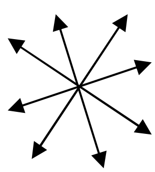
Scattering and Polarization Exploration

name______________________

BACKGROUND INFORMATION

Light waves emanating from most common sources, such as candles, light bulbs, and the sun, are unpolarized. That is, they are electromagnetic waves with components of the electric field in all directions. By contrast, *polarized light* consists of waves with the electric field predominantly in one direction (see figure). In this exploration you will explore polarization and four methods of producing polarized light. These methods include absorption, scattering, reflection, and bifrefringence.



unpolarized light

linearly polarized light

Activity 1: Polarization of Microwaves

Examine the small antenna in the microwave transmitter. Describe its orientation. That is, is it horizontal or vertical? After turning on the transmitter, direct it toward the receiver and note the reading on the receiver's meter. Adjust the alignment of transmitter and receiver until a maximum reading is achieved. Now insert the metallic grid between the receiver and transmitter. Rotate the grid and observe what happens. Can you extinguish the signal by proper alignment of the grid? If so, describe the orientation (horizontal or vertical) of the grid when this occurs. What could cause the decrease in the strength of the signal reaching the receiver?

Activity 2: Polarization due to Absorption

One of the most common methods of producing polarized light is through the absorption of one component of polarization while transmitting the perpendicular components. Developed by Edwin Land in 1928, a polarizing material called Polaroid™ consists of long chains of molecules that allow only one polarization to be transmitted.

To see the effects of a Polaroid filter, overlap two sheets of the material. Look at a source of light through the filters while rotating one of the filters. Describe what you see. When the light is completely extinguished by the overlapping filters, the filters are said to be "crossed." Rotate the filters them through 90 degrees. What do you observe now? Rotate the filters through an additional 90 degrees. Explain what is happening as you rotate the filters. How does this activity relate to Activity1?

Activity 3: Scattering

When light interacts with an object whose size is comparable to the wavelength of light, it shakes the charges in the object. These charges then radiate in all directions. This phenomenon is called **scattering.** Scattering occurs when light passes through dust in a room, smoke, or chalk dust. For example, the path of sunlight streaming into a room is seen because dust particles scatter light into our eyes. Without these particles, or other scattering centers, the light beam would not be seen from the side.

We see light in all direction when looking at the daytime sky because of scattering of sunlight by air molecules. Atmospheric scattering may be simulated by adding a few drops of milk to a container of water. This simulation works because the solid particles in milk are much smaller than the wavelength of visible light.

First fill a transparent container with water. Shine a flashlight beam through the water and observe the scattered beam from the side of the container. Also observe the transmitted beam by projecting it onto a piece of paper. Describe the scattered and transmitted light. What might be causing the observed scattering?

Now add a little milk to the water, a drop or two at a time. Carefully note the color of the mixture as the milk is stirred into the water. What color is the scattered light now? Note also the color of the transmitted light that is projected on the paper. What color do you observe on the paper? Continue adding milk in small amounts and notice changes in the scattered and transmitted light. Describe these changes.

The type of scattering you have just witnessed is called Rayleigh (ray-lee) scattering and occurs whenever the scattering particles are much smaller than incident wavelength and have resonances at frequencies higher than those of visible light. In this experiment with milk, and in our atmosphere, blue light is scattered more than red light in accordance with the rule for Rayleigh scattering:

The shorter the wavelength of the incident light, the more light is scattered.

Activity 4: Polarization due to Scattering
View the blue light scattered from the milk particles in Activity 3 through a polarizing filter. What do you observe as you slowly rotate the filter? Can you explain your observation? Also look at the top of the water through the rotating filter. What do you observe?

Now look end on into the transmitted beam. Is this light polarized? Additionally, place the filter between the flashlight and the milky water. Look from the side and notice what happens when you rotate the polarizer. Also notice what happens to the transmitted red "sunset."

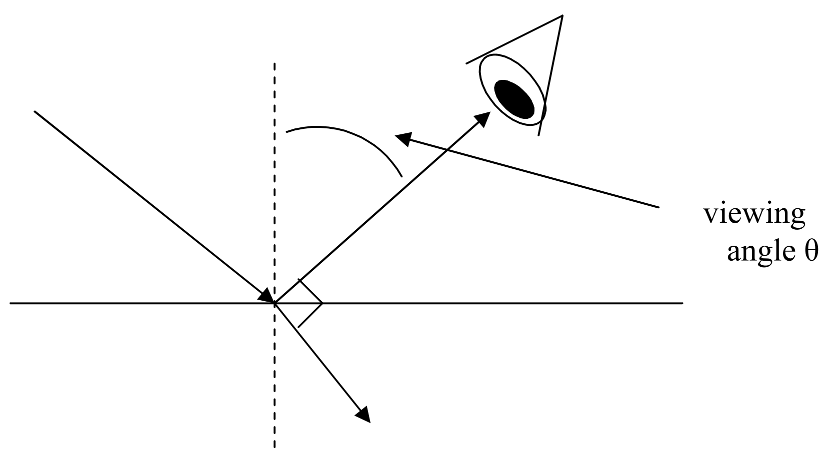
If the weather permits, go outside and investigate skylight with a polarizing filter. **DO NOT LOOK DIRECTLY AT THE SUN**! Slowly rotate the filter as you view a portion of the sky. Is it possible to reduce the brightness of the sky for certain orientations of the filter? Now examine other areas of the sky. Does the light in certain portions of the sky seem to be more polarized than others'? Estimate the angle formed by imaginary lines drawn between your head and, the sun and your head and the portion of the sky with the highest degree of polarization.

Look at the portion of the sky with the greatest polarization. If clouds are present in this region, observe what happens as you rotate your filter while viewing the clouds. Do the clouds seem to stand out for certain orientations of the filter? This occurs because the light scattered by the atmosphere is polarized, but the light scattered many times by water droplets in the cloud is not (see Activity 5).

Activity 5: Polarization by Reflection.

Locate a shiny, non-metallic surface such as a sheet of glass, a polished floor or a table top. View light reflected from the surface, often referred to as "glare" through a polarizing filter. Rotate the filter until you no longer see the reflected light. In this position, the filter's axis of polarization is vertical. Place a small piece of masking tape along the edge of the filter and indicate the axis of polarization with an arrow. Rotate the filter to pass the maximum amount of light. Describe the orientation of the axis of polarization now.

Again view the glare from a surface through a polarizing filter held close to one eye. When the axis of polarization of the filter is vertical, you will notice that the reflected light is dim for a variety of viewing angles but completely dark for only one. Adjust your viewing angle until total extinction of the light occurs. The angle of reflection that produces completely polarized light is called *Brewster's angle* and depends on the reflecting surface.



Experimentally find Brewster's angle for floor wax by using a waxed floor as your reflecting surface. To do this, have your partner extend a string from the filter to the spot on the surface where the light is totally extinguished. Use a protractor to determine the angle formed by a normal to the surface and the taut string.

Brewster's angle may be found by using the relationship

$$\tan\theta = n$$

where n is the index of refraction of the second medium, the first being air. Use the above relationship to determine the index of refraction of floor wax.

Using this relationship, what should be Brewster's angle for water glass? For water? Test the theoretical value for glass by actually measuring Brewster's angle.

View reflected light from a sheet of metal such as a piece of aluminum foil. Describe what happens this time as you rotate the filter. Compare the reflected light from a metallic surface to that reflected from a non-metallic surface. Use your filter to view light reflected from the surface of an automobile. Is this light polarized? How do you explain your findings?

Activity 6: Depolarizing Light through Multiple Scattering

Polarized light can be depolarized with multiple scattering. Polarized light, produced by atmospheric scattering, becomes depolarized when it is scattered many times by the particles that make up clouds. This phenomenon also occurs when polarized light passes through a sheet of wax paper.

Place two polarizing filters together and rotate them until they are crossed. Slide a piece of wax paper between the filters. Compare the light transmitted through the pair of filters before and after the insertion of the wax paper. Does your wax paper sample have a depolarizing effect?

Activity 7: A Remarkable Phenomenon

Cross two polarizing filters. With the axes of polarization of the two filters at right angles, no light passes through the pair of filters. Now insert a third polarizing filter, oriented at an angle of 45^0, an orientation midway between those of the first filter (the polarizer) and the second filter (the analyzer). Now look at a light source through this three-filter system. What do you observe? How in the world does this occur? The result is quite remarkable. The third filter does nothing but absorb some of the light, yet some light is now transmitted after you inserted the absorber! (Hint: Think vectors when trying to explain this strange phenomenon. Paul Hewitt uses this approach in the appendix of his Conceptual Physics.)

Activity 8: LCD Display

Examine the LCD display on a watch, calculator, or laptop computer through a single polarizing filter. Rotate the filter and note the effect. What does this tell you about light from liquid crystal displays?

Activity 9a: Birefringence

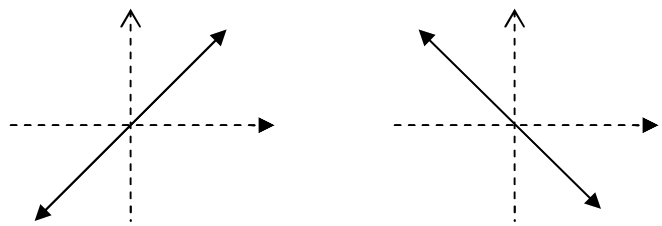
Some crystalline substances, such as quartz and calcite, have two indices of refraction. Such crystals are birefringent ("doubly refracting"). When a ray of unpolarized light enters a birefringent crystal, it divides into two rays. They two rays have different speeds and are polarized at right angles to each other.

Place a calcite crystal on some printed material. How many images do you see? Now view the printed material after you have placed a polarizing filter on top of the crystal. What do you see now? Can you extinguish one image at a time by rotating the filter? Why do you think this occurs?

Activity 9b: Half Wave and Quarter Wave Plates (optional)

Suppose that a birefringent material such as calcite is cut into a thin plate in such a way that the optic axis is parallel to the surface. If the E-field vibration of an incident light wave has components both parallel and perpendicular to the optic axis, then the two separate waves will follow the same path through the place, but at different speeds. Thus they will get out of step, or phase, with each other (one of them is retarded compared to the other).

If the plate is the right thickness, it is possible for the slow wave to get 180 degrees out of phase with the fast wave, which results in a rotation of the plane of polarization. Such a plate is called a half-wave plate because 180 degrees of phase shift is equivalent to half- wavelength. The figure below shows how the plane of rotation is affected by a half-wave plate.



If the slab discussed above is sliced so as to make it half as thick, the difference in phase introduced between the two polarization components is a quarter of a wave. Such a plate is called a quarter-wave plate because when light emerges from this plate, the two components will be one-quarter of a wave out of phase. The result of this phase shift is that is that the electric field moves around in a circle.

Make a quarter wave plate from a linear-polarizing filter and a piece of plastic wrap. Hold the plastic wrap behind the filter and immediately in front of a shiny metal surface. Gently stretch the plastic at a 45^0 angle to the filter. As you stretch the plastic, the metal should appear colored. (See Falk's Second Try It on page 361 for an explanation.)

Activity 10: Stress Birefringence

As was demonstrated in Activity 9b, when stressed, plastic and glass can become birefringent. Viewed between polarizing filters, this birefringence appears as colored contours. Place a plastic fork, or other plastic object, between your filters to make the stress lines visible. If you are using a fork, squeeze the tines together. What happens to the colored stress lines?

You can observe these colors in transparent plastic objects without using polarizing filters. Simply view the clear plastic object (plastic tape cassette boxes and tape dispensers work very we'll) in skylight. Tilt the object while looking at the reflection of the sky in the plastic. For a particular viewing angle, colors will appear. Can you explain how these colors are produced without polarizing filters? (Hint: polarized light must first enter the plastic, pass through the plastic, and then be "analyzed" by a second polarizing mechanism.)

Activity 11: Optically Active Substances

The corn syrup in the beaker on the overhead is *optically active.* Optically active substances rotate the plane of polarization of a beam of light. Note that there are polarizing filters on the top and bottom of the beaker. Rotate the top filter and observe the color of the light. Can you produce all the colors of the spectrum?

Activity **12: Polarized Tape Art**

The birefringent properties of some transparent tapes, for example cellophane, may be used to produce colorful tape art reminiscent of stained glass windows and cubist paintings. On a microscope slide or other clear substrate, place a short piece of tape. View the tape between crossed polarizers. Record what you observe. Apply a second layer of tape on the first and view between crossed polarizing filters. Continue this procedure until the colors begin to repeat themselves, each time noting the color produced. This procedure will allow you to develop a color key linking tape thickness with color.

Since you now know the relationship between color and tape thickness, you are now ready to produce your "work of art." Begin by cutting the tape into the desired shapes. As you prepare the shapes, apply them to a clean sheet of plastic. By layering pieces of tape, you can produce beautiful colored patterns that manifest themselves when viewed between sheets of polarizing material.