Khan Academy

STUDENT ACTIVITY GUIDE

Why do optical discs reflect rainbow colors?

The challenge

An optical disc, like a CD, DVD, or Blu-ray, reflects rainbow colors when white light shines on it. What is it about these discs that makes them separate white light into the colors of the visible spectrum?

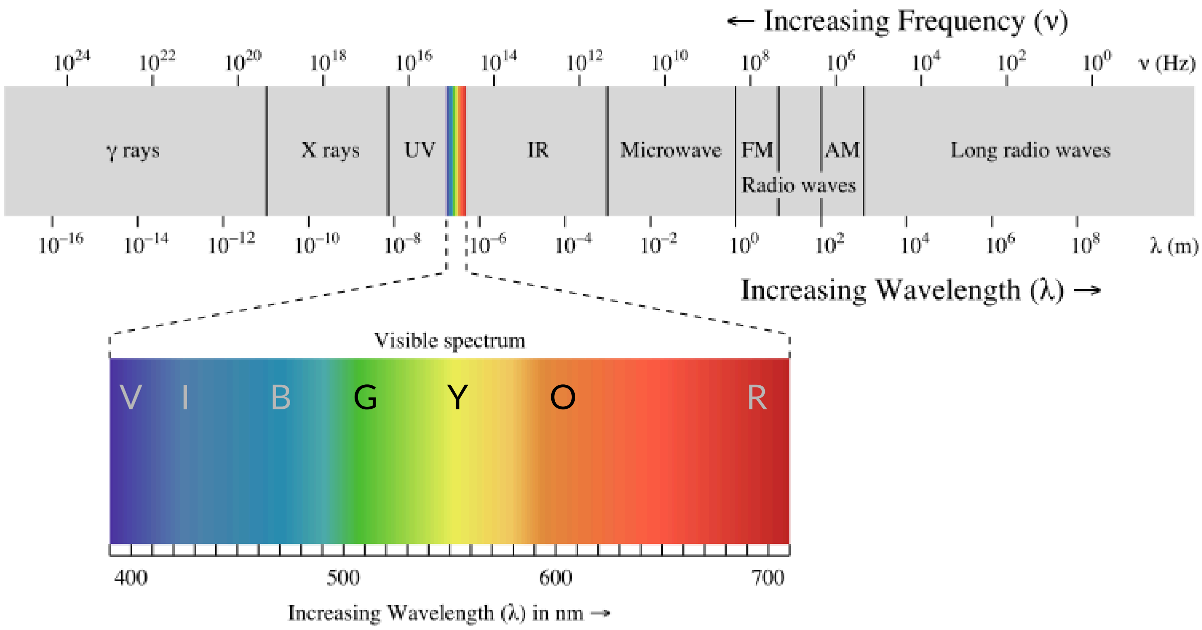
In this activity you'll apply your understanding of wave behaviors and the properties of electromagnetic radiation to explore, model, and explain this phenomenon.

By the end of this activity, I will be able to...

- model why an optical disc causes white light to separate into colors.
- explain how the behavior of light shining on an optical disc supports the wave model of electromagnetic radiation.

Setting the stage

Electromagnetic radiation consists of oscillating electric and magnetic fields. The different bands of electromagnetic radiation are organized by wavelength on the **electromagnetic spectrum**. Visible light is only a small portion of the entire electromagnetic spectrum, as shown on the following diagram.

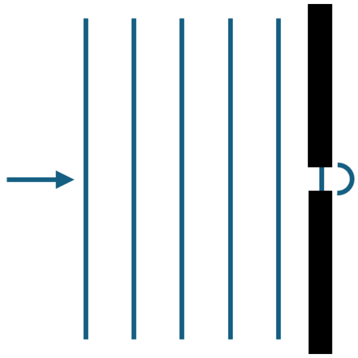


The electromagnetic spectrum by Phillip Ronan, CC-BY-NC-SA 3.0.

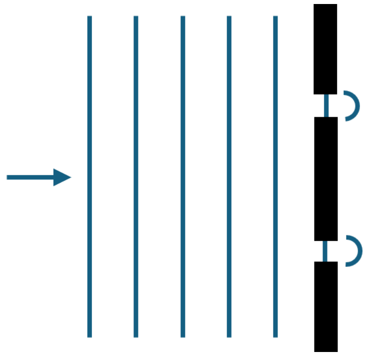
Based on the spectrum above, **visible light** ranges from wavelengths of about ______________________________ nanometers to about ______________________________ nanometers. The color with the shortest wavelength is ______________________________, and the color with the longest wavelength is ______________________________. When all colors of the visible spectrum enter our eyes simultaneously in equal amounts, we see ______________________________ light.

When a wave encounters an obstacle or opening that is *similar in size to its wavelength*, the wave will spread out in a phenomenon called ______________________________.

In the example below, a top-down view shows a wave encountering an opening. The wavefronts, shown as vertical lines, diffract as they pass through the opening. Finish the diagram by sketching additional wavefronts to model how they spread.



If the wave encounters two openings, it will diffract through both of them and produce a new wavefront from each. Finish the diagram below by sketching additional wavefronts from each opening. (*Hint: the wavefronts can overlap.*)

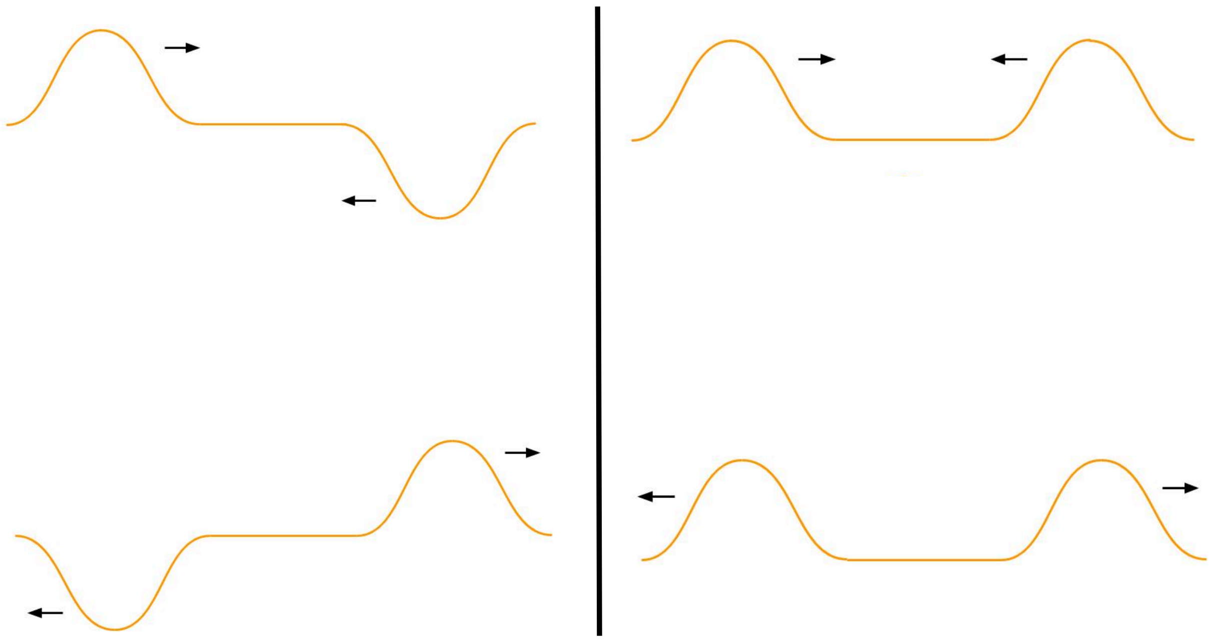


In the second diagram, the wavefronts meet and pass through each other. As a result, their effects sum together in a phenomenon called ______________________________.

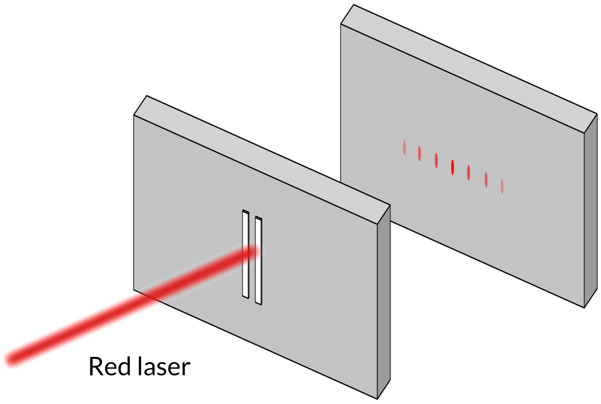
If the crests of the original waves line up with each other, or the troughs line up with each other, then the amplitude of the resulting wave will be (circle one) **greater than / less than** than the original waves. This is called ____________________________ interference.

On the other hand, if the crests of one wave line up with the troughs of the other wave, then the amplitude of the resulting wave will be (circle one) **greater than / less than** the original waves. This is called ____________________________ interference.

In the examples below, two wave pulses are shown approaching each other, then moving apart as they pass each other. In the blank space between, sketch what happens when the wave pulses meet and interfere.



A transmissive **diffraction grating** is a surface that has many tiny openings for light to pass through. In the example below, a red laser is shone through a portion of a diffraction grating containing two slits. Instead of two bright spots appearing on the screen behind the slits, a pattern of bright and dark areas appears.



The interference pattern on the screen demonstrates two important behaviors of light. The red light appears *spread out* after passing through the slits. This is evidence that the light experiences ______________________________ as it passes through the slits.

Additionally, the bright and dark areas are evidence that the light waves experience ______________________________ as they pass through each other. The bright spots appear where the light waves experience ______________________________ interference, and the dark spots appear where the light waves experience ______________________________ interference.

Now, get ready to apply these ideas as you explore and explain the rainbow effect produced by optical discs.

Let's get started!

Materials

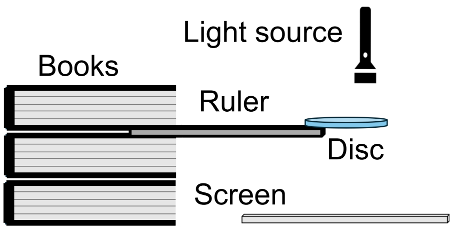
- White light source with a *focused beam* (*Note:* not all light sources will work equally well for this activity; recommendations for using an opaque screen are provided in the Teacher guide)
- Red laser
- CD with reflective layer
- CD with the reflective layer removed
- Sheet of white copy paper
- Colored pencils or markers
- Twenty-five small (3"x5") index cards and seventeen large (5"x7") index cards
- Masking tape
- Ruler

Investigation (Part 1)

1. Place a sheet of white paper on a flat surface to act as a screen. Hold the reflective disc above one end of the paper so that the reflective side is angled toward the center of the paper.

2. Shine a white light at the disc so that it reflects off the disc's surface onto the screen. Use colored pencils to sketch the light pattern observed on the screen.

3. Tape the nonreflective disc to the end of a ruler or pencil, and place the other end into a stack of books. Adjust the disc so that it's parallel to the screen and about 10 cm above it. Shine the white light through the disc. Use colored pencils to sketch the light pattern observed on the screen.



4. Before you continue, *predict* the pattern that will appear on the screen when the red laser shines through the disc. Sketch your prediction below.

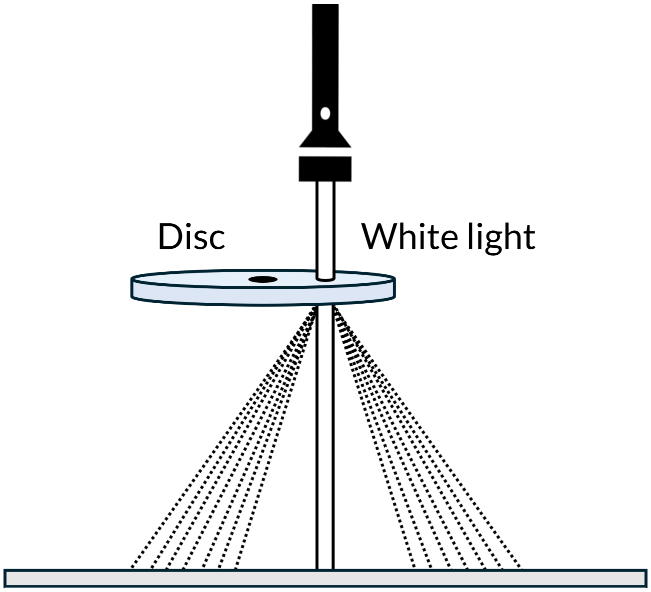
5. Shine the red laser through the disc, and use a red colored pencil to sketch the light pattern that appears on the screen.

Follow-up questions (Part 1)

1. Compare the pattern created by the reflective disc to the pattern created by the nonreflective disc when illuminated with white light. Is reflection responsible for separating the light into colors? Support your answer with evidence.

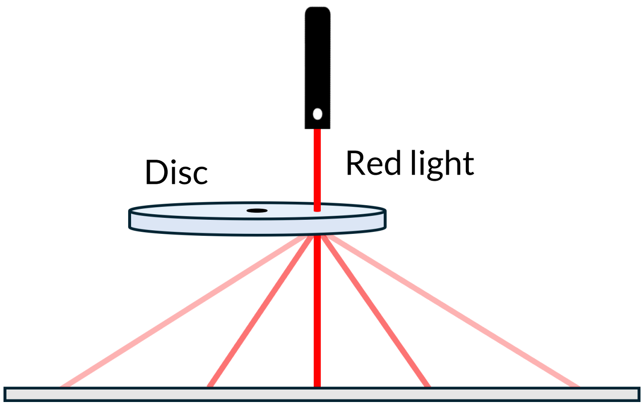
2. When white light passed through the nonreflective disc, it created a pattern on the screen. The pattern showed a bright central area of white light, with separated rainbow colors on both sides.

   In the diagram, use colored pencils or markers to show the arrangement of the spectrum as you observed.



Of the colors, the violet light appeared at the (circle one) **smallest / largest** angle from the central beam, and the red light appeared at the (circle one) **smallest / largest** angle from the central beam. So, we can conclude that the angle at which a color appears after passing through the disc is (circle one) **directly / inversely** related to its wavelength.

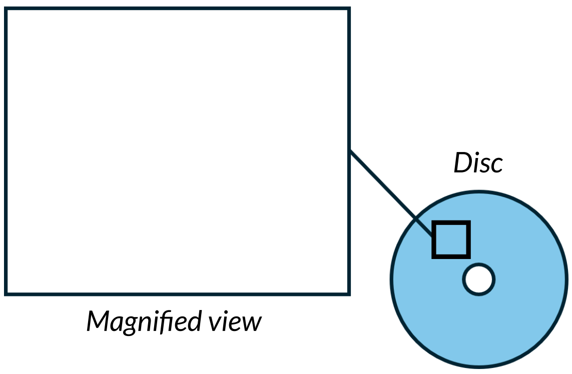
3. When the red laser beam passed through the nonreflective disc, it created a pattern consisting of a central spot of red light with two spots of red light on either side, and dark areas between. Try lowering the disc closer to the screen and shining the laser through. You'll notice that two more spots of red light appear on the screen, as shown in the diagram.



The pattern on the screen shows that the red light *spreads out* after passing through the disc. This is evidence that light experiences ______________________________ as it passes through the disc. Additionally, the alternating bright and dark areas are evidence that light experiences ______________________________ after passing through the disc. The dark spots appear where the light experiences (circle one) **constructive / destructive** interference, while the bright spots appear where the light experiences (circle one) **constructive / destructive** interference.

4. This evidence suggests that properties of the disc itself cause white light to split into colors. If you were to view the disc under a microscope, what features do you think you might see?

   On the diagram to the right, sketch your idea of what the disc's surface might look like when magnified.



5. How does your evidence from this investigation support the *wave model* of electromagnetic radiation?

6. If sunlight is allowed to enter into a dark room through a set of blinds that is slightly open, it will not separate into colors like the white light did when shone through the disc. Explain why a rainbow pattern is not observed in this scenario.

Investigation (Part 2)

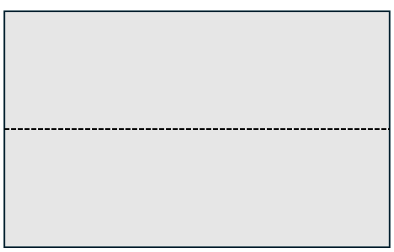
We've learned that the disc causes light to diffract and subsequently interfere. But, why do we see a rainbow effect from white light, and not just bright white spots similar to what we observed with the red laser? Why do the different colors spread out differently?

Let's model blue and red light waves to understand why a diffraction grating makes different colors visible at different locations.

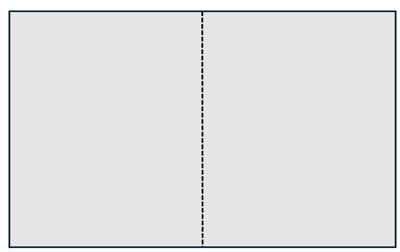
Procedure

1. Prepare the wave models.
    - Fold a small index card in half along its length and crease the fold. Unfold the card.

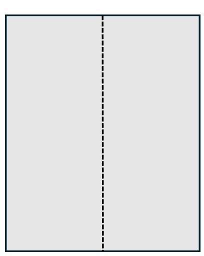
    - Fold the card in half along its width and crease the fold. Fold the card in half the same way, and crease the fold. Unfold the card. It should be divided into eight rectangles.



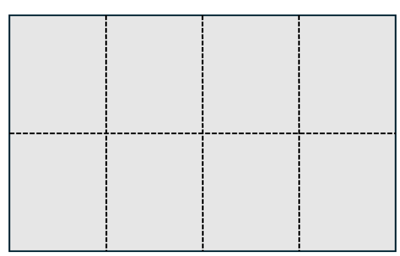
Fold along the length



Fold along the width



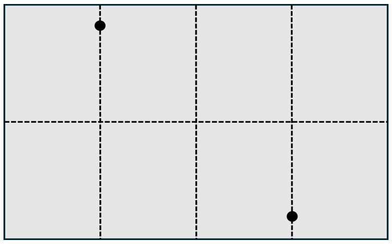
Repeat the fold



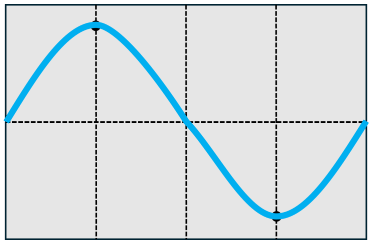
Unfold into eighths

- Use a marker to place a dot on the fold near the top-left edge, about 1.25 cm down from the top of the card. Place a dot on the fold near the bottom-right edge about 1.25 cm up from the bottom. These dots represent the minimum and maximum points of your wave.

- Use a blue marker to draw a smooth wave, starting at the crease on the left, center edge. Draw the wave up to the dot, down to the center, down to the dot, and back up to the center.



Draw max and min points

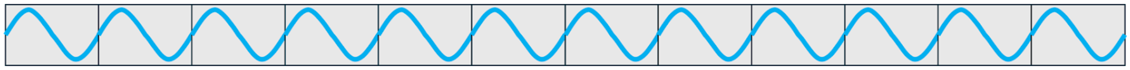


Draw the wave

- Use scissors to cut the card in two pieces along the wave. These two pieces will be templates used to trace waves onto the rest of the cards.

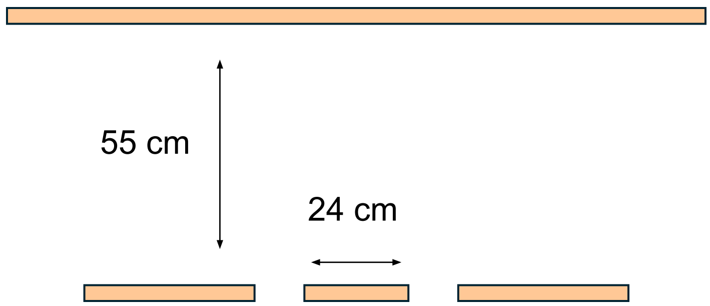
- Place a piece of the template onto a blank card so that the edges line up. Use a marker to trace the edge of the template, making the same wave pattern on the new card. Repeat this process with the remaining small cards until you have two sets of twelve cards.

- Use clear tape to join the edges of the cards together so that one continuous blue wave is created. You should make two blue waves that are each twelve cards long.



- Repeat the procedure with the large cards and a red marker. When finished, you should have two red waves that are each eight cards long. The red waves should have a longer wavelength than the blue waves.

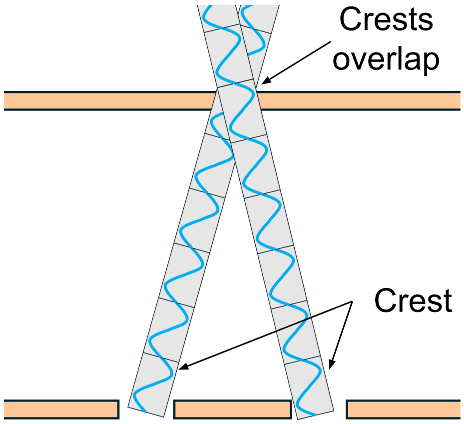
2. Cut three pieces of masking tape and place them on the floor. Arrange the tape to model a double slit pattern. The space between the slits should be about 24 cm apart (the size of two blue wavelengths). Place a long strip of masking tape parallel to the slits about 55 cm away. This strip will represent the screen in your model.



3. Place a blue wave strip at each slit. **Make sure both strips start with a crest pointing in the same direction.** Angle the waves so that they both cross the screen at the point midway between the slits.

4. Notice that *identical* parts of the wave overlap (two crests or two troughs). At this location, the two light waves interfere *constructively* to produce a bright spot. Place a blue dot on the tape.

5. Angle the two waves to find a location where a crest and a trough overlap. At this location, the two light waves interfere *destructively* to produce a dark spot. Place a blue X on the tape.



6. Continue until you have found at least two bright and dark spots on both sides of the screen. **Keep the beginning of each wave strip at the slit as you change their angles.**

7. Repeat this process using the red wave cards. Make sure to mark the bright dots and dark X's on the screen using a red marker.

Follow-up questions (Part 2)

1. Use the space below to sketch the pattern of red and blue dots from the screen.

2. Compare the pattern created by your model to the pattern observed in steps three through five of the previous investigation. What similarities do you see?

3. Suppose you continued the activity with wave strips to represent the wavelengths of the other colors in the visible spectrum. Each set of waves would constructively interfere at the center of the screen. How does this explain why a white spot appeared at the center of the screen?

4. Constructive interference of red light waves occurs at a (circle one) **larger / smaller** angle from the slits than blue light waves. This explains why, when white light shone through the optical disc, red light appeared (circle one) **closest to / farthest from** the central maximum of white light.

Keep creating!

Diffraction spikes are often seen in images captured by telescopes. For example, images from the James Webb Space Telescope show six diffraction spikes extending from bright stars. These spikes are not a part of the stars themselves, but are a result of the telescope's internal structure.

Stars behind the Carina Nebula, taken by JWST. Image from NASA, CC-BY- 2.0 / Cropped from original.

Research the phenomenon of diffraction spikes, and create a slideshow that explains why they form. Include different telescope designs, along with examples of the diffraction spikes they create. Then, develop a way to create your own diffraction spikes with a camera. Create an image gallery that showcases your photography skills, and share it with your classmates.

More creative activities!

Perhaps you've looked up to the Moon at night and noticed a hazy ring or bands of color around it. Two optical phenomena known as *halos* and *coronas* can be seen around the Moon when the conditions are right. One of these phenomena is the result of moonlight *refracting* through water in the atmosphere. The other results from water (or other particles) acting as a *diffraction grating* for moonlight. Research these meteorological phenomena to understand the optical physics behind them. Use Adobe InDesign to create a poster that illustrates how each phenomenon is formed.