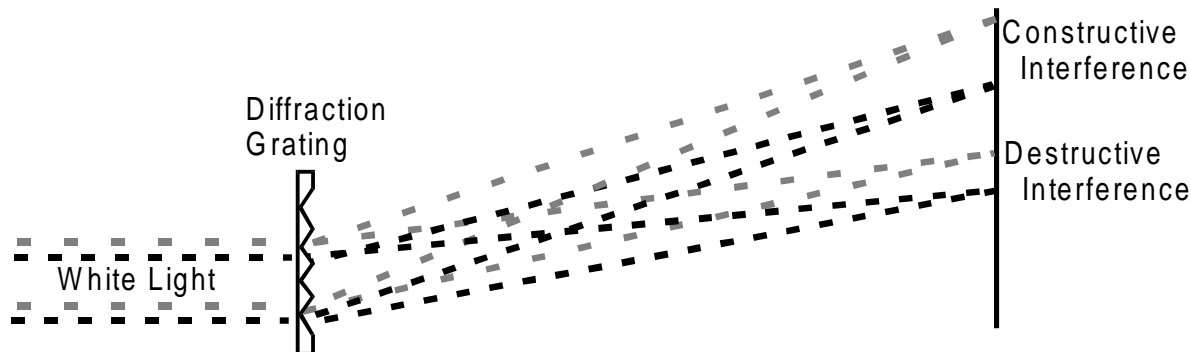
An application of this principle is seen in color laptop computer screens. A light source at the rear of the screen emits randomly polarized light which passes through a polarizer and then through optically active liquid crystals. The liquid crystals can be reoriented by adjusting the strength of the electric field across the pixel. The orientation of the crystal determines the rotation of the light, and a final polarizer will only transmit those colors that have rotated into alignment with the transmission axis.

¹ The polarization “rotation” actually involves a more complex explanation, outlined here. The cellophane polymers are oriented parallel to the length of the tape. Light polarized parallel to the polymer molecules travels more slowly than light polarized perpendicular to the molecules. The tape is birefringent since it has different indices of refraction for light polarized perpendicular and light polarized parallel to the tape. With the parallel component of the incoming wave traveling slower than the perpendicular component, the wave crests shift relative to one another. When light emerges from the tape, the superposition of the components results in a new plane of polarization. The effect, however, is the same: the polarization plane has been rotated.

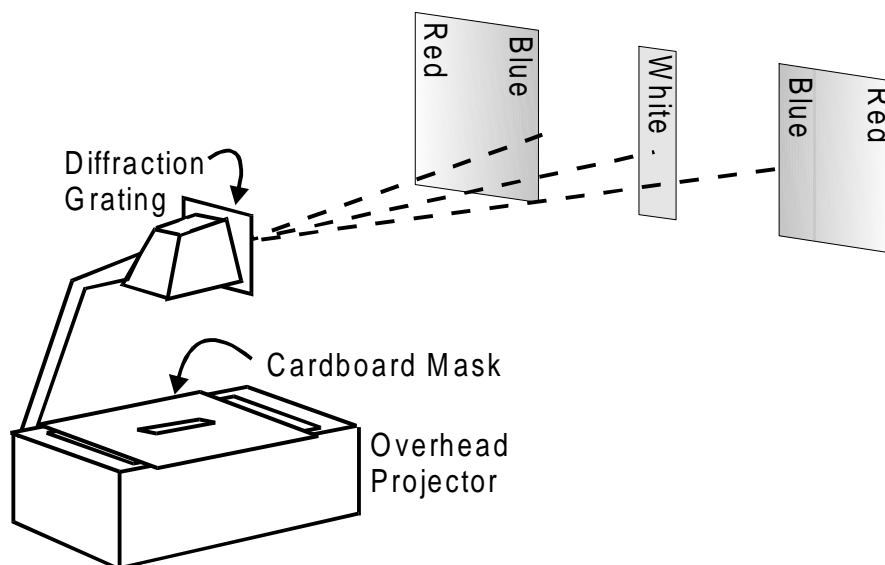
² The reason is closely tied to the first footnote. Shorter wavelengths like blue tend to travel more slowly in matter (and refract more) than longer wavelengths because they interact with the medium more. (There are exceptions when the light frequency is near the resonant frequency of the medium.) The difference in parallel and perpendicular component speeds is exaggerated, and the polarization rotates more.

Diffraction

When waves pass around or through a boundary they diffract, or spread out. A diffraction grating consists of a large number of evenly spaced parallel grooves. At each groove the colors of light spread in all directions and interfere with one another. Due to the geometry of the light rays, destructive interference results nearly everywhere. Only at a certain angle for each color will constructive interference result.



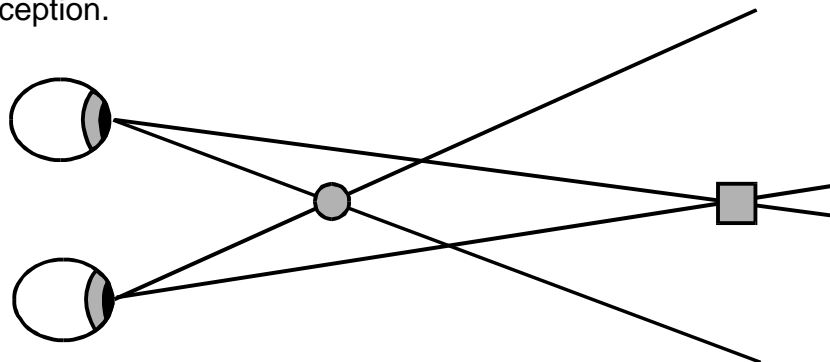
The diagram above illustrates key diffraction ideas. The white light approaching the diffraction grating from the left is comprised of many different colors, each with a different wavelength. Only two different wavelengths are shown here, where each dash can be taken to represent a wave crest. The waves spread after passing through the diffraction grating so that each color hits the screen everywhere (again, only a few representative light rays are shown). However, in most places the wave crests are out of alignment and destructive interference results as illustrated in the diagram. Only at a special angle for each color do the wave crests line up to form constructive interference. Also note that shorter wavelengths (such as blue) constructively interfere at smaller angles than longer wavelengths.



The diagram above illustrates the setup for observing diffraction effects. Cutting different shapes into the cardboard mask (which can also be made from construction paper or manila file folders) can allow the rainbow of colors to overlap so the colors of light mix.

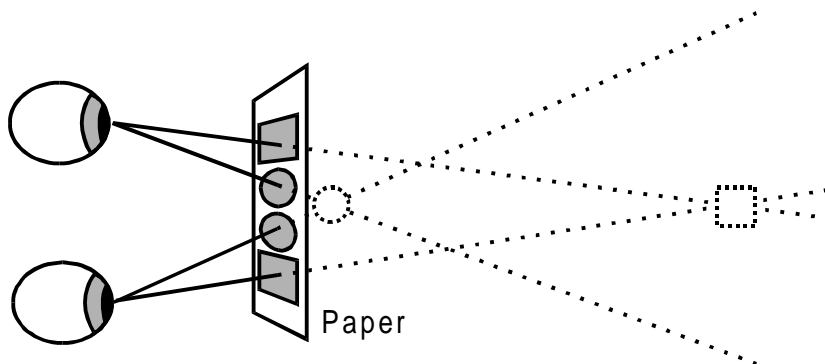
3-Dimensional Images

Please note: All sighted students can see and appreciate the polarization and diffraction art, but not everyone can see the 3-D images. Students with uncorrected differences in visual acuity between eyes and students with unequal eye muscle control (lazy eye, for example) tend to have difficulty seeing the 3-D effect. In addition, there are generally students who cannot see the effect for unknown reasons, although some viewing techniques presented here may help. Students who cannot see the 3-D effect can do the parallax activity included at the end of this section which uses other visual clues to aid depth perception.



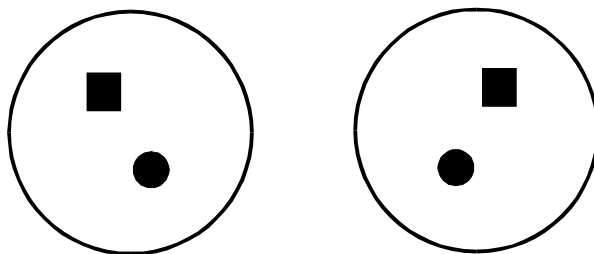
We learn from an early age how to connect the convergence of our eyes to an object's distance from us. The diagram above illustrates one way we perceive depth. Our eyes focus to one depth at a time, and each eye sees the scene differently. In the diagram above, the left eye sees the cube on the left and the ball on the right. Looking at the same scene, the right eye will see the ball on the left and the cube on the right. For the ball to be in focus, the eyes twist toward one another. The brain associates eye convergence with objects close to us. To see the cube in focus, the eyes twist apart. The brain associates eye divergence with objects farther away.

There are a number of ways to use the idea of eye divergence to trick the brain into seeing depth. The one we are using involves two separate and slightly different images, one for each eye. By looking beyond the surface of the paper, the two images overlap and become one. If there are several images are not equally spaced horizontally, the objects less separated will appear nearer, and the objects more widely separated will appear farther apart.



The illustration above shows how we can use two different images on a single sheet of paper, and trick the brain into seeing the images in 3-D. By looking just behind

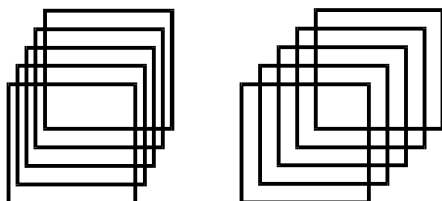
the paper, the two balls merge into one while the cubes remain out of focus. When the eyes diverge further, the cubes merge into one while the spheres go out of focus.



Use the image above to see if the 3-D effect works for you using one of the following techniques:

1. Look past the paper until the inner image from each eye merges.
2. Put your head close to the paper and slowly pull it away.

The dot will float in front of the circle and the square will float behind the circle. If the example above doesn't work for you, try the one below.



If you are still are having difficulty seeing the effect, here are two other techniques that can be helpful:

1. Mirror technique: Fold the paper so that the top edge of the diagrams is at the fold. Hold the paper against the mirror at eye level with the images toward you. You will need to look at the paper while seeing your head using peripheral vision. Start with your head close to the mirror and move your head back slowly keeping the reflection of your head in focus. The goal of this technique is to help you focus your eyes behind the paper. When you look into a mirror, you don't focus on the surface of the mirror. You actually look past the mirror surface in the same way that is needed to see these images.
2. "3-D glasses." The idea of the red-green 3-D glasses that were used for viewing movies is to make each eye more sensitive to the part of the image that was shot for that eye. (3-D movies are shot with two cameras spaced eye-width apart.) To create this effect, you need red and green filters and red and green markers. Pick one of the pairs of graphics and place a piece of paper over it, trace the left diagram in red, the right diagram in green, then look at it holding the red filter over your *right* eye and the green filter over your *left* eye. (Predict what will happen when you switch the filters and try it!)

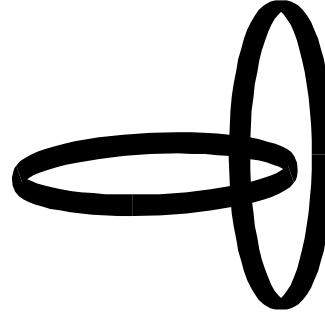
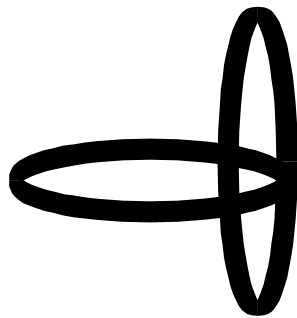
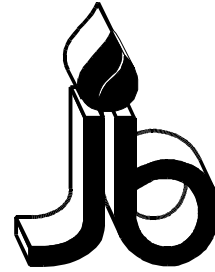
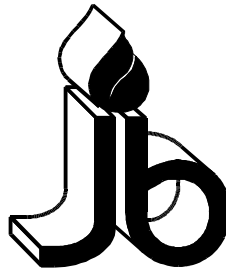
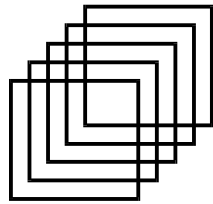
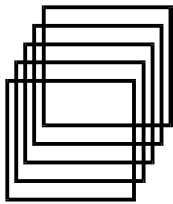
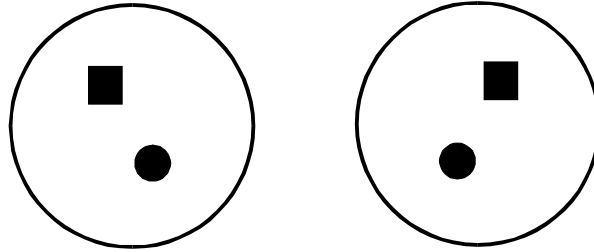
Parallax Activity (Alternate exploration into depth perception)

Close one eye and place your eye level at the edge of the table. Have your partner tear off a small piece of paper and drop it on the table 20-40 cm in front of you. Try to put your finger directly above the piece of paper and then put your finger down on the table. Try it a few times and switch with your partner.

1. How can you account for the fact that when your finger misses the piece of paper, your finger is in front of the paper or behind it, but not to the left or the right of the paper?
2. When your finger is in *front* of the paper and you move your head to the left, does the paper or your finger appear to be on the left?
3. When your finger is *behind* the paper and you move your head to the left, does the paper or your finger appear to be on the left?
4. Based on your observations in 2 and 3, devise a method for locating the piece of paper by holding your finger over it. Your method should include how to tell when your finger is in front of the paper, behind the paper, or over the paper.

The method you have devised for locating the piece of paper is called the *method of parallax*.

Student handout: 3-dimensional viewing examples

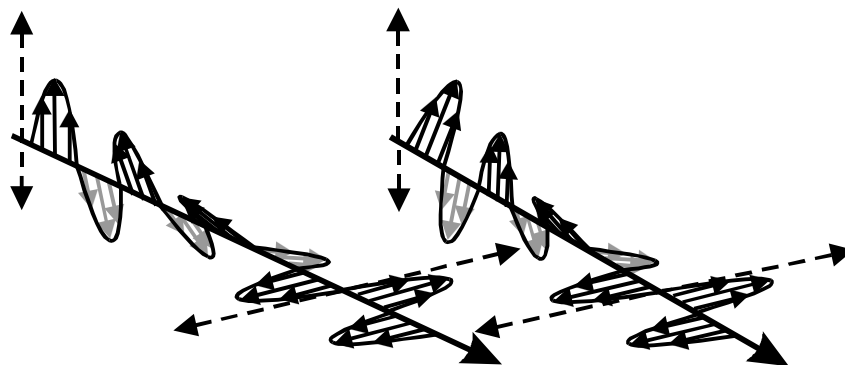


Hi.

Hi.

Science

Science



Physics: Optical Art Project

Create a work of art using one or more of the techniques we have discussed in class. Your artwork should be novel and unique through a combination of artistic media and skillful presentation. Your grade will be based on completion of the art project and a one page written description of the underlying physics.

3-D Images

- Create a 3-D image by making two similar pictures like the examples provided in class. Color images would be nice.
- The spacing between the two pictures must be less than the distance between your eyes (unless you're willing to try to make interlaced images Magic Eye style.)
- Corresponding parts of the two images must be horizontal from each other.
- Parts of the two pictures that are closer together than the rest of the picture will appear nearer and parts spaced farther than the rest of the picture will appear more distant.

Diffraction Patterns

- Make a special slit shape to place on the overhead. The light then passes through a diffraction grating and spreads into colors on the projection screen.
- Use heavy paper or cardboard.
- A single vertical slit makes a rainbow whose colors vary horizontally. A wider slit makes a brighter rainbow, but individual colors are less well defined and are added to the neighboring colors.
- Adjacent slits make rainbows that overlap and color addition occurs.

Polarization

- On a piece of clear plastic, build up layers of cellophane tape (magic tape doesn't work) which will be brilliant with color and fascinating patterns when viewed between a pair of polarizers.
- Recall that many other plastics are optically active or birefringent and could be used.

Some other materials or ideas you could integrate from our studies might include color filters, colored screens, lenses, mirrors and shadows.

The overhead projector will be available with polarizers and a diffraction grating if you would like to test your ideas.