OPTICS – THE HEILIGENSCHEIN

Materials required: A flashlight with a piece of cardboard to cover the lens or a laser pointer, a piece of plastic, glass, a container of water, or piece of jello to shine light through, a protractor, a water tank (a clear plastic storage container will work), some thin material to act as a fiber optic element, such as a long, thin, piece of plastic, a piece of optical fiber or bundle, etc. and clear plastic bottle of water. Optional: glass retroreflecting beads (available from author and suppliers of safety equipment).

Commentary:

The title of this exercise is a tough one. Heiligenschein is a German word meaning, literally, “Holy Light”, which refers to an optical phenomenon that most likely caused renaissance artists to paint halos around figures in religious art. It is also something you have probably observed and is based on the physical principle underlying the use of reflective beads to make the reflective portions of your sneakers, signs, and road markings. You have also seen the sparkle of cut (faceted) diamonds. There is a connection between sparkling diamonds, road signs, and dew on the grass. What does all this have to do with physics and optics? Plenty! We will take a look at the phenomenon of ***refraction***, a process by which the path light takes is “bent” due to the fact that its speed changes, and a closely related reflection phenomenon something called the “critical angle”.

Inquiry:

Firstly, we need a source of light. You can either use a laser pointer or make the equivalent by cutting a hole in a piece of cardboard and taping that over the lens of a flashlight. At any rate, you will need a well-collimated, narrow beam of light to perform the exercises below.

Part A:

- Place a block of plastic or a small container of water or a cube of transparent Jello™ on a piece of paper. Shine your light beam straight through the object. Make a drawing in your portfolio that shows what happened.

- Next, let's arrange the light source so the beam hits the transparent object at an angle, say 30 degrees. Draw the path your light beam takes now. In addition, draw a line which is perpendicular to the transparent object (this is called a "normal"—a math word which means perpendicular to a surface). When I say 30 degrees, I mean 30 degrees as measured FROM THE NORMAL. Determine the path of the beam INSIDE the material. If you see it, you can trace it. Otherwise, connect where it goes in to where it comes out. Measure the angle this **refracted** ray, or beam, makes with respect to the normal and record it.

- Repeat the above steps for large and larger angles (do at least four) and record your results.

- What "trend" (looking at the angle of the refracted ray) do you observe as the angles get larger?

- What you have been observing is described quantitatively by ***Snell's Law***, according to which the angles of incidence (between the incoming ray and the normal) and refraction (between the refracted ray and the normal) are related by:

$$\sin i / \sin r = n_r / n_i$$

where n is the ***index of refraction*** for a material and i s the ratio of the speed of light in vacuum (as fast as it can go) to the speed in the material, or medium. Thus, n is a quantity greater than one. If you have a calculator, see if you can use Snell's Law for one of your angles to determine n, the index of refraction, of your material.

- If you are using a beam of white light, take a really close look at the refracted ray inside the transparent material for a fairly large angle of incidence. Do you see any colors inside the material? If so, sketch what you see.
- As it turns out, the index of refraction is wavelength (color) dependent. Thus, blue light is refracted more than red is. Does this agree with your observation? Separating white light into its component

colors by refraction is called dispersing the light. The fact that different wavelengths travel at different speeds in a medium is called dispersion and the amount of dispersion is a property of the material itself.

- So, now, provided the front and back faces of your material are parallel to one another, why do you see a white ray emerging from the back rather than a rainbow? How could you use the same material to produce one?

- Put a pencil or straw in a glass of water. Does it appear bent? Explain what you see in terms of Snell's Law.

- Put some water in your tank. Look at an object, such as a penny, on the bottom. Does it appear closer, the same, or farther away than it does without the water? What you are observing is an "apparent depth". Explain how this works, in terms of refraction of light. You should include a drawing in your answer in your portfolio.

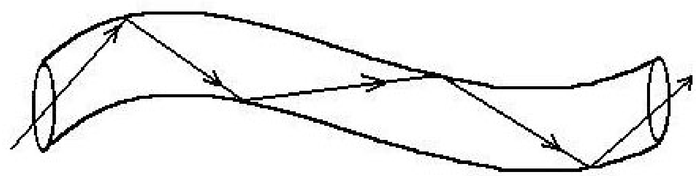
- Suppose you are spearing a fish from above the water (or shooting it with a bow and arrow as some sportsmen do). If you are hungry, should you aim above, at, or below the fish? Justify your answer.

Part B:

Next, we will be looking at the situation IN REVERSE (light going from the slower to the faster medium). As you saw in your initial diagrams, the light refracts AWAY from the normal when it speeds up again. Snell's Law leads us to an interesting and unavoidable conclusion. The sin function cannot have a value greater than one. Thus, there are values of the angle of incidence (inside the denser or slower medium) such that the light cannot escape! The smallest angle for which this occurs is called the **critical angle**. Anyone who has gone snorkeling or swimming underwater has observed this. For certain angles, when you look up, you can see the sky. If you look further out to the side, you only see a shimmering water surface or, perhaps, a reflection of what is below--perhaps tiles in the swimming pool. This phenomenon has been put to use in the form of fiber optics. You use these every time you use a computer connected to the internet with a fast connection and often when you watch cable TV or speak on the telephone. It is a dandy way to get light signals from here to there. Sometimes fiber optics are called “light pipes”. You should be able to see why.

- Pick up your water tank filled with water (not too full--it will spill) and this time look up through the bottom of the tank. Look through the sides as well. Are there any places from which you can’t see out through the surface of the water? Describe what you see. A picture helps a lot!

- Next, shine your light beam through the water from below. Find the angle for which it cannot escape (the angle of refraction ABOVE the water would be equal to 90 degrees) and approximate and record its

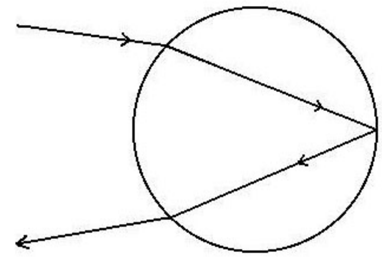


value.

- If you were a fish, it would appear that you could see out of the water inside a cone of angular size of ___________ degrees. Can you see why fly fisherman try to stay far away?

- If you are provided with some, take a look at an optical fiber. It is just a long, skinny piece of plastic or glass. These are always sold at carnivals, fireworks displays, etc. and are often incorporated into decorations. See if you can explain how one works, making the light come out the other end rather than the sides. Why must they be so thin (small diameter)?

- Why don’t we make a liquid optical fiber? Take a clear plastic soda bottle and poke a small hole in the side. Fill it with water and you’re your finger over the hole. Shine a laser beam (or light beam) at the hole from the opposite side and take your finger off the hole so the water can escape. Let the water empty into a beaker or cup. Describe what you see and explain why.



- Why doesn’t the water in the glass or cup also glow??

- Now for the Heiligenschein: If you have gone outside on a dewy morning with the sun behind you or in the fog at night with a light behind you, you should have seen a glow around your body. It is kind of a silvery, shimmering, spooky effect. This is due to the small size of the droplets. Light from the front of the droplet is “trapped” as it enters the drop, reflects off the back, and exits the front surface again because it must obey Snell’s Law. See the diagram of a droplet. Duplicate this drawing and indicate where the critical angle plays an important role. When light is “trapped” because the critical angle cannot be exceeded, this effect is called ***total internal reflection***.

- Lets make our own “Heiligenschein”. Spread out some reflective glass beads (these are the same ones used on highway signs and mixed into the paint used for road stripes and are now even being woven into fabrics) on a sheet of cardboard. Darken the room. Alternatively, you may be able to duplicate this by spraying a fine mist of water from a spray bottle onto a surface, making your own “dew”. Hold an object (your hand, a shape, etc.) above the beaded surface and shine a light (not a beam this time, but a regular flashlight) from above. Alternatively, work in a darkened room and allow light to shine in through the door. Describe what you see!

- Explain how the above is related to fiber optics in terms of the critical angle.

- Play a bit with the beads (they are VERY small, so be careful not to get them all over the place). What do you see if you place them on top of colored paper or objects having different colors and you illuminate them? Do they do anything interesting if you put them in a cup and shine light on them? Record any other observations you might make--you might discover a new use!