

Name _____ Date _____ Partners _____

LIGHT LESSONS WITH A LASER PEN

A Geometric Optics Activities Manual

(Developed for use with a Laser Pointer and Metrologic's Laser Pointer Education Kit)

Written by
Lynn Lucatoro
Spotswood High School
Rockingham, County

Presented at the
Virginia Association of Science Teachers (VAST) Conference
Roanoke, Virginia
November 10, 2000

Presented by
Dr. Richard A. Lindgren, Lynn Lucatoro,
Karyn Traphagen, and Charlene Wyrick

Submitted in partial fulfillment of the requirements for
Research Experience and Curriculum Enhancement for Teachers (RECET)
and
Master of Arts in Physics Education (MAPE)
University of Virginia
Mentor: Dr. Richard A. Lindgren

Supported in part by
The National Science Foundation
The State Council of Higher Education in Virginia
The Physics Department of the University of Virginia

TABLE OF CONTENTS:

Introduction.....	2
Warning.....	2
Definition of laser light.....	3
Activities	
1. Oh Where, Oh Where has My Laser Light Gone? Scattering	4
2. Is it Yellow? Color by reflection	7
3. Rose Colored Glasses Color by transmission	9
4. Mirror, Mirror on the Wall..... Verification of the Law of Reflection	12
5. Bent but not Broken (5 different procedures) Use of Snell's Law for Refraction and demonstration of a gradient optical density	13
I. Rectangular glass block refraction.....	13
II. Triangular glass block refraction	17
III. Air to water refraction.....	18
IV. Continuous refraction.....	21
V. Turbulent refraction.....	22
6. Like Totally, Dude! (2 procedures) Demonstration of Total Internal Reflection	24
I. Total internal reflection standing water.....	25
II. Total internal reflection in water stream.....	27
7. The Future's so Bright... I have to wear Shades!..... Polarized analyzer of laser light	29
Appendix	
More Laser safety.....	31
Optics kit inventory.....	33
Additional/optional materials.....	33
References.....	34
Protractor transparency master.....	35
Polar graph paper	36

Introduction

Welcome to the world of lasers. Laser light is an intense, monochromatic and coherent beam of light with very small angular divergence. These characteristics distinguish it from ordinary light. Either a He-Ne laser or a VLD laser pointer can perform these activities. The laser included is a class IIIa laser with a power in the range of 1mW to 5mW. All safety procedures for the handling of any laser should be followed. See below and Appendix.

This activity manual is by no means the extent of laser applications or demonstrations. It hopes to serve as a starting point to familiarize you and your students with lasers and can be followed with many more activities from other sources listed in the appendix. It is recommended that you read each procedure thoroughly before using them in your classroom.

Safety

The laser contained in this kit is a VLD California-Pacific TI-306 high tech laser pointer that emits light of wavelength 650nm at a maximum output of <5mW. It is a class IIIa laser and will not burn the skin or other objects. When handling any laser, the following precautions should be followed.

Classroom safety for a laser:

- **Do not look into the laser or stare at bright mirror like reflections of laser beam.**
- **Be sure to block off beam at a point beyond the farthest point of interest. Use a dull, non-reflective object like a piece of wood.**
- **If the beam must travel a long distance keep it close to the ground or overhead so that it does not cross walkways at eye-level.**

Definition of laser light

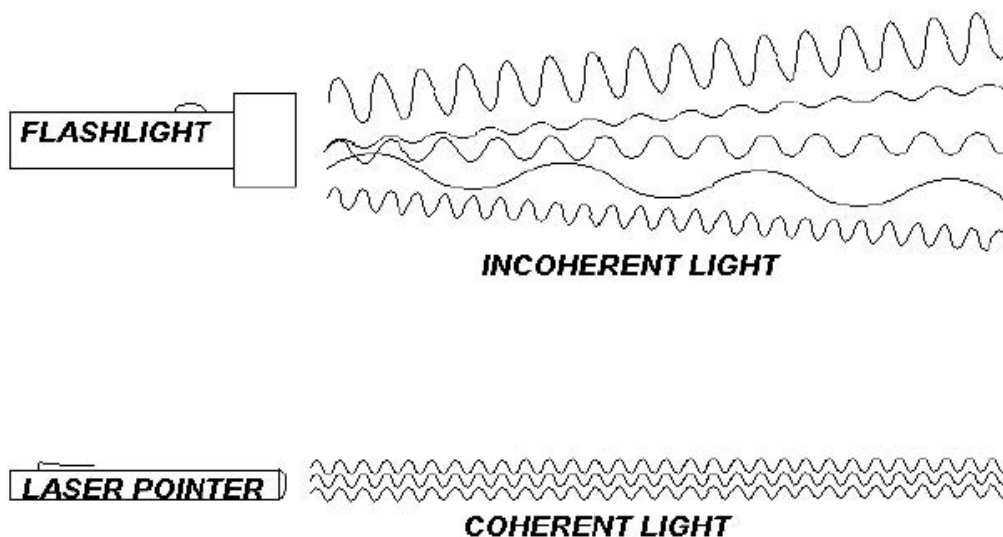
Light emitted from a common incandescent light bulb or the sun is incoherent. That is, the light has many different phases of vibrations and wavelengths. The light is as incoherent as the footsteps on an auditorium floor when a mob of people is chaotically rushing about. Incoherent light is chaotic. Interference within a beam of incoherent light is rampant, and a beam spreads out after a short distance, becoming wider and wider and less intense with increased distance.

Even if a beam is filtered so that it is monochromatic (of a single wavelength), it is still incoherent, for the waves are out of phase and interfere with one another. The slightest differences in their direction results in a spreading with increased distance.

A beam of light that has the same frequency, phase and direction is said to be coherent. There is no interference of waves within the beam. The name laser comes from **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. The laser is not a source of energy. It is simply a converter of energy and like all devices; a laser can put out no more energy than is put in.

The laser light produced by the VLD laser (type of laser included in this kit) is generated in a thin active layer sandwiched between p-doped and n-doped semi-conductors. Typical dimensions of these laser chips are on the order of 1 – 2 mm. The laser chips are built on a slab of gallium arsenide crystal. This crystal acts as an n-type semi-conductor, which has a surplus of mobile electrons within the crystal lattice. Applying a 2.5V dc to the laser electrodes causes any mobile electrons to move toward the positive electrode. Holes move toward the negative electrode. With sufficient energy both electrons and holes are injected into the active layer. When an electron-hole pair meet, they annihilate each other and release their energy to produce a photon of red light. By itself, a photon does not create much light. But combined with many others of the same wavelength, an intense laser beam is produced.

The beam emitted from the aperture of a VLD differs from that of a He-Ne laser in 3 significant ways: shape, visibility, and coherence.



Activity #1

Oh where, oh where has my laser light gone?

Objective: Scattering and the straight-line propagation of light. Students will determine if a laser is on or off and the path of the beam.

VA SOL's covered:

PH.3 – The student will investigate and understand how to demonstrate scientific reasoning and logic.

PH.4 – The student will investigate and understand how applications of physics affect the world.

PH.9 – The student will investigate and understand how to use models of transverse waves to interpret wave phenomena.

PH.10 – The student will investigate and understand that different frequencies and wavelengths in the electromagnetic spectrum are phenomena ranging from radio waves through visible light to gamma radiation.

PS.9 - The student will investigate and understand the nature and technological applications of light.

Theory: To be able to see something, one of two things must happen: either the light emitted from a luminous source enters your eye, or a fraction of the light emitted from some source is scattered off an object it illuminates and bounces in the direction of your eye. This is how you can see objects that don't emit light. For example you can see the moon at night because the light from the sun scatters off the surface of the moon and the moon is illuminated.

Materials:

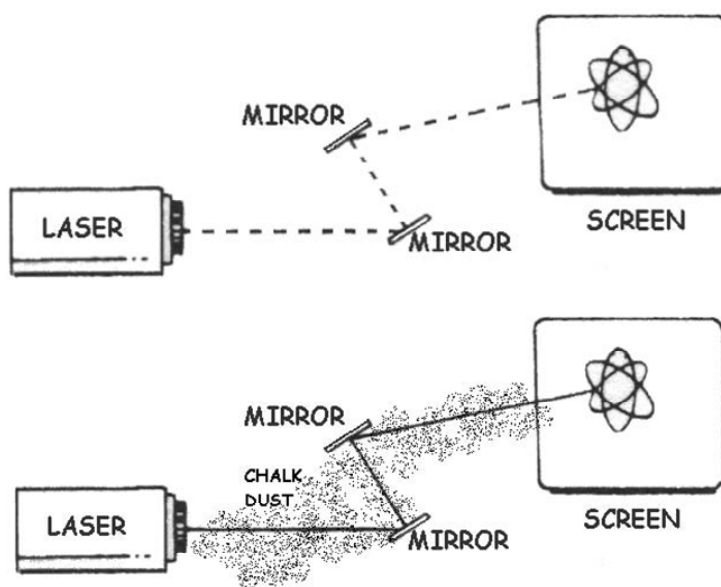
Laser pointer	included
2 front surfaced mirrors	included
white screen or wall	not included
dusty chalk erasers or baby powder	not included
modeling clay (optional)	not included
rubber bands (optional)	not included

Procedure:

- This procedure should be arranged before students enter the room. After the students have entered and are seated, discretely turn on the laser and attach binder clip.
- Arrange two, front surfaced mirrors so that laser light reflects from one mirror to another mirror and then strikes a white screen (or wall). See figure below.
- Modeling clay may be used to support mirrors or they can be secured with rubber bands to small wood blocks for support.
- Turn on the laser pointer and use the medium binder clip to keep the laser's power button depressed. Place the laser pointer on a firm and stable surface. **Caution:**

be sure to check that the path of the laser beam will not fall incident upon a student's eye.

- Arrange the laser beam so that your students will not be able to view the red dot of laser light reflected in the mirrors or on the final screen. Strategically placing a couple of textbooks can work while not distracting them from the main objective. Encourage students to determine whether the laser is on or off. If the air in the room is relatively dust free, this will be a difficult task for the students.
- Once the students have replied to your question, scatter the beam by clapping dusty chalkboard erasers above beam or lightly sprinkle baby powder in the beam path. The class will then be able to briefly view the beam path and you should remove any objects blocking the red laser dot.
- Draw on board the path of the laser beam.



Reprinted with permission Metrologic 101 Things to do with a laser

Alternate procedure:

- Shine the laser against the wall, such that the students cannot see the scattered light (red dot). This can be easily accomplished with a book blocking the student's view of the dot.
- Have students determine when the laser is on and when it off. If the air in the room is relatively dust free, this will be a difficult task for the students. But, if the air is fairly dusty the student will probably see the laser scattering off the dust.
- Have a student scatter the laser beam by clapping dusty chalkboard erasers above beam or by lightly sprinkling baby powder on the beam path.

Student Questions:

- **How can students tell if the laser is on or off?** It is impossible to tell without a medium of particles to scatter the beam or the ability to see the final reflection (red dot)

of laser light.

- **Given the safety considerations of lasers how can this be determined?**

Possible answers: Index card or object to break beam. Chalk dust, smoke or steam. Never look directly into laser that might be on.

- **Why can we see the spot of laser light?** You can see the laser spot on the wall because the light is scattered by the wall.

- **However, if the light were not scattered, what would you see?** Nothing, remind students they could not see the beam path with out chalk dust or powder.

- **What happens when you shine a flashlight up at the sky when it's pitch black?** You won't be able to see the light from the flashlight, unless it happens to scatter off something like a tree or a cloud. Similarly, if you conceal that laser spot, can you be sure whether the laser is on or off?

Activity #2**Is it Yellow?**

Objective: Demonstration of color by reflection. Students will see that the color of an object is determined by the color it reflects.

VA SOL's covered:

PH.3 – The student will investigate and understand how to demonstrate scientific reasoning and logic.

PH.4 – The student will investigate and understand how applications of physics affect the world.

PH.9 – The student will investigate and understand how to use models of transverse waves to interpret wave phenomena.

PH.10 – The student will investigate and understand that different frequencies and wavelengths in the electromagnetic spectrum are phenomena ranging from radio waves through visible light to gamma radiation.

PS.9 - The student will investigate and understand the nature and technological applications of light.

Theory:

To the physicist, the colors of things are not in the substances of the things themselves. Color is in the eye of the beholder and is provoked by the wavelengths of light emitted or reflected by things. People diagnosed with colorblindness perceive these wavelengths of light differently.

The color of most objects around you is due to the way the objects reflect light. Electrons are forced into vibration by the vibrations of the absorbed electromagnetic waves (light). Once vibrating, these electrons re-emit energy waves that we perceive as color.

Most materials absorb some wavelengths and reflect or transmit the rest. If a material absorbs all colors except for reflecting red, then the material will appear red. If it reflects all colors it will appear white, if it absorbs all colors it will appear black because there is no light being reflected.

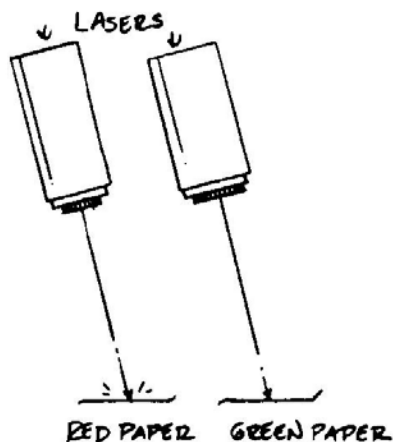
Note: The object can only reflect the wavelengths of light that are present in the illuminating light.

Materials:

Laser pointer	included
1 short focal length lens and holder	included
5" X 5" squares of colored paper	not included (pieces of bright construction paper (red, blue, yellow, green, etc) will work)
Tape	not included

Procedure:

- Place the small lens in the black plastic tube and slide the tube onto the front end of the pointer. This will increase the size of the beam spot.
- Tape the colored squares so they can be seen easily in the front of the room
- Have students make predictions. What color will the various papers appear in the red laser beam spot? Then, shine the red laser light on the various colored papers to check their responses.
- Were their predictions correct?
- For best results, the room should be darkened.



Reprinted with permission Metrologic 101 Things to do with a laser

Student Questions:

Do some colors reflect the laser light better than others do? Yes, the ones that had wavelengths of red light reflected.

What color does a red object appear in red laser light? Red, because the object reflects the red light incident upon it.

What color does a green object appear in red laser light? Black, because it does not reflect red light it absorbs it.

What color does a white object appear in red laser light? Red, because a white object is capable of reflecting all wavelengths and when red is the only light incident it is the only color reflected

If you are a designer of bar codes for grocery packages and the bars are to be printed with black ink, what would be the best background color for the barcode?

The background is to appear bright when illuminated with red laser light, then the best color would be white.

What if light from a red and a green laser where mixed on a white screen? Yellow is produced. (If you have access to both red and green lasers this is easily demonstrated for your class. Try it!)

Activity #3:**Rose colored glasses!**

Objective: Demonstration of color by transmission. Students will make predictions whether the laser pointer light will be transmitted or absorbed by a colored filter.

VA SOL's:

PH.3 – The student will investigate and understand how to demonstrate scientific reasoning and logic.

PH.4 – The student will investigate and understand how applications of physics affect the world.

PH.9 – The student will investigate and understand how to use models of transverse waves to interpret wave phenomena.

PH.10 – The student will investigate and understand that different frequencies and wavelengths in the electromagnetic spectrum are phenomena ranging from radio waves through visible light to gamma radiation.

PS.9 - The student will investigate and understand the nature and technological applications of light.

Theory: A **transparent** material is one that light is able to pass through. A colored transparent material will absorb incident light but will only transmit light that is of a certain wavelength. The color of a transparent object depends on the color (wavelength) of the light it transmits. White light is a combination of the color spectrum (all the wavelengths) of visible light. The color spectrum is considered to be the following 7 colors of light: Red, Orange, Yellow, Green, Blue, Indigo, and Violet. Laser light is light of one color (wavelength). In our case Red (wavelength = 670 nm).

Additional terminology:

- **Translucent** materials allow light to pass through but diffuses the light so that a clear image is not formed.
- **Opaque** materials do not allow any light to pass through and all incident light is absorbed and/or reflected.

Materials:

Laser pointer	included
1 short focal length lens and holder	included
1 color filter set (red, green, blue)	included
white screen or wall	not included
flashlight or other white light source	(optional)
transparent materials	(optional)

Procedure:

- Place the small lens in the black plastic tube and slide on the front end of the pointer to increase the size of the beam spot.
- Darken the room. Shine the laser pointer on a white screen.
- Choose the red colored filter and ask students to predict if light will be transmitted through the filter.

- Hold the filter in one hand and direct the laser beam on the filter.
- Did the student's observations support their prediction?
- Repeat with other filters.

Optional activities:

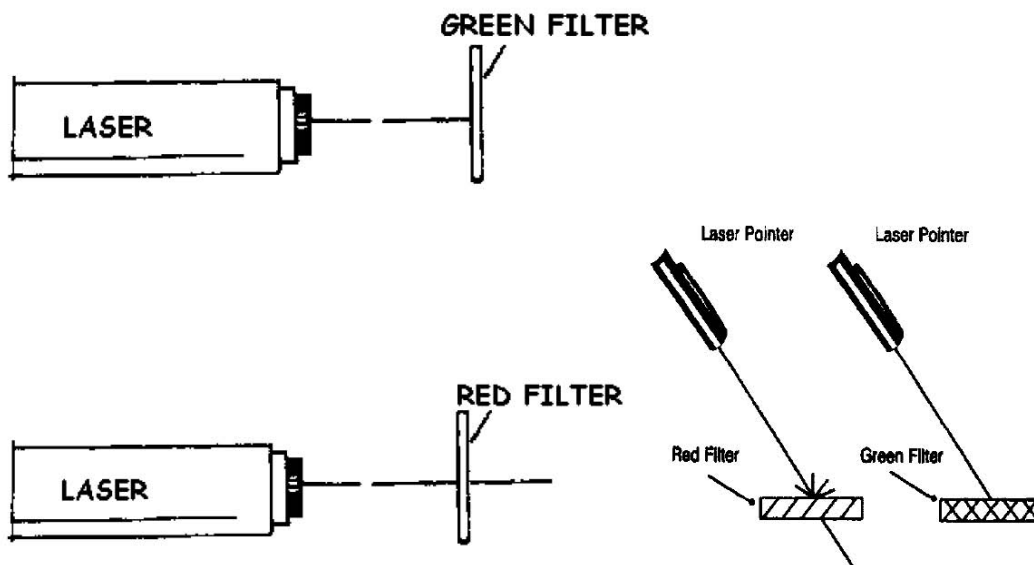
- Use other transparent materials ("Kool-Aid," Jell-O, clear juices or sodas, cellophane,... etc), as a filter. Have fun!
- **Why do some of the transparent materials absorb the red laser light better than other materials?** Because the material does not transmit red, which is the only color present in the laser beam. Similarly, the red laser light does not contain the wavelength of light that would be transmitted.
- Instead of the laser pointer use a flashlight or some other white light source on the filters.
- **In this case, why do the filters always transmit the color of the filter?** Because the wavelength of light that could be transmitted is present in the white light.

Student Questions:

What color filter was the best absorber (does not let light transmit) of the red laser light? Green, because it absorbed the red light.

What color was the best filter for transmission of red light? Red, because it transmits red light.

What happens when the red laser light is incident upon a blue filter? The intensity of the laser light is decreased. **Why?** The blue filter transmits a combination of red and blue light but since only red is present in the laser beam, some of the light is absorbed and some is transmitted and some is reflected.



Reprinted with permission from Metrologic 101 Things to do with a laser

Activity #4:**Mirror, mirror on the wall**

Objective: Verification of the law of reflection. Students will view the angles of incidence and reflection for comparison.

VA SOL's:

PH.3 – The student will investigate and understand how to demonstrate scientific reasoning and logic.

PH.4 – The student will investigate and understand how applications of physics affect the world.

PH.9 – The student will investigate and understand how to use models of transverse waves to interpret wave phenomena.

PH.10 – The student will investigate and understand that different frequencies and wavelengths in the electromagnetic spectrum are phenomena ranging from radio waves through visible light to gamma radiation.

PS.9 - The student will investigate and understand the nature and technological applications of light.

Theory: Light is reflected when light rays (electromagnetic waves) strike a plane barrier, such as a mirror, and new rays are generated that move away from the barrier. The angle at which the incident ray strikes the barrier is equal to the angle the reflected ray leaves the barrier. This is called the **Law of Reflection**. Both angles are measured from the normal, an imaginary line perpendicular to the surface at the point where the ray is reflected. See diagram below.

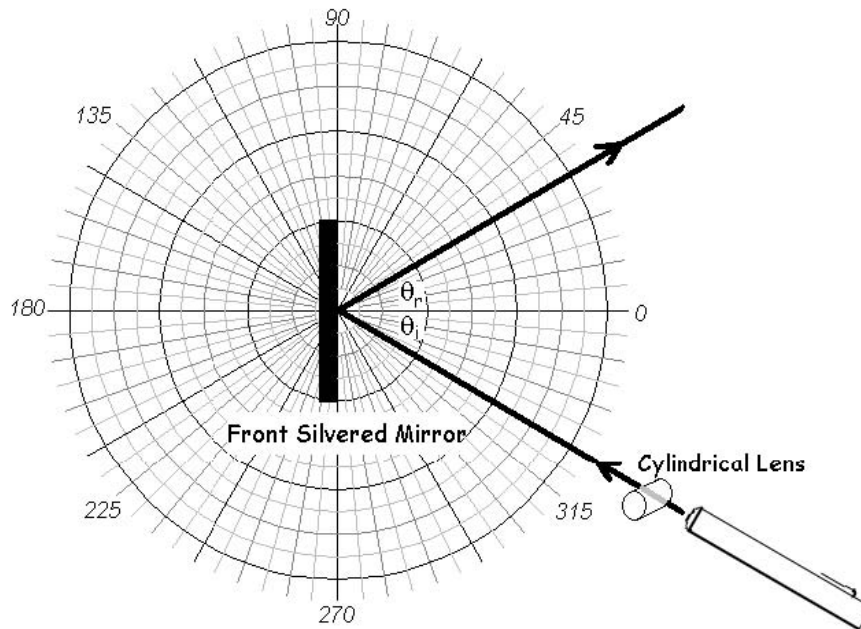
Materials:

Laser pointer	included
Cylindrical lens (mounted in black tube)	included
Medium binder clip	included
1 front, silvered mirror	included
Rubber band included polar graph paper	included (see appendix)

Procedure:

- Mount the cylindrical lens on laser to spread the beam in one direction.
- Clip the medium binder clip on the pointer to keep it powered. Then place the laser pointer on a level table so that the beam is spread vertically, not horizontally. (It is easier to adjust the cylindrical lens by turning the tubing than to keep re-clipping the pointer. Also to spread the beam vertically the cylindrical lens needs to be horizontal.)
- Use the rubber band to secure one of the front, silvered mirrors to the spine of the plastic education kit case.
- Lay the polar graph paper in front of the pointer and align the front of the mirror on the axis of a piece of polar graph paper so that 0° is perpendicular to the mirror surface. **The accuracy of your results will be determined by the precision of the mirror alignment on the polar graph paper.**

- Move the laser pointer so that the beam is incident on the mirror at the origin of the polar graph paper. See figure below. **Caution: Make sure not to look into the laser's path or at the reflected image.** View from directly above and read the 2 angles from the graph paper. θ_i is the angle of incidence and θ_r is the angle of reflection.
- Carefully and slowly move the pointer to increase the angle of incidence. Notice what happens to the angle of reflection.



JAFE Designs

Student Questions:

What happened as the incident angle increased? The reflected angle also increases.

Does this support the law of reflection? Yes because the measurement of the incident angle and the reflected angle are equal.

Does the law of reflection work for all waves? Yes, the law of reflection holds true for sound, water and all electromagnetic waves (e.g. Radio, micro and visible light).

Can you think of anything else that would behave this way? Many collisions obey the law of reflection (e.g. billiard balls when no 'English' is put on ball).

Activity #5:**Bent, but not broken**

Objective: Refraction, Snell's Law and demonstration of a gradient optical density (5 different procedures). Scattering is also mentioned again. Students will observe refraction of light in various media, perform calculations with Snell's law and gain an understanding of real world light phenomena.

VA SOL's:

PH.3 – The student will investigate and understand how to demonstrate scientific reasoning and logic.

PH.4 – The student will investigate and understand how applications of physics affect the world.

PH.9 – The student will investigate and understand how to use models of transverse waves to interpret wave phenomena.

PH.10 – The student will investigate and understand that different frequencies and wavelengths in the electromagnetic spectrum are phenomena ranging from radio waves through visible light to gamma radiation.

PS.9 - The student will investigate and understand the nature and technological applications of light.

Theory: Light travels at different speeds in different media. The index of refraction of a medium, n , is the ratio of the speed of light in a vacuum, c , to its speed in the medium,

$$n = c/v_{\text{medium}}$$

Since light travels fastest in a vacuum and slower in any other media, all indices of refraction are greater than one.

Light travels in a straight line only when traveling in a medium with a constant index of refraction. As light rays pass at an angle other than 90° from one medium to another, they are refracted or bent at the boundary between the two media. If a light ray enters an optically more dense medium (one with a higher index of refraction) at an angle, it is bent toward the normal. If a light ray enters an optically less dense medium (one with a lower index of refraction), it is bent away from the normal. This change in direction or bending of light at the boundary of two media is called **refraction**.

Snell's law expresses the relationship between the indices of refraction of two media and the ratio of the sines of the incident angle and the refracted angle.

$$n_i \sin \theta_i = n_r \sin \theta_r$$

(note: lower case r refers to refracted angle, not reflected angle in this case.)

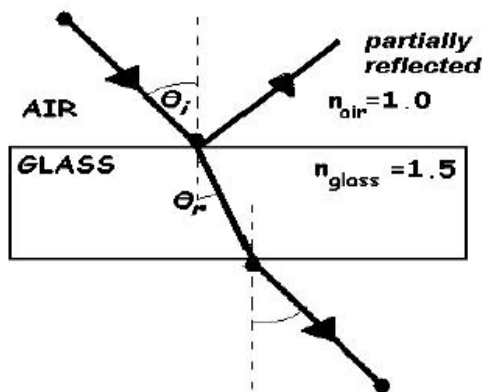
Experiment I: Rectangular glass block refraction**Materials**

Laser pointer	included
Cylindrical lens	included
Medium binder clip	included
Rectangular glass block	included

White paper	not included
Protractor transparency	included (see appendix)
Triangular glass block	not included

Procedure

- Mount the circular lens on laser pointer to spread the beam in one direction.
- Clip the medium binder clip on the pointer to keep it powered. Then place the laser pointer on a level table so that the beam is spread vertically, not horizontally. (It is easier to adjust the cylindrical lens by turning the tubing than to keep re-clipping the pointer. Also to spread the beam vertically the cylindrical lens needs to be horizontal.)
- Place a glass block on a piece of paper and shine the laser beam through it.
- View the path from directly above. Caution: be aware of where the beam terminates so that it is in nobody's line of sight.
- Carefully without moving the block, trace the block on the paper and put four dots on the beam path at the positions noted in the figure below.
- Unclip the laser pointer and remove glass block. Connect the dots with a ruler to represent the path of the light.
- Use a protractor to add the normal at the point where the incident ray intersects the boundary of the glass and measure both the incident and refracted angles.



JAFE Designs

Fill in the values and calculate n for glass

$$n_{\text{air}} \sin \theta_i = n_{\text{glass}} \sin \theta_r$$

θ_i	$\sin \theta_i$	θ_r	$\sin \theta_r$	Index of refraction, n_{glass}

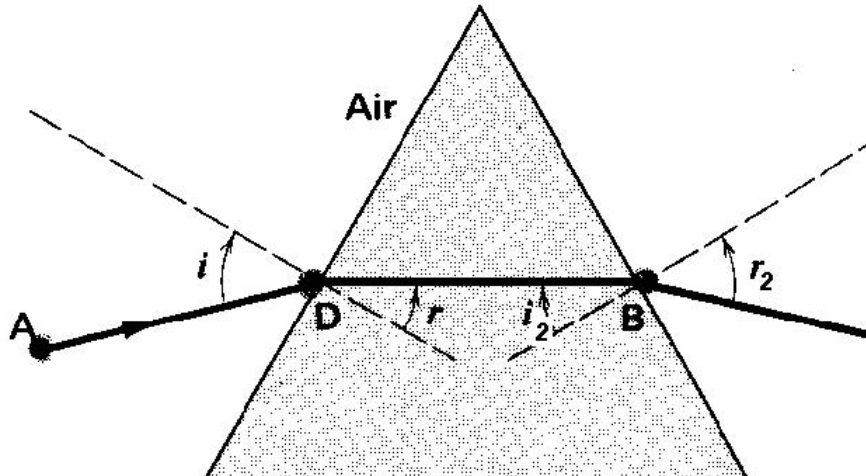
Student Questions:

Do you think light is speeding up or slowing down going from air into glass?
Slowing down.

How could you measure the speed of light? From the definition of the index of refraction, $n = c/v_2$, $v_2 = c/n$, and $v_2 = (3.00 \times 10^8 \text{ m/s}) / 1.33 = 2.0 \times 10^8 \text{ m/s}$.

Experiment II: Triangular glass block refraction**Procedure**

Repeat procedure I using a triangular glass block.



JAFRO Designs

Fill in the values and calculate n for glass prism using 2 different positions for the incoming light. Index of refraction $n_{\text{air}} = 1$. $n_i \sin \theta_i = n_r \sin \theta_r$

θ_i	$\sin \theta_i$	θ_r	$\sin \theta_r$	Index of refraction, n_{glass}

Student Questions:

How did the rectangular glass block's index of refraction compare to the triangular glass block's index of refraction? Answers will vary depending upon the block and prism used.

Would you expect all glass to have the same index of refraction? No, because there are many different types of glass and each different glass material would have a different index of refraction.

How did the value of angle i compare to the angle r_2 for the triangular glass block?
They are equal.

Does the index of refraction depend upon the incident angle or the medium? Only the medium because as the incident angle changes the refracted angle changes and the index of refraction remains constant.

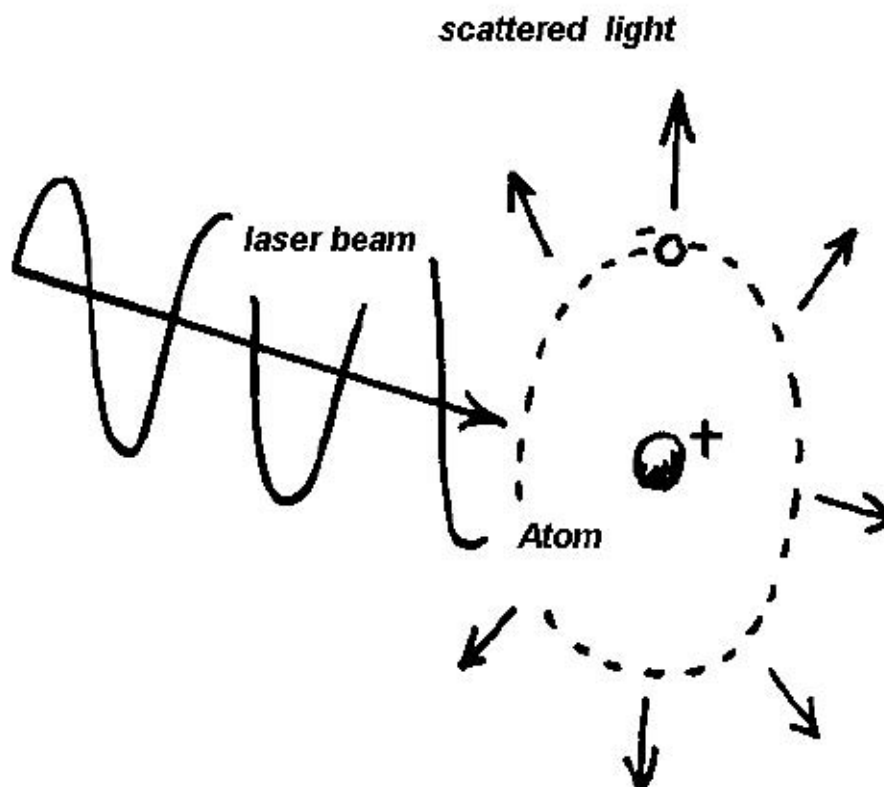
Experiment III: Air to water refraction

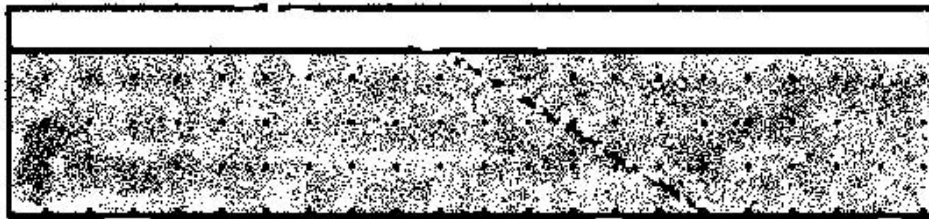
Materials:

Laser pointer	included
Clear rectangular box (fish tank, plastic shoe box,...etc)	not included
Powdered milk flakes (AgNO ₃ works too!)	not included
3-5 lbs. of sugar (optional) Ruler	not included

Procedure

- Fill a fish tank or clear shoebox $\frac{3}{4}$ full with water.
- Add a pinch of milk powder to scatter the laser beam enough to make it visible in the water. (Add milk powder carefully. Using too much will completely diffuse the light.)
- **OR** dissolve 3-5 lbs. of sugar in the tank of hot water to create a saturated solution. Cool before using. **This is the recommended method because one can then save the set up for other procedures.**
- Shine the laser pointer from above onto the surface of the water and let the students view from the front the path of the beam.
- Use the ruler to show the beam path above the water and how the beam they see in the water is not continuing along the same line.
- Reemphasize to the students that they are able to see the beam in the water because of the scattering of laser light by the milk (or sugar) particles. **Note:** Scattering occurs, when a beam of light encounters suspended particles with dimensions that are small compared to the wavelengths of the light (activity # 1, page # 4). See diagram below.
- Do not throw out the water in tank, if you used sugar instead of milk powder you can let it sit for a week and use for **Procedure IV and Activity #6** (page #18).





JAFE Designs

Complete data table and calculate n for water.

θ_i	$\sin \theta_i$	θ_r	$\sin \theta_r$	Index of refraction, n_{glass}

Student Questions:

In which media would light ray bend more: water or glass? Why? Glass, it has a higher index of refraction.

Could you predict the refracted angle for water knowing the incident angle, the index of refraction of water, and Snell's law? Yes, $n_{\text{water}} = 1.33$?

$$\theta_r = \sin^{-1}((n_{\text{air}} / n_{\text{glass}}) \sin \theta_i).$$

How could you measure the speed of light in glass? From the definition of the index of refraction, $n = v_1/v_2$ and $v_2 = c/n$ where $v_2 = c$ speed of light in a vacuum and $n =$ index of refraction of glass = 1.5 or use your calculated value from above table. $v_2 = (3.00 \times 10^8 \text{ m/s}) / 1.5 = 2.0 \times 10^8 \text{ m/s}$.

If light had the same speed in air and in glass, would light be refracted in passing from air into water? No, refraction depends upon a change in wave speed.

Can different indices of refraction exist in "basically" the same medium? Yes, try the next procedure!

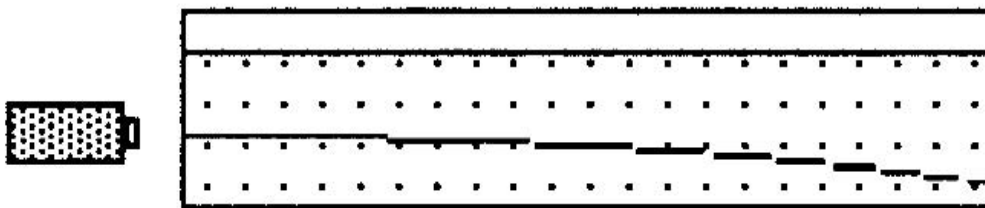
Experiment IV: Continuous refraction

Materials:

Laser pointer	included
Clear rectangular box (fish tank, plastic shoe box,...etc)	not included
Powdered milk flakes (AgNO ₃ works too!)	not included
3-5 lbs. Of sugar	not included

Procedure

- Fill a fish tank or clear shoebox $\frac{3}{4}$ full with water.
- Dissolve 3-5 lbs. of sugar in the tank of hot water and let cool.
- **OR** use the set up from procedure III.
- Allow the set up to remain undisturbed overnight (a few days or even a week is better) so that the sugar will dissolve and form a solution that is dense at the bottom and gradually becomes less dense toward the surface.
- Aim the beam horizontally into the solution and have the students view beam from the side to observe how the beam gradually bends as the index of refraction of the solution increases.



Student Questions:

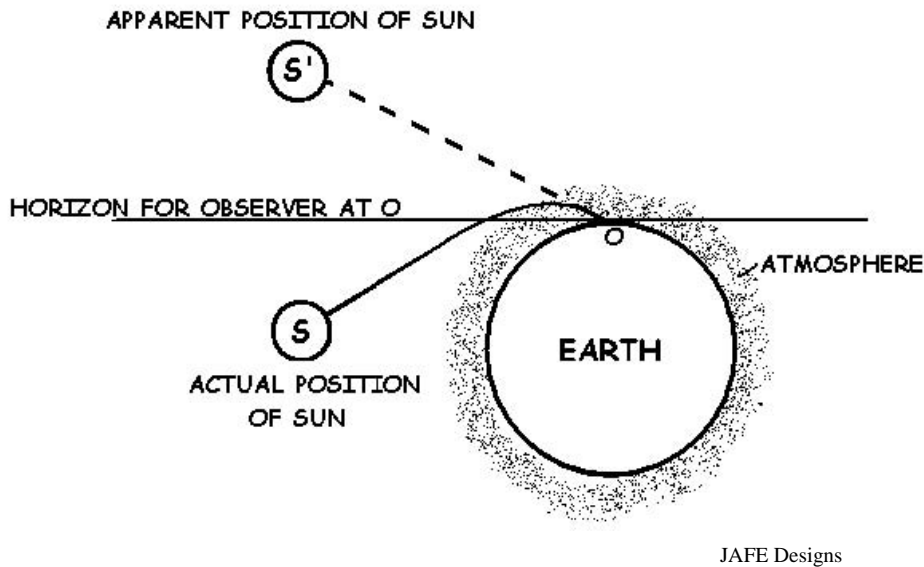
Why did the light bend more at the bottom of the tank of sugar water? The solution was more optically dense near the bottom. The index of refraction of the solution increased toward the bottom of the tank. There was a higher concentration of sugar.

Give an example where refraction is gradual? Mirages, Convection “Heatwaves”, “pumpkin” suns.

The Setting Sun: An example of continuous refraction.

Theory:

Whenever you watch the sun set, you see the sun for several minutes after it has really sunk below the horizon. This is because the light is refracted by the Earth’s atmosphere. Since the density of the Earth’s atmosphere gradually changes from more dense to less dense the farther one is from the surface, the refracted rays bend gradually to produce a curved path. See diagram.



Student Questions:

Does this mean our days appear longer than they actually are? Yes, by about 5 minutes.

If the speed of light were the same in the various temperatures and densities of air, would there still be slightly longer daytimes? No, there would be no refraction of light.

Why does the daytime sky on Earth appear bright while the daytime sky on the moon appears dark? Because the Earth has an atmosphere with particles that scatter the light while the moon has almost no atmospheric particles. Remember Activity #1!

Experiment V: Turbulent refraction

Theory:

Light travels in a straight line only when traveling in a medium with constant index of refraction. The index of refraction of air also depends slightly on temperature as well as density. Thus the hot air above a hot plate deflects the light slightly, and in a time varying way, due to the turbulence of the air currents above the hot plate. So the way light travels through air, depends upon the temperature of the air as well as the density. This is similar to the temperature gradient above the hot pavement of the road in front of you that produces a mirage of water. Also this is exactly what happens when one views the stars through the temperature gradient of the Earth's atmosphere.

Materials:

Laser pointer	included
Cylindrical lens	included
Medium binder clip	included
Heat source (hot plate, Bunsen burner, etc)	not included
Screen or wall	not included

Procedure

- Mount the circular lens on laser pointer to spread the beam in one direction.
- Clip the medium binder clip on the pointer to keep it powered. Then place the laser pointer on a level platform or clamp on a stand so that the beam is spread vertically, not horizontally. (It is easier to adjust the cylindrical lens by turning the tubing than to keep re-clipping the pointer. Also to spread the beam vertically the cylindrical lens needs to be horizontal.)
- Turn on the heat source.
- Turn on your laser.
- Align the laser pointer (with the circular lens) so that the beam passes over the top of your heat source and makes a line on the wall or screen some distance away.
- Observe the laser light on the wall.
- Then turn the hot plate to high. The laser light will start to move around. If the hot plate is turned off the light will eventually stop moving.

Student Questions:

How is this like the twinkling of stars in our atmosphere? On Earth, when you look at a twinkling star its light passes through Earth' turbulent atmosphere (temperature gradient air currents). The temperature changes are smaller than the above demonstration, but the light shines through a much longer path so the effect is noticeable.

Why doesn't the moon twinkle, or does it? It appears that only stars twinkle, but this is because the moon and most planets appear larger than a star and the effect of twinkling is less noticeable. So the moon presumably does twinkle, but it occupies such a large segment of the sky that it is not noticed.

How can the stars be viewed without atmospheric refraction? Place telescopes on satellites or spacecraft.

What is the Hubble telescope? Deployed on April 25, 1990, the Hubble Telescope is a giant observatory aboard a spacecraft. It can make observations of the universe using visible, near-ultraviolet and near-infrared light spectra above the filtering effect of Earth's atmosphere due to density and temperature. Because of its ability to capture faint light in fine detail and the precision of its observations the Hubble Space Telescope is rapidly expanding astronomers understanding of the cosmos.

Activity #6**Like Totally Dude!**

Objective: Total internal reflection. Students will observe how the path of light traveling from a more optically dense medium to a less optically dense medium is affected by changing the incident angle.

VA SOL's:

PH.3 – The student will investigate and understand how to demonstrate scientific reasoning and logic.

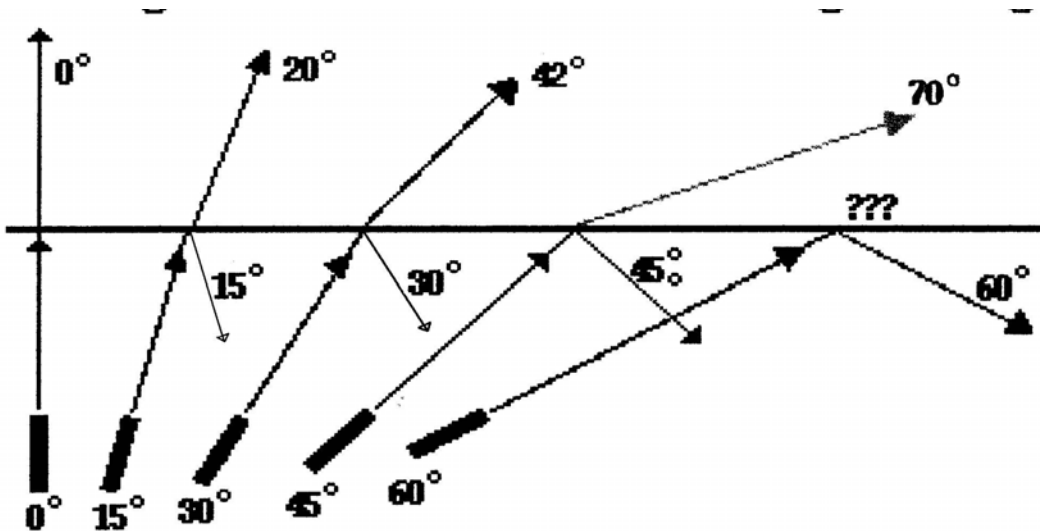
PH.4 – The student will investigate and understand how applications of physics affect the world.

PH.9 – The student will investigate and understand how to use models of transverse waves to interpret wave phenomena.

PH.10 – The student will investigate and understand that different frequencies and wavelengths in the electromagnetic spectrum are phenomena ranging from radio waves through visible light to gamma radiation.

PS.9 - The student will investigate and understand the nature and technological applications of light.

Theory: When light travels from a less optically dense medium to a more optically dense medium the refracted ray bends toward the normal (see Activity #5, procedure I page #). When light travels from a more optically dense medium to a less optically dense medium the refracted ray bends away from the normal. Thus the angle of refraction is greater than the angle of incidence. As the angle of incidence approaches 90° , the angle of refraction reaches 90° first. When the refracted angle is equal to 90° , the incident angle is called the **critical angle**. For any incident angle greater than the critical angle the light is no longer refracted but **totally, internally reflected**.



Reprinted with permission of the Physics Classroom

Experiment I: Total internal reflection in standing water

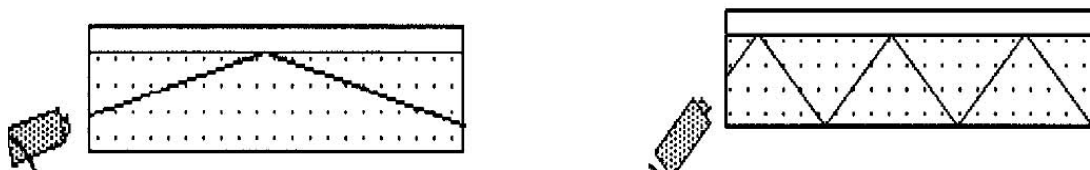
Materials:

Laser pointer	included
Clear rectangular box (fish tank, plastic shoe box,...etc)	not included
Powdered milk flakes (AgNO ₃ works too!)	not included
3-5 lbs. of sugar (optional) Ruler not included Mirrors	included

Procedure

- Fill a fish tank or clear shoebox $\frac{3}{4}$ full with water.
- Add a pinch of milk powder to scatter the laser beam enough to make it visible in the water. (Add milk powder carefully. Using too much will completely diffuse the light.)
- **OR** dissolve 3-5 lbs. of sugar in the tank of water.
- Shine the laser pointer from the side into the water angled to strike the water air boundary and let the students view from the front the path of the beam. Start with a very small angle of incidence and increase so the students can visually follow the beam path. This may take some practice.
- Use the ruler to show how the beam path above the water would continue and that beam they see in the water is not continuing along the same line.
- Remind the students, that they are able to see the beam in the water because of the scattering of laser light by the milk (or sugar) particles. **Note:** Scattering occurs, when a beam of light encounters suspended particles with dimensions that are small compared to the wavelengths of the light. (see Activity #5, procedure I).
- For multiple total internal reflections, mirrors can be placed on the bottom of the tank to reflect the beam back to the water air boundary. This really takes some time to set

up but is an impressive demonstration



Student Questions:

Does the milk powder change the index of refraction of the water? No, the laser light does not pass through the milk powder; it is only scattered by the powder.

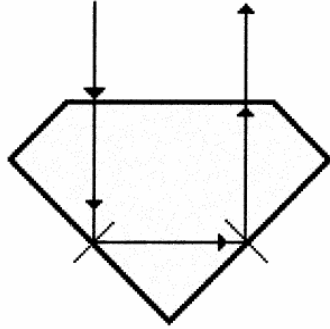
What if too much milk powder was added? The laser beam would be completely diffused or scattered and no beam would be viewed in the container.

Why doesn't the laser beam totally internally reflect from the bottom of the tank without mirrors? Because the index of refraction of the tank is greater than water and the beam is refracting toward the normal.

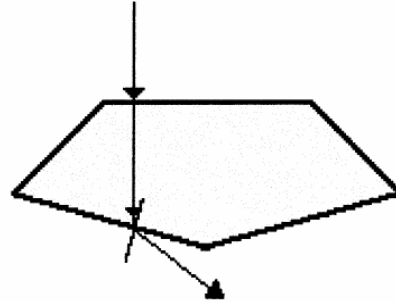
Could a large mirror placed under a clear bottom tank or a mirror that fits on the inside bottom of the tank work in reflecting the beam to the water air boundary?

Yes! Try it.

How does the critical angle for total internal reflection relate to the index of refraction of the substance? They are directly proportional. The greater the index of refraction the greater the critical angle. Thus diamond, with one of the highest indices of refraction is able to reflect all light that enters the top of the gem back out the top



Light entering through the top facet undergoes TIR a couple of times before finally exiting.

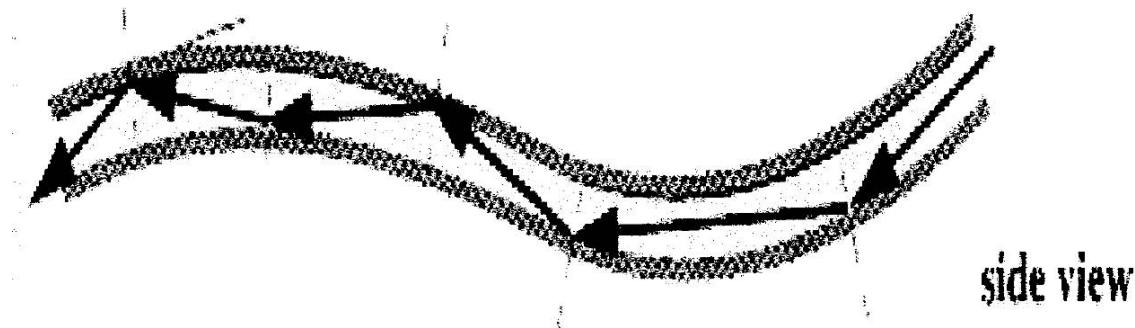


Light entering through the top facet of the diamond quickly exits at the second boundary since its angle of incidence is less than the critical angle.

Reprinted with permission The Physics Classroom

Experiment II: Total internal reflection in a water stream

Theory: The index of refraction of water is 1.33, and the critical angle for a water/air interface is $\theta_c = \sin^{-1}(n_{\text{air}}/n_{\text{water}}) = 49^\circ$. So, if the water stream does not bend at too sharp of an angle, then light traveling along the length of the stream strikes the water/air interface at an angle greater than 49° with respect to the normal to the interface and is thus totally reflected.



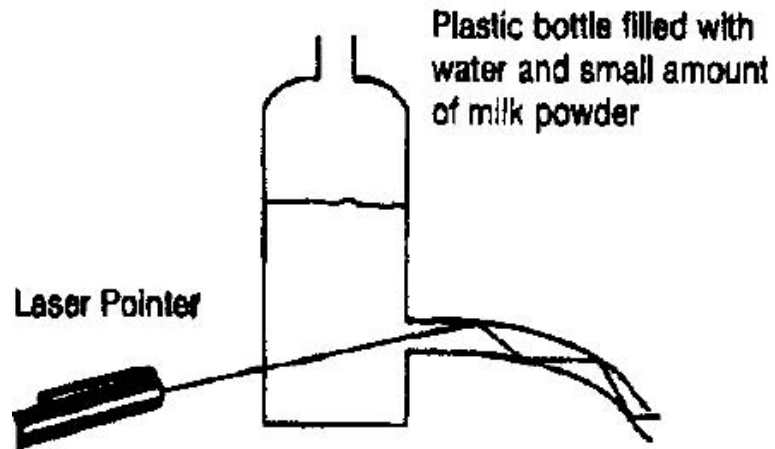
Reprinted with permission The Physics Classroom

Materials:

Laser pointer	included
Clear plastic bottle with lid (1 liter works well but any will work)	not included
milk powder (AgNO ₃ , etc)	not included

Procedure

- Melt a hole near the bottom of a clear water bottle with a hot nail (see diagram for placement.)
- Fill bottle with water, add a very small amount of milk powder, and replace cap. The water will not leak with the cap on tight.
- Align laser so that it shines into the bottle on one side and leaves through the hole on the other side. (Caution: make sure you are not aiming at someone's eyes!)
- Have class view from the side.
- Loosen the lid with out moving the bottle and let the stream of waterfall into a bucket or sink. The room should be darkened for best viewing but can also be seen with the lights on too. An illuminated stream should be seen.
- Have a student hold a hand under the stream so that they can see the laser dot on their hand and to confirm that the light is traveling within the water stream. As the level of water in the bottle decreases, the stream bends at a sharper angle until suddenly the condition for total reflection is violated, and a bright spot is seen on the opposite wall.



Reprinted with permission Metrologic ML211 Education kit

Student Questions:

Why is the light unable to escape the water stream? Because the light is striking the water to air boundary at an angle greater than the critical angle and all light is being reflected.

What is the critical angle for air to water? $\theta_c = \sin^{-1} (n_{\text{air}}/n_{\text{water}}) = 49^\circ$

Activity #7

The Future's so Bright...I have to Wear Shades!

Objective: Polaroid analyzer and transverse waves. Students will observe the change in intensity of laser light (polarized) by using a Polaroid filter as an analyzer.

VA SOL's:

PH.3 – The student will investigate and understand how to demonstrate scientific reasoning and logic.

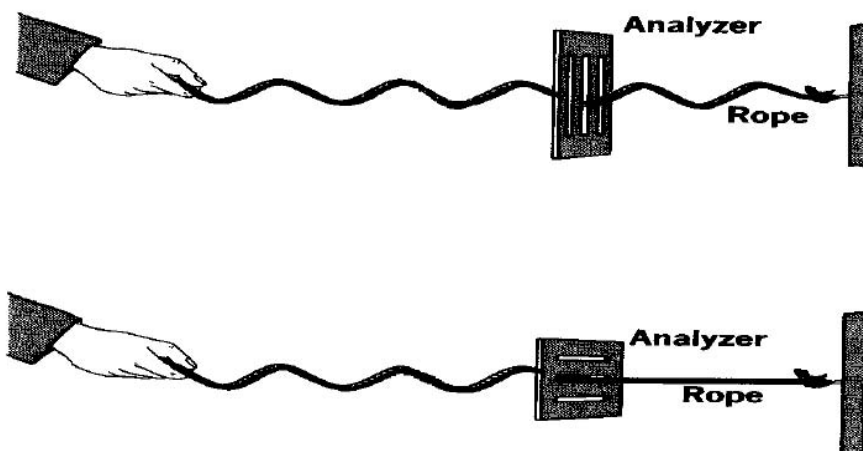
PH.4 – The student will investigate and understand how applications of physics affect the world.

PH.9 – The student will investigate and understand how to use models of transverse waves to interpret wave phenomena.

PH.10 – The student will investigate and understand that different frequencies and wavelengths in the electromagnetic spectrum are phenomena ranging from radio waves through visible light to gamma radiation.

PS.9 - The student will investigate and understand the nature and technological applications of light.

Theory: Only transverse waves can be polarized, or made to vibrate in one plane perpendicular to its direction of propagation. Since light travels in transverse waves, it can be polarized by absorption, reflection, or scattering from shiny objects or materials. Light is also polarized when it is passed through certain materials. If you rotate a polarizing filter while observing a polarized light beam, the light intensity will vary. Since laser light is already polarized (most light is not), then the beam can be analyzed with a single polarizing filter. If light from a source was not polarized then a first Polaroid would polarize the light and a second Polaroid could be rotated to analyze the light. A polarizing filter has a crystalline structure that allows waves vibrating in line with the crystals to pass while restricting waves that vibrate in other planes.



JAFE Designs

Materials:

Laser pointer	included
Medium binder clip	included
Polaroid filter	included
White screen or wall	not included
Metal stand and clamp	(optional)

Procedure:

- Place the small lens in the black plastic tube and slide on the front end of the pointer to increase the size of the beam spot.
- Darken the room. Turn the laser pointer on and clip with the medium binder clip.
- Aim laser at a white screen. It is best if the laser pointer is resting on a level surface or clamped to a metal stand.
- Place a Polaroid filter in the path of the beam.
- Slowly rotate the filter until the intensity of laser light is at a maximum. Then rotate the filter slowly 360°

Student Questions:

Explain what was happening when the beam was the brightest. When the polarized laser light wave was aligned with the crystals of the Polaroid the light was the brightest and the light was able to pass through the filter.

Why did the intensity decrease to a minimum and increase again? When the alignment is off by 90° the intensity of the light is a minimum and in the case of laser light (polarized light) no light can pass through the filter.

Laser safety

Princeton University Environmental Health and Safety Recommendations for Laser Pointers

Introduction

The use of laser pointers has become widespread. The pointers are useful tools for educators in the classroom and at conventions and meetings. However, due to the low cost and ubiquitous supply, these pointers are now being purchased and used by the general public, including children, and used in ways not intended by the manufactures. As a result, serious concerns about the hazards of laser pointers have surfaced.

While the majority of the laser pointers contain low to moderately powered diode lasers, more powerful lasers are now being imported from China. These pointers present a significant potential for eye injury and are often not properly labeled according to FDA regulations.

There are currently no restrictions for purchasing laser pointers in the U.S. Last December, the FDA issued a warning for laser pointers, urging that the pointers be used as intended, not as toys, and not by children unless under adult supervision.

Types of laser pointers

The majority of the laser pointers used in the U.S. use Class IIIa diode lasers in the 630 – 680 nm wavelength (red), with a maximum power output of between 1 and 5 nW. The length of exposure to visible lasers is usually limited by the eye's blink reflex, which normally occurs within a quarter of a second. Theoretically, Class IIIa lasers could cause injury to the eye if viewed directly for less than 0.25 seconds.

Most laser pointers manufactured before 1993 were Class II lasers, with a power output of less than 1 nW. These lasers are safe to view directly for short periods of time.

A recent report by James Rockwell, et al, in the Journal of Laser Application noted that more powerful laser pointers are now being imported from Russia and China. Some of these lasers lack the appropriate warning labels. These lasers emit green beams from frequency doubled Nd:YAG lasers operating at 532 nm and have emissions significantly exceeding the maximum permissible exposure (as per the ANSI laser standard, Z136). One of the lasers has a filter in the cap, which if removed, allows the laser to emit both 532 nm and 1064 nm beams, in excess of 15mW, making it an even more hazardous Class IIIb laser.

The same article noted a recent advertisement for a “super power diode pointer that is 20 times brighter than other conventional lasers.”

Potential Hazards

The hazards of laser pointers are limited to the eye. Although with most visible lasers, the largest concern is potential damage to the retina, most laser pointers are not likely to cause retinal damage. The possible exception might be the green light lasers described above.

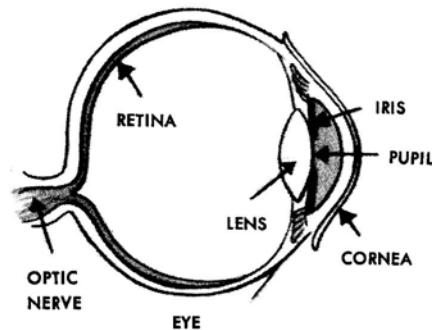
The most likely effects from exposure to viewing the beam from a laser pointer are afterimage, flashblindness and glare. Flashblindness is temporary vision impairment after viewing a bright light. This is similar to looking directly at a flashbulb when having a picture taken. The impairment may last several minutes.

Afterimage is the perception of spots in the field of vision. This can be distracting and annoying, and may last several minutes, although there have been reports of afterimages lasting several days.

Glare is a reduction or complete loss of visibility in the central field of vision while being exposed to the direct or scattered beam. This is similar to viewing oncoming headlights on a dark night. Once the beam is out of the field of vision, the glare ceases. While this does not pose a hazard to the eye, it can cause serious distraction and outrage. Glare can be exacerbated when the beam is reflected from a mirror-like surface.

Remember:

Hazards to the skin by laser radiation are insignificant compared to exposure to the eye. Eye damage may occur in the cornea from high powered and some exotic lasers. The main concern is prolonged exposure to the retina when using low power visible light lasers.



Reprinted with permission from LIA

Figure of eye

Optical lesions that formed on a patient's retina due to brief exposure healed within a week with no long-term effects. Exposure to a 60mW (much more intense than our pointer) source for a short burst resulted in temporary loss of vision in a small part of the visual field. This cleared without treatment in a few weeks.

Don't let this fool you! While the hazards of low power lasers appear to be minimal, **be careful and use common sense.** You wouldn't stare at the sun or light from arc lamps so don't stare directly into laser beam or at its bright reflections.

Optics kit inventory

- 1 Laser Pointer Activities Manual
- 1 VLD California-Pacific TI-306 high tech laser pointer
(<http://www.calpaclab.com/lasers/>) 1-888-3CALPAC
- Metrologic laser pointer education kit #45-211
(<http://www.metrologic.com/Pointer.html>) 1-800-667-8400
- 1 Laser Pointer Education Kit Manual (Metrologic)
- 1 color filter set (red, green and blue)
- 1 rectangular prism
- 2 front surface mirrors
- 1 cylindrical lens
- 1 lens, long focal length
- 1 lens, short focal length
- 1 Polaroid filter
- 1 Holographic diffraction grating
- 1 solar cell
- Plastic case (use at least 1 rubber band to hold case closed)
- 1 medium binder clip

Additional materials needed for the various activities

- White screen or wall
- Dusty chalk erasers or baby powder
- Modeling clay (optional)
- Rubber bands (optional) to be used with small, wood blocks
- 5" X 5" squares of colored paper (red, blue, yellow, green, etc. pieces of bright construction paper will work)
- Clear rectangular box (fish tank, plastic shoebox, etc)
- Powdered milk flakes (AgNO_3 works too!)
- 3-5 lbs. of sugar
- Ruler and tape
- Flashlight or other white light source
- Transparent materials
- White paper
- Protractor transparency included (see appendix)
- Triangular glass block
- Heat source (hot plate, Bunsen burner, etc)
- Clear plastic bottle with lid (1 liter works well but smaller will work too)
- Metal stand and clamp

REFERENCES

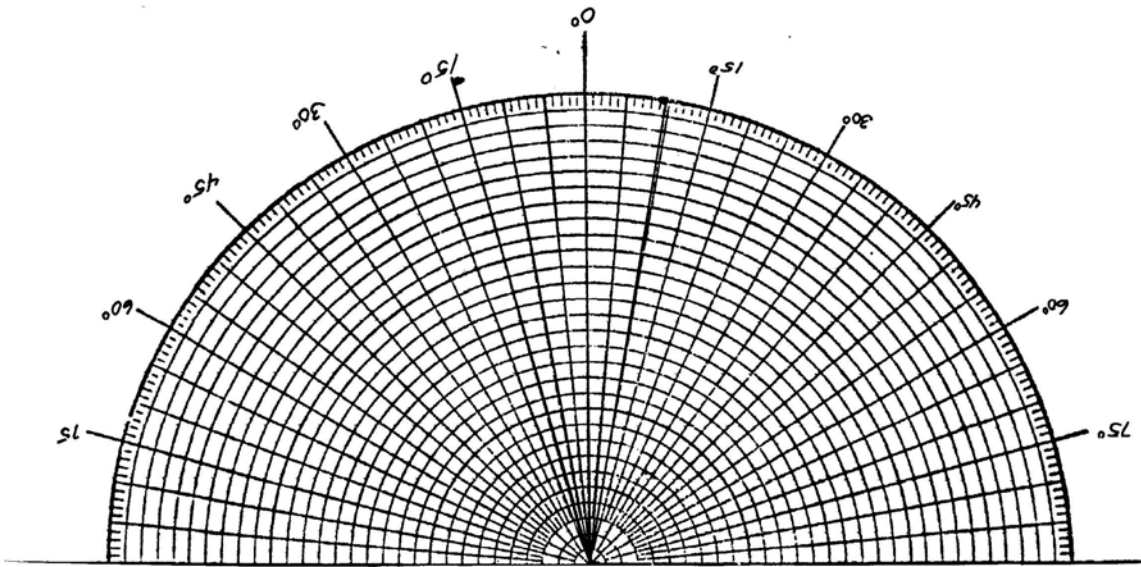
Websites:

<http://www.calpaclab.com/lasers/>
<http://www.metrologic.com/Pointer.html>
<http://www.laserinstitute.org/>
<http://www.osa.org/>
<http://www.mobius.demon.co.uk/lasers/geomet.html>
<http://www.metrologic.com/metrologic.html>
<http://www.psrc-online.org/>
<http://www.aapt.org/>
<http://www.glenbrook.k12.il.us/gbssci/phys/Class/refrn/u14l3b.html>
<http://www.tim.paton.net/bec/rainbows/TIR.htm>
<http://www.exploratorium.edu/snacks/>
<http://howstuffworks.com/>

Texts:

- Carpenter, Jr. D. Rae and Richard B. Minnix. *The Dick and Rae Physics Demo Notebook*.
Lexington, Virginia: DICK and RAE, Inc., 1993.
- Hecht, Eugene. *Optics*. Reading, Massachusetts: Addison Wesley Publishing Company,
1987.
- Hewitt, Paul G. *Conceptual Physics*. Reading, Massachusetts: Addison Wesley Publishing
Company, 1987.
- Pantell, Richard H. *Experiments in Optics with a Laser Source*, Optics Technology, Inc, 1969.
- Tipler, Paul A. *Physics for Scientists and Engineers 3rd edition*. New York: Worth Publishers,
Inc., 1991.
- Williams, John E. and Frederick Trinklein and H. Clark Metcalf. *Modern Physics*. New York:
Holt, Rinehart and Winston, Publishers, 1984.

PROTRACTOR



POLAR GRAPH PAPER

