Performance:
Report:

Total:

Physics 212-9

Optics

NAME: ______________________________ ☐

STUDENT ID: ______________________________ ☐

LAB PARTNER(S): ______________________________ ☐

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Check the box next to the name of the person to whose report your group's data will be attached.

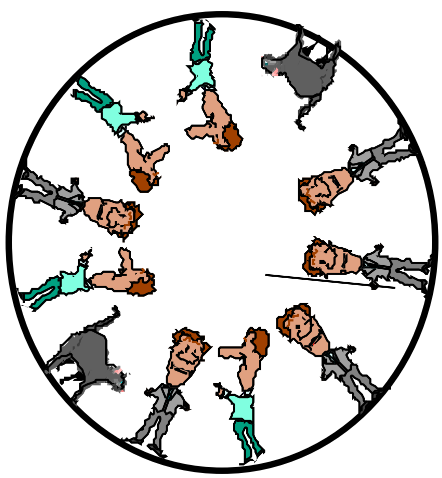
LAB SECTION: ________________________

INSTRUCTOR ID: ________________________

DATE: ________________________

TABLE: ________________________

(YOU WILL BE TAKEN 3 POINTS IF TABLE IS VACANT.)



Life from the Fish's point of view…

Written by Beda, Hearn, Hertzog, Kwiat, Makins & Weissman, modified by Xia Huanxin for ZJUI

Physics Lab 212-9

Equipment List
Ray box
Graph paper, 11 x 17 in (sheets are at the end of the lab in the manual)
Vinyl tape (one roll per station)
Ruler (centimeter rule, one per station)
Plastic rectangular block, used for Snell's Law
Equilateral prisms (2) for dispersion activity
Right triangular prisms (2) for total internal reflection
Laser
Short optics bench and carriers(6)
Linear Polarizers (3)
Plastic plate
DMM
Light sensor

Computer File List
Capstone file “212-09 Current vs. Angle”

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Physics Lab 212-9

Optics

Investigation 1: Polarization

To find out
- How to measure polarization
- How polarizers, reflections, and chiral materials modify polarization

Preview:
- Use a laser and adjustable polarizers to explore Malus' law
- Investigate the effect of a reflection on polarization
- Use the phenomenon of optical activity to determine the sugar concentration of a solution

Caution!
You will be using a laser for parts of this lab. It is not powerful enough to harm your skin, but it can damage your vision. Be careful not to look directly into the beam or into a reflection of the beam!

Activity 1 Malus' Law

In this lab you will have a chance to study polarization of light using a laser, a detector, and polarizing filters. The detector will produce a current when light hits it—you might be more used to thinking about detectors as parts of solar panels. Since it will produce a larger current when more light hits it, you can use it to determine the intensity of the laser beam being transmitted through the polarizers.

Each of the linear polarizing filters should be attached to a frame that will allow it to rotate. The angle markings along their rims indicate the orientation of the axis of transmission, which you can align with the marks on top of the frames. When the 0° marking is pointing to the vertical mark on the polarizer's frame, the filter is transmitting only vertically polarized light.

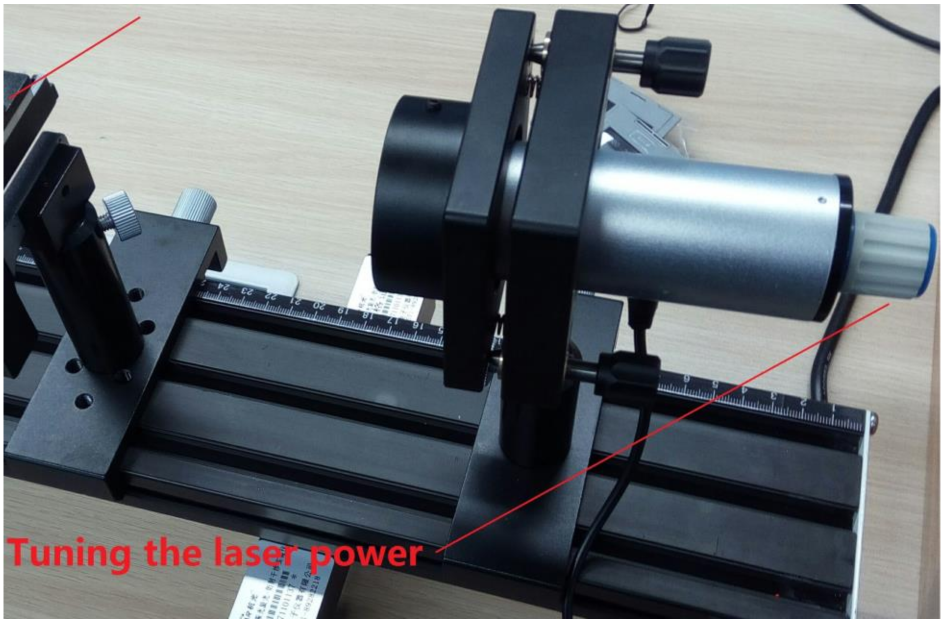
Once the laser is power on, the laser will shoot out!!! So do not plug the connector into the power strip before you want to use the laser!!! Before you run the laser, make sure everything is safe!!!

Turn off the laser if you want to change the setup!!!

Take off your watch, ring, or anything can reflect light!

1. Set up the detector and laser.

   Set laser: laser power could be adjusted by the knob. Adjust the laser power to a modest value so that the powermeter could read it (reading should be 600~1000 units when collimated). Just turn on the powermeter and don’t press any button on the its interface.



   Set the powermeter: Just turn on the powermeter and don’t press any button on the its interface.

   - Make sure the laser is plugged in and securely attached to the bench. Make sure it is pointing at the laser detector (temporarily run the laser).

Now we will place two polarizers between the laser and the detector to examine the effect they have on the amount of light hitting the detector. However, the light that comes out of these lasers is already mostly polarized. This means that a polarizer placed in front of the laser will transmit more or less light depending on its orientation! We want the polarizer to be present so we are dealing with completely polarized light, but we also want as much light to get through as possible (since larger values will be easier to measure). Therefore, we will turn the first polarizer to a value that is close to the laser's polarization.

2. Set up the polarizing filters as in Figure 1 below.
   - Place the first filter in a frame and secure the frame to the optical bench so it is close to, but not touching, the barrel of the laser.
   - The amount of current the multimeter is measuring should have dropped. Watch this current, and slowly turn the polarizer (we'll call it polarizer A) until the current is at its maximum.
   - So that it is easy to calculate the angle of other polarizers in reference to this one.
   - Set up a second polarizer (polarizer B) between the polarizer A and the detector.

3. Measure the background radiation.
   - There is some ambient light in the room which will affect the measurements that you make.
   - Block the laser beam near its source with a piece of paper and measure the current across the detector.
   - The current the detector is producing is the amount of background light incident on the detector. Record this value. Background light = ______________ A
   - Unblock the laser.

Q1 You don't know the angle at which light is polarized coming out of the polarizer A. But you know the polarization of laser beam is the same as the polarizer orientation. From your knowledge of polarization, what angle do you think the polarizer B should be at to let the largest amount of light through (to produce the largest current from the detector)? Which orientation will produce the smallest current?

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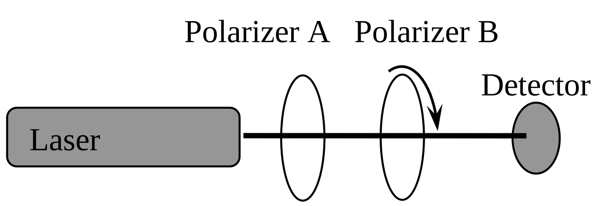

Figure 1. Rotation of polarizer B

4. To study the effects of polarizers on light and to test your prediction, you will make a plot of the intensity of the transmitted laser light (measured by the current across the detector) as polarizer B is rotated.
    - Start by rotating polarizer B to the same position as the polarizer A. The angle between them ($\theta_B - \theta_A$) should be 0°.
    - Note the current you measure across the detector (including background radiation) and enter this value in the first row of Table 1. Subtract the value for background light you obtained earlier to find the current due to the laser beam.
    - Rotate polarizer B by 15° (one hash mark), recording the total current across the detector and the current due to the laser beam.
    - Repeat this process, filling Table 1 with the currents for thirteen different alignments of polarizer B, each 15° apart.

Angle $\theta_B - \theta\theta_A$ (degrees)	Total Current (A)	Current from Laser (A)
0		
15		
30		
45		
60		
75		
90		
105		
120		
135		
150		
165		
180		

Table 1

Q2 Did the largest and smallest currents fall where you predicted they would? Did you record any currents of zero? Why or why not?

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5. To get a visual feel for your data, plot them with the computer.
    - Double-click on the file "212-09 Current vs. Angle" in the "212 lab files" folder on your desktop.
    - Type in the currents from the laser from Table 1 for each alignment of the polarizers.

- Your data should appear on the graph of "Current from Laser" vs. "Angle between Polarizers A and B" ($\theta_B - \theta\theta_A$). Adjust the scale so that all of your points are visible.
- Give your graph a title with your names or initials on it and **Print...** a copy of your results.

Q3 You are only looking at the intensity for 180° of rotation. What do you think the plot would look like if you had measured the intensity for a complete rotation of the polarizer (360°)?

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6. To study three polarizers at once, begin with the setup from your last experiment.
   - Add a third polarizing filter ("C") to the optical bench between polarizer B and the detector, as in Figure 2.
   - Rotate polarizers B and C so they align with polarizer A. This will result in the maximum amount of laser light reaching the detector.

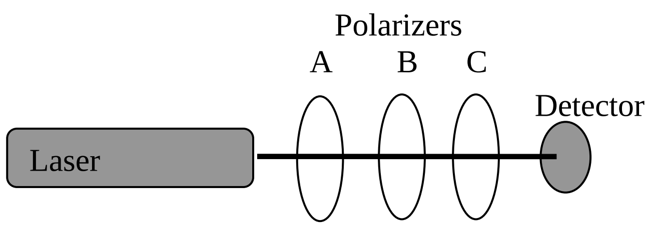

Figure 2. Setup with three polarizers

7. Measure the amount of light through A, B, and C before any of them are rotated.
   - Record the current across the detector from the laser (subtracting the background light): ______________A
   - Although ideally polarizers B and C have no effect on the transmitted intensity, in practice they have some loss even for light polarized along the transmission axis.

Prediction:	How much light do you think will hit the detector if polarizer C is rotated 90° from its current position? ____ ____

8. Test your prediction.
   - Rotate polarizer C by 90° in either direction.
   - Record the current across the detector due to the laser beam (i.e., subtracting the background light).
     ______________A

Prediction:	Using Malus' Law, what fraction of the light hitting a polarizer 45° off its axis of transmission will go through? If there were no losses, what would be the intensity of the light transmitted through polarizers B and C if B were rotated 45°, compared to the intensity when A, B, and C were aligned? ____ ____

9. Try it.
   - Rotate polarizer B by 45°, so that it is halfway between the orientations of polarizers A and C.
   - Record the current from the laser beam (total current minus current from background light):
     _____________A
   - What fraction of the light coming out of polarizer A is now transmitted by polarizers B and C?
     ____

Q4 Would it matter if polarizer B had been rotated 45° in the opposite direction?

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Activity 2 A Moment to Reflect

In this activity we will investigate the phenomenon we saw in the prelab, that non-perpendicular reflections off a dielectric surface (like glass or water) can change the polarization of the reflected light, because one polarization is reflected less efficiently (or not at all!).

1. Keep the setup from the previous activity.
   - Remove the middle polarizer (polarizer B).
   - Rotate polarizer A until the transmitted light is very dim (to protect operators).
   - Put a round platform with an arm between polarizer A and C. Put the glass block on the platform. The (incident) angle between the laser beam and glass front face should be around 45°. And the reflected beam should go along the platform arm, as in Figure 3.

2. Observe the phenomena.
   - Put polarizer B on the platform's arm.
   - If the laser beam doesn't go through polarizer B, slightly turn the position of glass block and/or tune the height of the laser.

- Remove polarizer A.
- Rotate polarizer B (which is on the platform's arm) until the transmitted beam on the screen is dimmest.
- Keep the setup, just remove polarizer B and put it between the light source and glass block.
- Check that the now the transmitted beam through polarizer B is still quite bright.
- Now check beam reflected by the glass block.

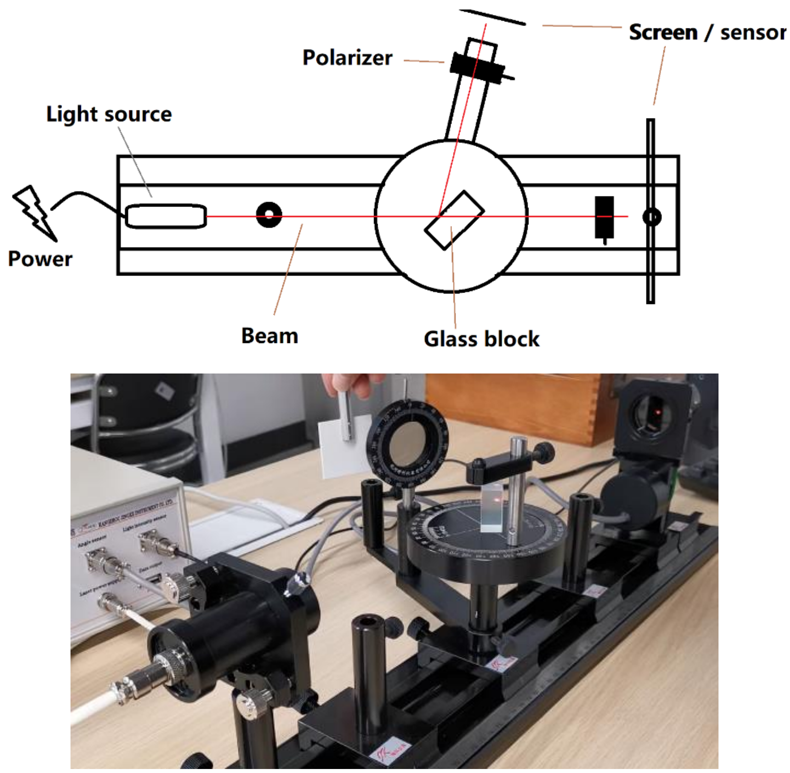

Figure 3. Top view of setup with glass plate.

Q5: What do you observe? What has reflection off the glass block done to the light (suppose now polarization of polarizer B is horizontal)? If now rotate polarizer B 90 degrees, what will happen to the beam transmitted (that is the refracted light) by the glass block?

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Activity 3 Optical Activity

In lecture and the prelab you learned about birefringence, the fact that in some materials the speed of propagation of light depends on its polarization. This fact is used, for example, to make "quarter-wave plates" which can convert linearly polarized light into circularly polarized. In the examples discussed so far, the fast and slow polarizations were always *linear* polarizations. In this activity we will investigate a different phenomenon in which the fast and slow polarizations are right and left *circular* polarizations.

Some materials, particularly some molecules (e.g., sugars), are "chiral" – a chiral molecule is one that is not superimposable on its mirror image – that is, it has a natural "handedness", like a left-handed or right-handed screw. You can imagine that the molecule is like a helix, which either spirals clockwise or counter-clockwise. **A chiral substance has the property of rotating the plane of polarization of linearly polarized light that is passed through it. This phenomenon is called *optical activity*,** and is very useful for detecting chiral substances. If we shine linearly polarized light through a sample of optically active material, the direction of linear polarization will slowly rotate. The *direction* of the rotation will depend on the handedness (right- or left-handed) of the optically active material, and the *amount* of rotation will depend on how much material there is. For example, soft drink companies use this to check the sugar concentration of their products—the more the light rotates, the more sugar in your favorite soda.

Although we can synthesize sugars with either type of handedness (i.e., both clockwise and counterclockwise "spirals") in the laboratory, naturally occurring sugars like dextrose always have the same handedness. In fact, the enzymes in your stomach cannot digest sugars with the wrong handedness!

Why does it happen?

Just as we saw that any circular polarization can be written as the sum of two linearly polarized waves with a 90° phase shift between them, it also turns out that any linearly polarized wave can be written as the sum of right- and left-circularly polarized components, with some phase shift between them. The size of this phase shift determines the angle of the linear polarization. If circularly polarized light travels through a material with only one direction of spiral, it should not surprise you that the speed of propagation of the light depends on whether the circular polarization of the light is spiraling in the same direction as the molecular spiral, or in the opposite direction. If linearly polarized light travels through the same material, then, one circular polarization component will pull ahead of the other component, causing their relative phase shift to change. The result is a rotation of the linear polarization.

The setup for this activity is located at the front of the room. (You might need to wait for another group to finish with it.) A laser beam is passed through two polarizers and the transmitted beam then shines on a blank card. There are two cells, *A* and *B*. One contains pure sugarcane (which has a high concentration of sugar) and the other contains sugarcane that has been diluted with water (water is not optically active). These are in turn placed between the polarizers and the rotation of the polarization axis due to their presence is measured.

1. You know that to get the **minimum** transmission without optical activity, you would put the second polarizer at right angles to the first.
   - Try this now. Watch the laser light on the card become brighter as the polarizers are aligned, and dimmer as the angle between them increases.
   - Set the angle between the polarizers to 90° (minimum transmission).

2. Place cell A between the polarizers in such a way that the laser beam shines straight through the shortest horizontal dimension of the sugarcane solution in the cell.
   - The intensity of the light on the card should have changed. Take note of the angle of the second polarizer and then rotate it counter-clockwise so that it transmits as little light as possible.
   - Record the angle that the second polarizer had to be rotated. This angle should be between 0 and 90 degrees. The sugarcane solution has rotated the polarization of the light by this amount.
   - Rotation due to cell A = ______________ degrees

3. Remove cell A, rotate the second polarizer clockwise back to where transmission is minimized, and then place cell B between the polarizers.
   - Repeat the procedure (again rotating the second polarizer counter-clockwise) to find the orientation of the second polarizer that gives the smallest transmission.
   - Record the angle that the second polarizer had to be rotated. This angle should also be between 0 and 90 degrees.
   - Rotation due to cell B = _____________ degrees

Q6: Which of the two cells, A or B, contains the most concentrated sugarcane solution?

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Q7: Since the amount of rotation is directly proportional to the concentration of the optically active solute, you can calculate the relative concentrations of the two sugarcane solutions. Do so.

Ratio of concentrations = ______________

Investigation 2: Index of Refraction

To find out

- How light passes from one medium to another; Snell's law
- The essence of dispersion
- The phenomenon of total internal reflection

Preview

- Use a lab bench optics kit to investigate quantitatively the index of refraction of a piece of plastic
- Investigate dispersion using a prism
- Find the critical angle for total internal reflection inside of a dielectric

Note: use the light box which can produce white light and three colors light. It's not necessary to follow the detailed steps in the manual.

Activity 4 (optional) Snell's Law

In the first part of this lab, you saw how the index of refraction of a material could change the polarization of light passing through it (if the index of refraction depends on the polarization). Here we will explore how the index affects the *direction* of the light. Although you will soon see that light is a wave and accordingly obeys the peculiar properties of waves, the study of optics is predicated on the idea that we can use *rays* to determine the path followed by light waves. This is a valid assumption when the wave effects (interference, diffraction, etc.) are negligible. So, think of a ray of light as an arrow with a definite direction.

You already know that if light reflects off an interface, the angle of reflection (if there *is* any reflection) is equal to the angle of incidence; this result does not depend on the properties of the material (as long as it is smooth). However, the propagation in the material clearly *does* depend on the material – the light does not propagate at all in a metal (although high energy photons – x-rays and gamma rays – can penetrate some metals). When a wave travels from one medium to another, its speed changes. Since light is an electromagnetic wave, it exhibits this effect as well. The *index of refraction* is used to characterize the speed of light in a transparent medium. It is defined as

$$n \equiv \frac{c \text{ (speed in vacuum)}}{v \text{ (speed in medium)}} \qquad \text{(Eq. 1)}$$

and since nothing is faster than the speed of light in a vacuum, you will notice that this results in a quantity that is always greater than or equal to 1. The speed of light in a vacuum is $c = 2.99792458 \times 10^8$ m/s.

When light strikes a boundary between two different media, two things occur. First, part of the light is reflected. Second, some of the light is transmitted into the second medium and is then bent, or *refracted*. Snell's Law describes the refraction of light between two media. An expression for Snell's Law using the characteristic index of refraction of materials is

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad \text{(Eq. 2)}$$

If the medium is a vacuum, then the index of refraction is exactly 1.0. The index of refraction for air is usually taken to be 1.0 even though it is slightly more than this.

A typical textbook picture is shown in Figure 3 with the angles in Equation 2 corresponding to those on the diagram.

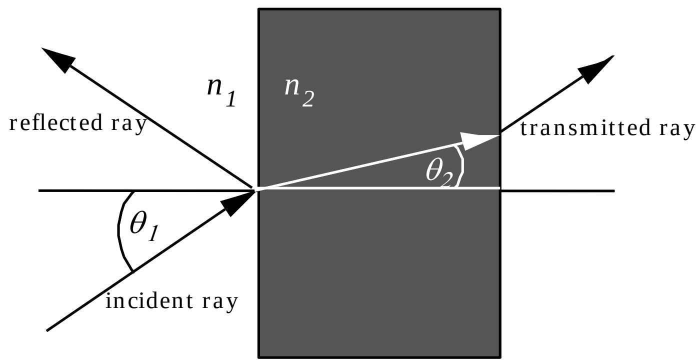


Figure 3. Typical Snell's Law diagram

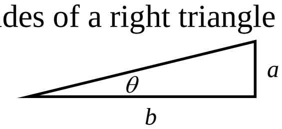
Let us use Snell's Law to find out the index of refraction of a rectangular piece of plastic.

1. Prepare your setup.
    - Figure 4 shows the special light source at your table. This light box is designed so that you can see and trace individual rays of light.
    - Turn on your light box by turning on the switch on the power bar. The AC adapter may need to be plugged into the power bar and/or the box. When you do not plan to use the box for an extended period of time, please turn it off.
    - Slide the shutter on your light box so that a single, well-defined ray of light emerges.
    - Carefully tape a large sheet of graph paper flat on your table. You will use this graph paper to take data. Be sure to carefully annotate any data you record on it, as it will be turned in with your report at the end of the class. Without recording your observations and how they were made, you will not be able to go back to explain what was done when your TA comes by to talk about it.
    - Find the clear rectangular block and place it inside the grid lines approximately in the middle of your graph paper.
    - Trace a line around the rectangle directly on the paper.
    - Choose the single slit on your light box and aim the beam at the rectangle so that you achieve a picture similar to that in Figure 3. Make the angles θ_1 and θ_2 as large as possible in order to make measuring them easier. Make sure you use the clear sides of the plastic block!

Figure 4. Basic light box with single beam setup

2. Make your measurements.
   - Carefully mark the following four points on your graph:
     1. on the incoming light ray, a point as far away from the block as possible but still on the paper
     2. at the point where the incoming ray hits the plastic
     3. at the point where the ray emerges from the plastic
     4. on the outgoing ray as far away as you can from where it exits the plastic, but still on the paper
   - Remove your light box and plastic rectangle, turn on your desk lamp, and connect the points using a ruler.
   - Label this section of the graph paper "Snell's Law."

3. Calculate some quantities.
   - Using some trigonometric relations, deduce the angles θ_1 and θ_2.   You may find it helpful to extend the ray that is “inside” the block by placing a ruler on it and just continuing it along your graph paper. As a hint, measure the sides of a right triangle and recall that



$$\tan \theta = \frac{a}{b}$$

Calculation space

4. Record your values.
   - Record your values for θ_1 and θ_2

     $\theta_1 =$ ______________

     $\theta_2 =$ ______________

Q8 Based on Equation 2, what is the index of refraction for the plastic block?

$n_{plastic} =$ ______________

Q9 Based on your value, what is the speed of light in the plastic block?

$v_{plastic} =$ ______________ [m/s]

Q10 Is this value reasonable for the speed of light in plastic? Explain.

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Activity 5 Dispersion

All of us have witnessed the sight of a beautiful rainbow. How does this happen? Here is a hint. It is based on both reflection and refraction. However, more than what we have investigated so far is needed to explain this phenomenon.

Prediction Suppose you repeated an experiment similar to the one above, but this time used a triangle of glass instead. Trace the expected refraction (no reflections) inside the glass (n = 1.5) and the direction of the emerging ray.

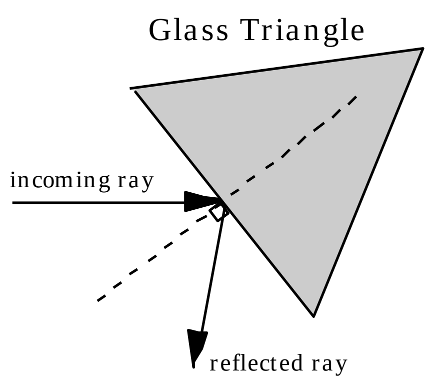

Figure 5. Rays on a glass triangle

1. Set up the experiment.
   - Select the *glass* equilateral triangle and place it on an unmarked part of your graph paper.
   - Turn on the beam and aim it at the triangle as drawn in Figure 5.
   - Draw the resulting rays on the graph paper.

Q11 How did your result compare with your prediction? If you were off, choose a different color pen or pencil and indicate on the drawing above the true direction of the rays.

____

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Q12 Besides the general direction of your light beam, what else do you notice?

____

____

2. Magnify the effect!
   - Place a second equilateral triangle (okay, let us go ahead and call them prisms) next to the first as in Figure 6. You should then find a large spread of colors, although you may need to adjust the positions of the prisms in order to find them.

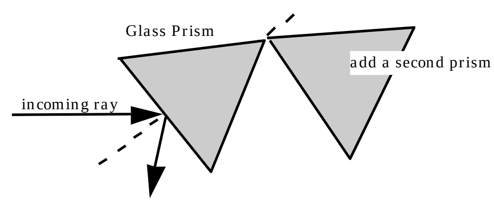

Figure 6. Two prisms

The phenomenon you have just explored is known as *dispersion*. A combination of reflection and the wavelength dependence of refraction make up the mechanism for the formation of a rainbow.

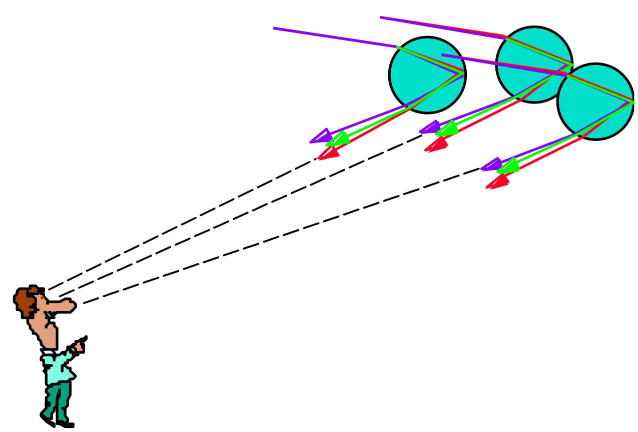

Figure 7. Reflection, refraction, and dispersion in water droplets give us a rainbow.

Q13 If the individual colors are bending by different amounts, what does this say about the index of refraction? On what characteristics of the light might the index of refraction depend?

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____

Q14 Which color bends the most? Which the least?

____

____

Activity 6 Total Internal Reflection

Consider a material with an index of refraction n_i, which is greater than n_o, the index of refraction outside of the material. Examining the rays starting from the inside and traveling outside of such a medium and looking at Snell's Law, $n_i \sin\theta_i = n_o \sin\theta_o$, we notice that an interesting thing happens if the outside angle θ_o is 90°. This corresponds to a ray that "skims" along the boundary between the two media. At 90°, $\sin\theta_o = 1.0$ which corresponds to an incident inside angle θ_i such that

$$\sin\theta_i = \frac{n_o}{n_i} \qquad \text{(Eq. 3)}$$

The incident inside angle that satisfies this equation is called the *critical angle*, θ_c. For all angles of θ_i larger than the critical angle, no light escapes from the medium of higher index of refraction. Optical fibers, which can transmit light through very long distances with little loss, are based on this principle.

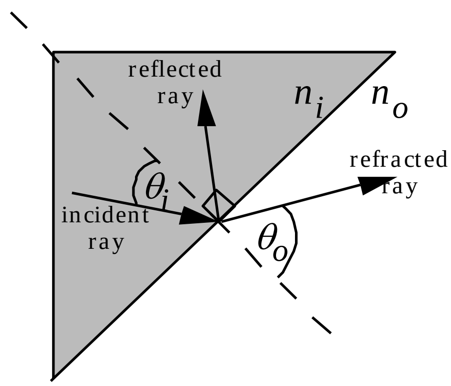

Figure 8. Setup for checking critical angles

Theory Calculation

Calculate the *critical angle* for one of the plastic right triangles in your set using the index of refraction of 1.5. Show your work.

θ_c = ____________ [degrees]

1. Make some observations.
   - Set the light box shutter to a single slit.
   - Place one of the right-angle triangular prisms on an empty region of your graph paper, and orient the ray and the prism as shown in Figure 9. Notice that the incoming ray is initially refracted through the prism.

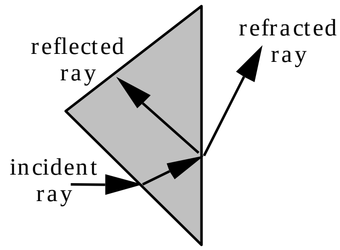

Figure 9. Ray through prism

2. Find the critical angle.
   - Slowly rotate the prism *clockwise* while watching both the refracted ray and the fainter ray inside the prism. You will know when you have reached the critical angle when the refracted beam disappears along the hypotenuse of the prism, and the reflected ray becomes much brighter.
   - Make the appropriate measurements on the graph paper, calculate the critical angle, and record it here

θ_c = ___________ [degrees]

   - Continue rotating the prism. Notice how the back surface of the prism acts just like a mirror. You can make the incoming ray and the reflected ray be at 90º to each other.
   - Label this section of the graph paper "Critical Angle."

Q15 Was the measured value for θ_c greater or lesser than the calculated value? Given the value that you measured for θ_c, is the index of refraction of the plastic right triangle greater or lesser than 1.5?

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3. Using a pair of these, can you build a periscope?
   - Select the three slit shutters and arrange two right triangular prisms to bend the rays around a corner. This is how the prisms inside binoculars allow optical designers to construct short instruments.
   - Sketch your device below.

Draw your construction and trace some light rays.

CLEAN UP CHECKLIST

- ☐ Turn off the light box.
- ☐ Put everything away. Neatly organize your light box components and clean any that may have been rudely smudged.
- ☐ Attach the printout to the lab report of the designated member of your group.
- ☐ Collect the paper onto which data was taken (and annotated) and attach them to one of the lab reports.
- ☐ Make your setup look neat for the next group.
- ☐ Put your discussion section on the front of the lab so your TA has a chance of returning your graded lab to you.
- ☐ Staple everything together, make sure you have answered all the questions and done all the activities, make sure the first page is completed with lab partners' names and check boxes, hand in your work, leave.

Draw the light path of the refraction here: