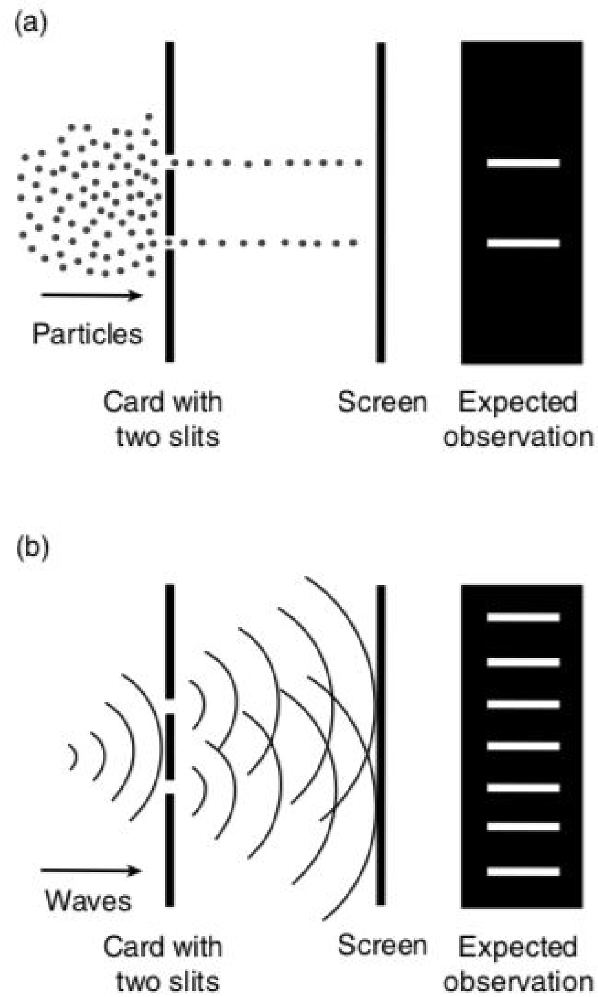
Reflection and Refraction: How Can You Predict Where a Ray of Light Will Go When It Comes in Contact With Different Types of Transparent Materials?

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.

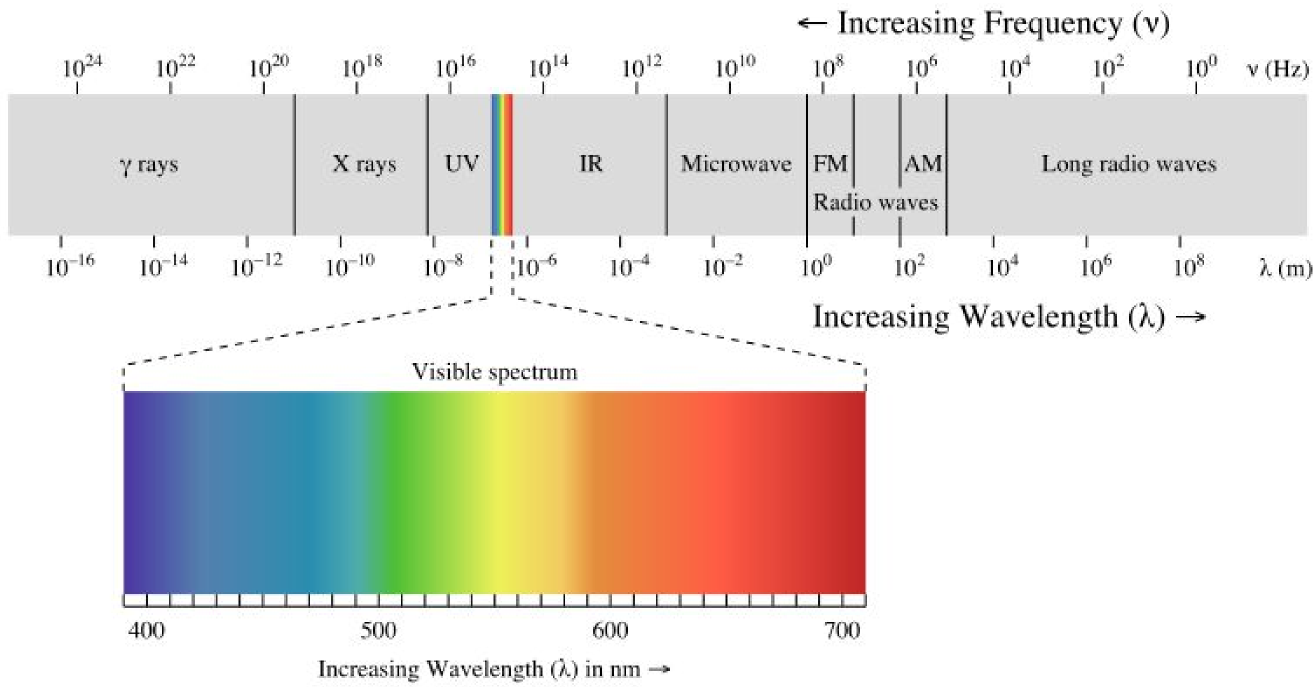
Appearance of light on screen if light is composed of particles (a) or waves (b)



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 particles 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 to the right [a]) but it would be possible if it traveled through space and time as a wave (see figure to the right [b]).

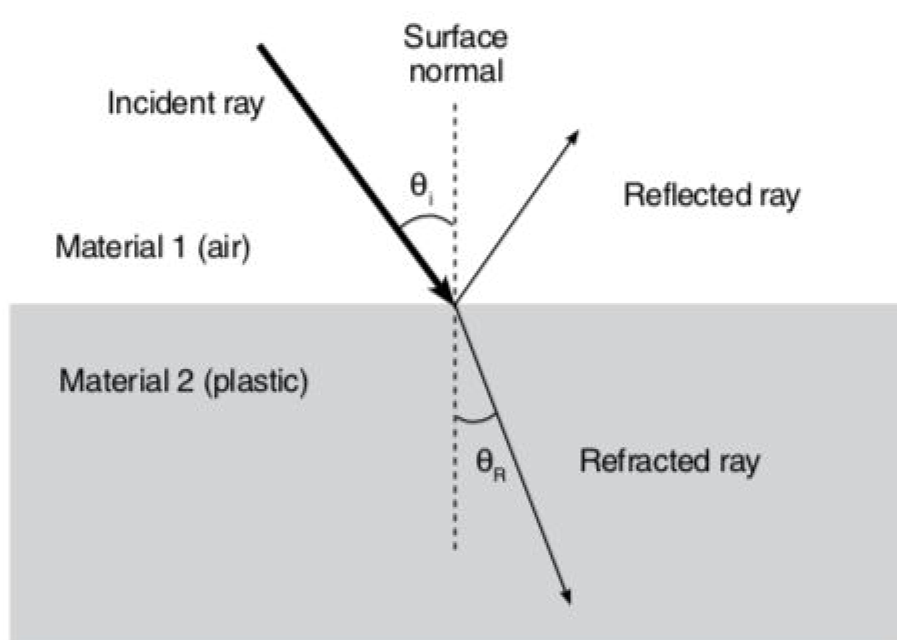
Then in the 1860s, James Maxwell created a new model that described the nature of light as electromagnetic radiation. Electromagnetic radiation does not need a medium to travel through like sound waves do, and when it is traveling in a vacuum (such as space), it moves at a speed of about 300,000 kilometers 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 on next page). 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.

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.

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



The figure to the right 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 (θi). The angle the reflected ray makes with the normal is called the angle of reflection (θr), and the angle the refracted ray makes with the normal is called the angle of refraction (θR). 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.

Your 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?***

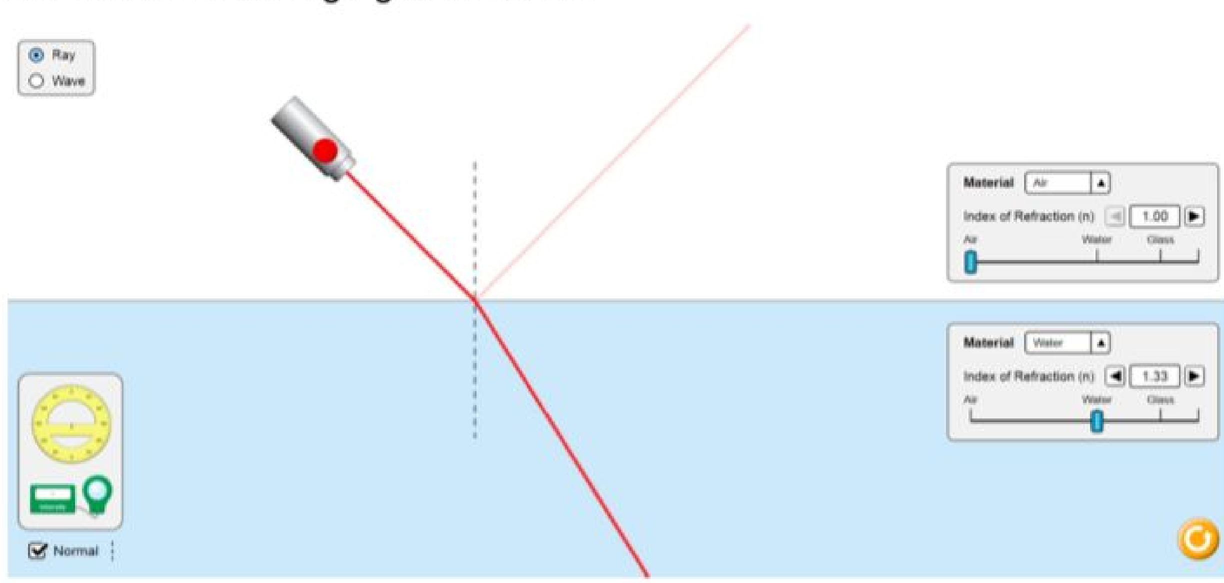
Materials

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/sims/html/bending-light/latest/bending-light_en.html.

Getting Started

The *Bending Light* simulation (see figure below) 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 to 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.

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 independent variable or variables? Be sure to focus on changing only one factor at time (i.e., angle of incidence, material 1, material 2, or index of refraction) so it is easier to determine a relationship.
- How will you vary the independent variable?
- What will serve as your dependent variable or variables? Be sure to record actual values (e.g., angle of incidence, angle of reflection, angle or refraction, light intensity, index of refraction, rather than just attempting to describe what you see on the computer screen (e.g., the angle was bigger).
- 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? What kind of data tables will you make to record your data?

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, you 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.

Report

Once you have completed your research, you will need to prepare an investigation report that consists of four sections (be sure to have section headings):

1. Introduction: Give some background information on the topic. Explain what question you were trying to answer and include a hypothesis. (Background info, research question and hypothesis)
2. Procedure: What did you do during your investigation and why did you conduct your investigation in this way? (How you collected and analyzed data)
3. Data: Include a data table and/or graph to show your results. Be sure to include a title for your table or graph with labels for the variables.
4. Conclusion: What is your argument? (Claim - Evidence - Reasoning)

Your report should answer these questions in two pages or less. The report must be typed, and any diagrams, figures, or tables should be embedded into the document. Type your report on Google Docs (12 point font, double-spaced) and share it with your teacher. Your report will be graded based on the rubric in the class syllabus.