Lab Handout

Lab 20. Reflection and Refraction

How Can You Predict Where a Ray of Light Will Go When It Comes in Contact With Different Types of Transparent Materials?

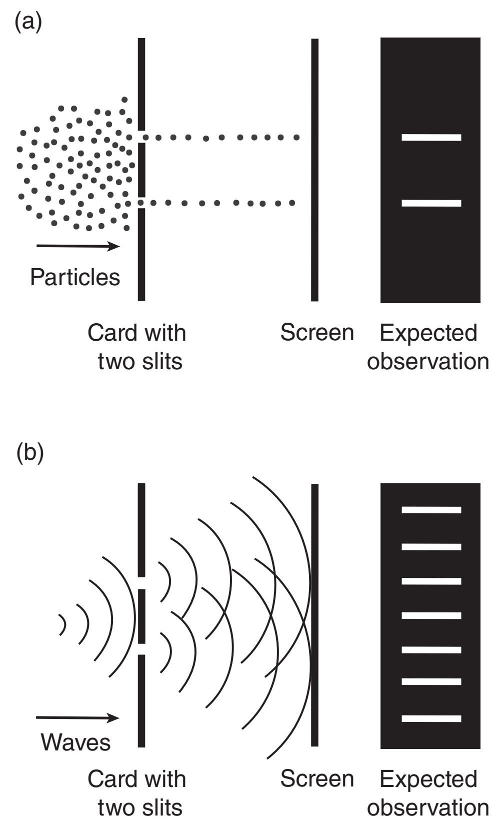
Introduction

Our understanding of the nature of light and how it behaves has changed a great deal over the centuries. The first real explanations for the nature and behavior of light came from the ancient Greeks. Most of these early models describe the nature of light as a ray. A ray moves in a straight line from one point to another. Euclid and Ptolemy, for example, used ray diagrams to show how light bounces off a smooth surface or bends as it passes from one transparent medium to another. Other scholars took these ideas and refined them to explain the behavior of light when it strikes a mirror, a lens, or a prism. This field of study is now called geometrical optics. The most famous practitioner of geometrical optics was the 10th–11th century Arab scientist Ibn al-Haytham, who developed mathematical equations that describe how light bends as it travels through different media.

Scientists began to use different models to explain the nature of light in the 17th century. For example, Christiaan Huygens claimed that light is a wave that moves through an "invisible ether" that exists all around us. Isaac Newton, in contrast, claimed that light is composed of small particles, because it travels in a straight line and bounces off a mirror, much like a ball bounces off a wall. Most scientists continued to use a model that treated light as particle in their research until the early part of the 19th century. In 1801, however, Thomas Young showed that if light is made to travel through two slits in a card, it produces a series of light and dark bands on a screen. He argued that this observation would not be possible if light was composed of particles that travel in a straight line (see Figure L20.1[a]) but it would be possible if it traveled through space and time as a wave (see Figure L20.1[b]).

FIGURE L20.1

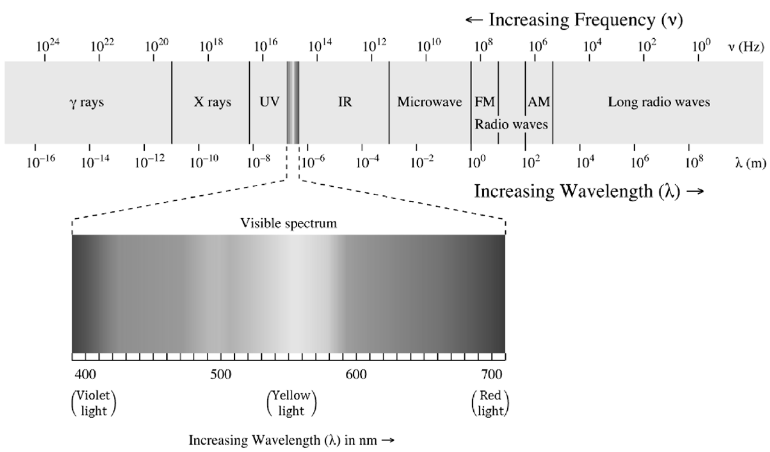
Appearance of light on screen if light is composed of particles (a) or waves (b)



Then in the 1860s, James Maxwell created a new model that described the nature of light as electromagnetic radiation. Electromagnetic radiation does not need a medium to travel through like sound waves do, and when it is traveling in a vacuum (such as space), it moves at a speed of about 300,000 kilometers per second. According to this model, light waves come in many different sizes and these waves can be described in terms of wavelength and frequency (see Figure L20.2). The wavelengths of light that we can see are between 400 and 700 nanometers long, but all the different wavelengths in the electromagnetic spectrum range from 0.1 nanometer (gamma rays) to several meters (radio waves) in length. The frequency of a light wave is the number of waves that pass a point in space in a specific time interval. We measure frequency in hertz (cycles per second), abbreviated Hz. Red light has a frequency of 430 trillion Hz, and violet light has a frequency of 750 trillion Hz.

FIGURE L20.2

Wavelengths and frequencies of the different types of waves in the electromagnetic spectrum



As it turns out, all of these models for the nature of light are both right and wrong at the same time, because they can only be used to explain or predict certain behaviors of light. Scientists now use a model that describes the nature of light as being a particle and a wave. In this investigation, however, you will use a ray model of light to investigate how light behaves when it comes in contact with different types of transparent materials. When a ray of light passes between two transparent materials (such as air, water, plastic, or glass), part of the ray is reflected and stays in the first material, while the rest of the ray is refracted as it passes into the second material. The ray of light refracts when it enters the second material because it changes speed (slows down or speeds up) as it begins to travel through the new materials.

Figure L20.3 shows a ray of light crossing the boundary between two transparent materials. In the field of optics, a line perpendicular to the boundary is used to measure the angles of the light rays. This line is called the surface normal. The angle the incoming ray makes with the surface normal is called the angle of incidence (θ_i). The angle the reflected ray makes with the normal is called the angle of reflection (θ_r), and the angle the refracted ray makes with the normal is called the angle of refraction (θ_R). Your goal in this investigation is to develop one or more rules that you can use to predict the behavior and path of the reflected and refracted rays, much like Ibn al-Haytham did when he created mathematical equations to describe the behavior of light when it strikes a mirror, a lens, or a prism.

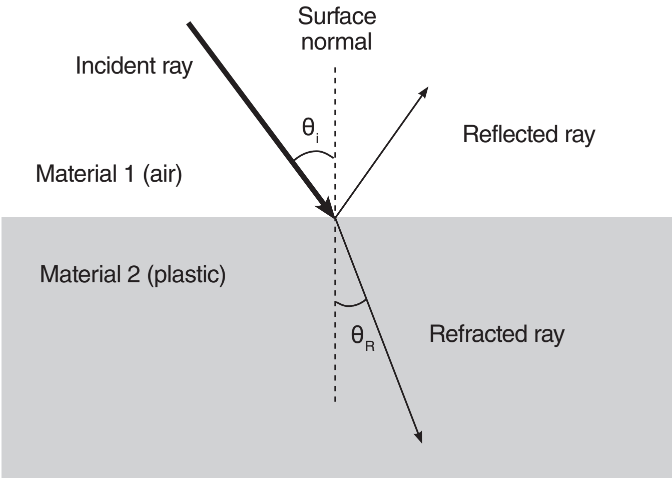
The Task

Use what you know about light, uncovering patterns in nature, and the use of models in science to design and carry out an investigation using a simulation to determine how light behaves when it travels through one transparent material and then enters into a different one.

The guiding question of this investigation is, **How can you predict where a ray of light will go when it comes in contact with different types of transparent materials?**

FIGURE L20.3

A ray of light crossing the boundary between two transparent materials (air and plastic)



Materials

You will use an online simulation called *Bending Light* to conduct your investigation. You can access the simulation by going to the following website: *https://phet.colorado.edu/en/simulation/bending-light.*

Safety Precautions

Follow all normal lab safety rules.

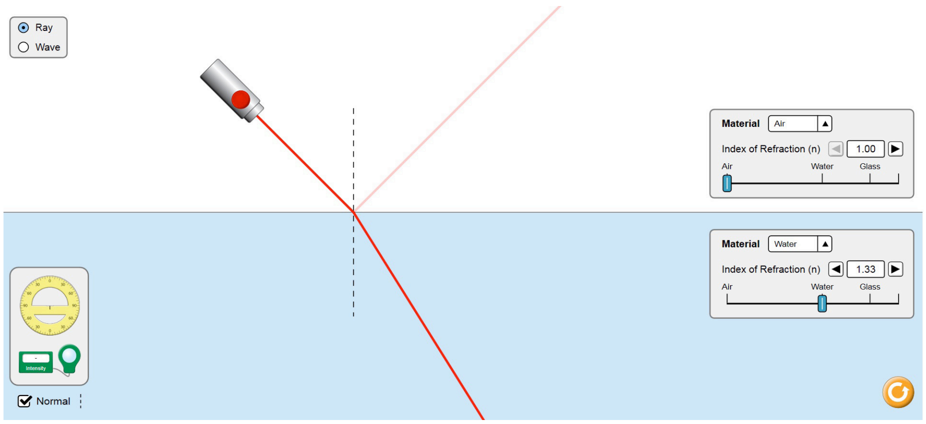
Investigation Proposal Required? ☐ Yes ☐ No

Getting Started

The *Bending Light* simulation (see Figure L20.4, p. 194) enables you to change the angle of incidence of a light ray that crosses the boundary between two transparent materials and then measure the angle of reflection and refraction. You can also adjust the properties of the two materials and measure the light intensity of each light ray. To use this simulation, start by clicking on the "Intro" button. You will then see a laser pointer and a horizontal line that represents the boundary between two different materials. Click on the red button on the laser pointer to turn it on. This will allow you see a light ray and what happens to it as it crosses the boundary between the two transparent materials. You can change the angle of incidence of the light ray by clicking and dragging on the left end of the laser pointer. To measure the angle of incidence, the angle of reflection, and the angle of refraction, simply drag the protractor in the lower-left corner and drop it on the surface normal (which is represented by the dashed line). You can change the properties of the two transparent materials using the gray boxes on the right side of the screen. Finally, you can measure the light intensity of any ray by dragging and dropping the green light intensity meter where you need it. The green light intensity meter is located in the lower-left corner of the simulation.

FIGURE L20.4

A screen shot of the *Bending Light* simulation



To answer the guiding question, you must determine what type of data you need to collect, how you will collect the data, and how you will analyze it. To determine *what type of data you need to collect*, think about the following questions:

- Which factors will you need to account for to be able to make accurate predictions?
- What type of measurements will you need to record?

To determine *how you will collect the data using the simulation*, think about the following questions:

- What will serve as your dependent variable or variables?
- What will serve as your independent variable or variables?
- How will you vary the independent variable?
- What will you do to hold the other variables constant during each experiment?
- What types of comparisons will you need to make using the simulation?
- How many comparisons will you need to make to determine a trend or a relationship?
- How will you keep track of the data you collect and how will you organize it?

To determine *how you will analyze the data*, think about the following questions:

- What type of calculations will you need to make?
- What type of graph could you create to help make sense of your data?

Once you have collected the data you need, your group will need to use your findings to develop an answer to the guiding question for this investigation. Your answer to the guiding question must explain how to predict the path of the ray as it crosses the boundary between two transparent materials. For your claim to be sufficient, your answer will need to include both the angle of reflection and the angle of refraction. You can then transform the data you collected using the simulation to support the validity of your overall explanation.

Connections to Crosscutting Concepts, the Nature of Science, and the Nature of Scientific Inquiry

As you work through your investigation, be sure to think about

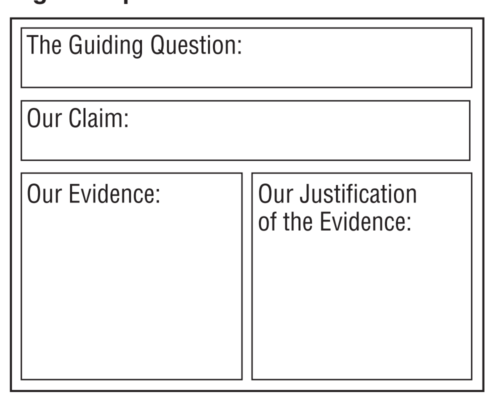
- the importance of looking for and understanding patterns in data,
- the importance of using models to study natural phenomena in science,
- how scientific knowledge can change over time, and
- the culture of science and how it influences the work of scientists.

Initial Argument

Once your group has finished collecting and analyzing your data, your group will need to develop an initial argument. Your initial argument needs to include a *claim*, *evidence* to support your claim, and a *justification* of the evidence. The claim is your group's answer to the guiding question. The evidence is an analysis and interpretation of your data. Finally, the justification of the evidence is why your group thinks the evidence matters. The justification of the evidence is important because scientists can use different kinds of evidence to support their claims. Your group will create your initial argument on a whiteboard. Your whiteboard should include all the information shown in Figure L20.5.

FIGURE L20.5

Argument presentation on a whiteboard



Argumentation Session

The argumentation session allows all of the groups to share their arguments. One member of each group will stay at the lab station to share that group's argument, while the other members of the group go to the other lab stations to listen to and critique the arguments developed by their classmates. This is similar to how scientists present their arguments to other scientists at conferences. If you are responsible for critiquing your classmates' arguments, your goal is to look for mistakes so these mistakes can be fixed and they can make their argument better. The argumentation session is also a good time to think about ways you can make your initial argument better. Scientists must share and critique arguments like this to develop new ideas.

To critique an argument, you might need more information than what is included on the whiteboard. You will therefore need to ask the presenter lots of questions. Here are some good questions to ask:

- How did you collect your data? Why did you use that method? Why did you collect those data?
- What did you do to make sure the data you collected are reliable? What did you do to decrease measurement error?
- How did your group analyze the data? Why did you decide to do it that way? Did you check your calculations?
- Is that the only way to interpret the results of your analysis? How do you know that your interpretation of your analysis is appropriate?
- Why did your group decide to present your evidence in that way?
- What other claims did your group discuss before you decided on that one? Why did your group abandon those alternative ideas?
- How confident are you that your claim is valid? What could you do to increase your confidence?

Once the argumentation session is complete, you will have a chance to meet with your group and revise your initial argument. Your group might need to gather more data or design a way to test one or more alternative claims as part of this process. Remember, your goal at this stage of the investigation is to develop the most acceptable and valid answer to the research question!

Report

Once you have completed your research, you will need to prepare an *investigation report* that consists of three sections. Each section should provide an answer to the following questions:

1. What question were you trying to answer and why?
2. What did you do to answer your question and why?
3. What is your argument?

Your report should answer these questions in two pages or less. This report must be typed, and any diagrams, figures, or tables should be embedded into the document. Be sure to write in a persuasive style; you are trying to convince others that your claim is acceptable and valid!