

Super Gelatin: Teacher Lesson Plan

Can gelatin (like Jell-O ®) change the speed of light? Students investigate the refraction properties of gelatin to calculate its index of refraction and discover that as the light travels through the gelatin, its speed and wavelength also change. This activity offers students a challenge to find the index of refraction of an everyday, intriguing, translucent substance outside the standard listing of materials and refraction indexes.

Astronomy Related TEKS grades 9-12:

112.33(c)-2F: collect data and make measurements with accuracy and precision;
112.33(c)-2G: organize, analyze, evaluate, make inferences, and predict trends from data, including making new revised hypotheses when appropriate;
112.33(c)-8C: recognize that the angle of incidence of sunlight determines the concentration of solar energy received on Earth at a particular location.

Physics Related TEKS grades 9-12:

112.39(c)-7A: examine and describe oscillatory motion and wave propagation in various types of media;
112.39(c)-7B: investigate and analyze characteristics of waves, including velocity, frequency, amplitude, and wavelength, and calculate using the relationship between wavespeed, frequency, and wavelength;
112.39(c)-7D: investigate behaviors of waves, including reflection, refraction, diffraction, interference, resonance, and the Doppler effect;

Student Product:

Students measure the angles of refraction of laser light traveling through gelatin, then plot their data to calculate the gelatin's index of refraction.

You may choose from two different "Elaborate" activities:

Gelatin Stack: students formulate a hypothesis and design a simple experiment to test it.

The "Super" in Super Gelatin: students calculate how the wavelength and speed of light change inside the gelatin.

Note:

Please download the PowerPoint presentation that goes with this lesson plan. It contains illustrations designed to help you and the students understand the directions for this lesson.

Materials:

Per student lab group:

- Wax paper sheet
- graph paper (1/4 inch ruled with blue ink)
- protractor
- scientific calculator (like a TI-30)
- Laser pointer
- binder clip big enough to grip the laser pointer and hold down the “on” switch.

To prepare Gelatin for distribution to lab groups:

- Knox® gelatin (8 x 7 ounce envelopes)
- dessert gelatin *with sugar* (like Jell-O®) in red (strawberry) and yellow (pineapple).
- cookie sheet (1/2 to 3/4 inch deep, smooth and non-stick surface) or brownie pan (8 x 8 inches, 2 inches deep).

Gelatin Preparation

- 3 gelatin pans, preferably 8 x 8 x 2 inch brownie pans
- Measure cup with a 2-cup capacity
- Cooking spray (like Pam®)
- 2 packages of Knox® plain gelatin (4 envelopes per pack)
- 1 package of red gelatin (Jell-O® strawberry works well). Not sugar free.
- 1 package of yellow gelatin (Jell-O® pineapple). Not sugar free.
- Gelatin preparation time: 2.5 hours.

Students should not eat the gelatin. This recipe will result in firm gelatin.

Prepare three pans of gelatin (red, yellow, and clear):

Spray the bottom of each pan with cooking spray (like Pam®). This will allow you to remove the firm gelatin in one step.

Boil water:

Bring 6 cups of water to a boil.

Prepare the gelatin:

For each color, use 2 envelopes (7 grams each) of Knox! plain gelatin and the entire contents of the dessert gelatin package. Combine 2 cups boiling water and the dry ingredients in a mixing bowl. Stir gently for at least 3 minutes. Once all the dry ingredients have dissolved, pour into one of the brownie pans. The pan should be 3/4 inch full of liquid.

Clear gelatin: combine 4 envelopes (7 grams each) of Knox® gelatin + 2 cups of boiling water in a mixing bowl. Gently stir for at least 3 minutes. Lumps of gelatin will slowly dissolve – just keep stirring. Pour into the last brownie pan.

Chill the gelatin:

Chill the gelatin for about 2 hours in a refrigerator. After about 1.5 hours, the gelatin is very firm.

Remove the gelatin from the pans:

Place each pan in hot water to loosen up the gelatin. Set out a sheet of wax paper nearby. Flip the pan over onto the wax paper to free the gelatin.

Slice the gelatin into 2-inch squares with straight smooth sides:

Using a pizza cutter or long sharp knife, slice the gelatin into at least 2-inch squares.

Serve it cold:

The gelatin will be easiest for students to work with while it is cold or cool. Students should be able to comfortably work with the gelatin for at least 45 minutes. Set aside three gelatin samples (yellow, red, and clear) for the "Elaborate: Gelatin Stack" part of this activity.

Activity:

Preparation

Materials set up:

Divide up the remaining gelatin squares for the students to examine – one sample per group. Each group should have: gelatin, a laser pointer & binder clip, graph paper, protractor, and a scientific calculator.

Each student should have a copy of the "Super Gelatin" student worksheet.

Choose an "Elaborate" activity:

Choose one (or both) of the "Elaborate" activities.

Engage

As a whole class, ask students to brainstorm the properties of their favorite gelatin dessert.

On an overhead projector or using PowerPoint, list the different properties that students offer. If anyone has not mentioned "refracts light" or "bends light," add it to the list. Zooming in on refraction, ask students what they think happens to the light when it enters a new medium, like glass, water, plastic, or gelatin.

Explore

Assemble students into lab groups of two or three. Each group will work with one of three types of gelatin: clear, red, or yellow. Ask one member of each group to gather materials, or pass them out to each group. Remind students of basic lab safety rules: Don't taste anything, even if it looks edible.

Tell students that their goal is to calculate the index of refraction for their gelatin sample.

Identify the variables

What variable are you trying to find?

The index of refraction for your gelatin sample, (n_{gel})

What variables do you already know, and what variables can you control?

You can control the incident angle (θ_i) with the position and angle of the laser pointer. You know the index of refraction for air at STP (n_{air}) is 1.

What variables can you measure?

You can measure the refraction angle (θ_r) and the incident angle (θ_i) using your protractor.

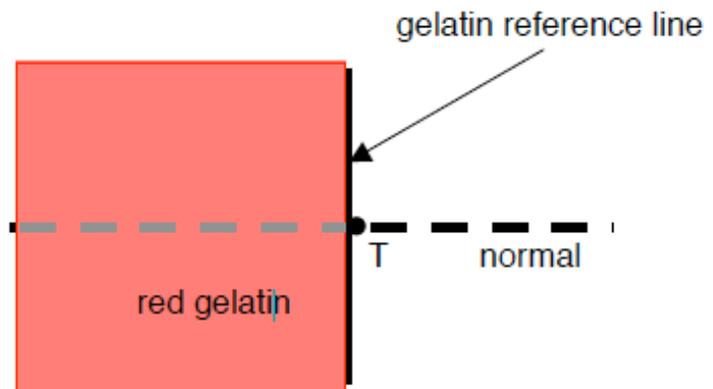
Here's the relationship between the variables expressed mathematically as the Law of Refraction, or Snell's Law:

$$n_{air} \sin(\theta_i) = n_{gel} \sin(\theta_r)$$

Set up the experiment

A. Set up your graph paper to test the gelatin

1. Draw a vertical line to represent the surface of the gelatin sample. Mark the midpoint.
2. Draw a long horizontal normal dashed line through the midpoint.
3. Mark the point where the normal meets the surface of the gelatin. Label it "T" for target.



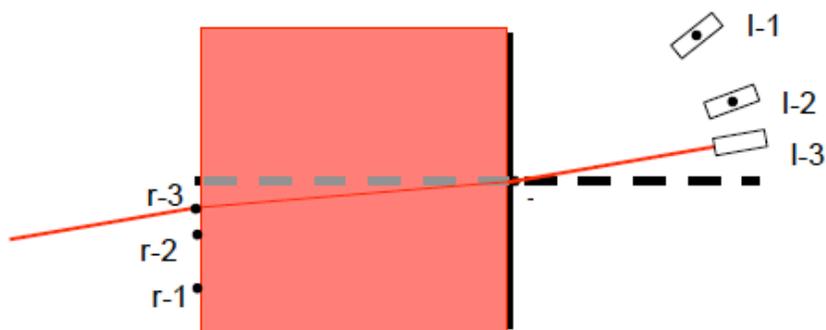
B. Prepare the gelatin sample for testing

1. Trim the wax paper around the edges of the gelatin.
2. Place the gelatin sample (on wax paper) on the graph paper. Align one side on the vertical line.

The laser can cause permanent eye retina damage. Students should always be aware exactly where the laser is pointed. Students should point the laser in a safe direction as they set it up.

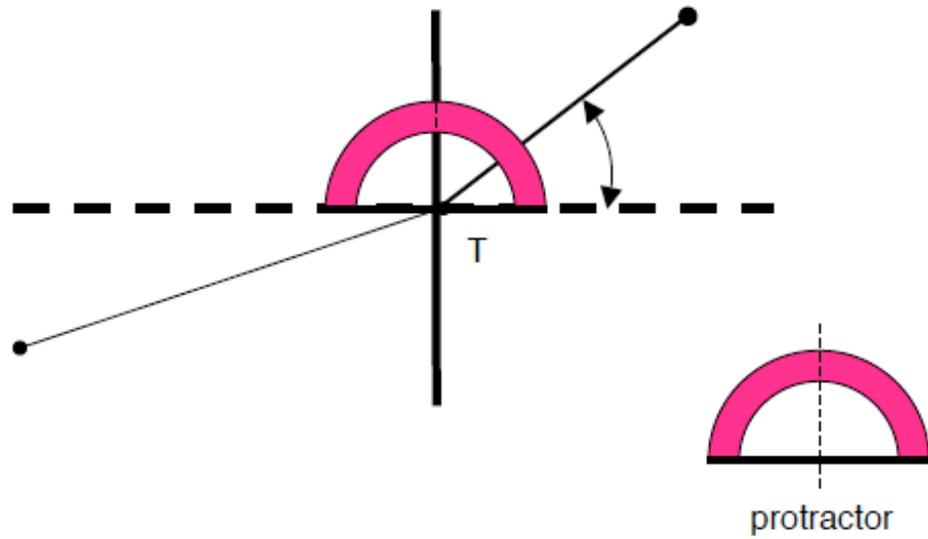
C. Mark the incident and refracted light rays

Note: students may measure incident and refraction ray angles using a protractor or measure the x,y coordinates of each reference point (see step 11 and 13). The x,y coordinate method gives students a geometric way to find the sine of the angle.

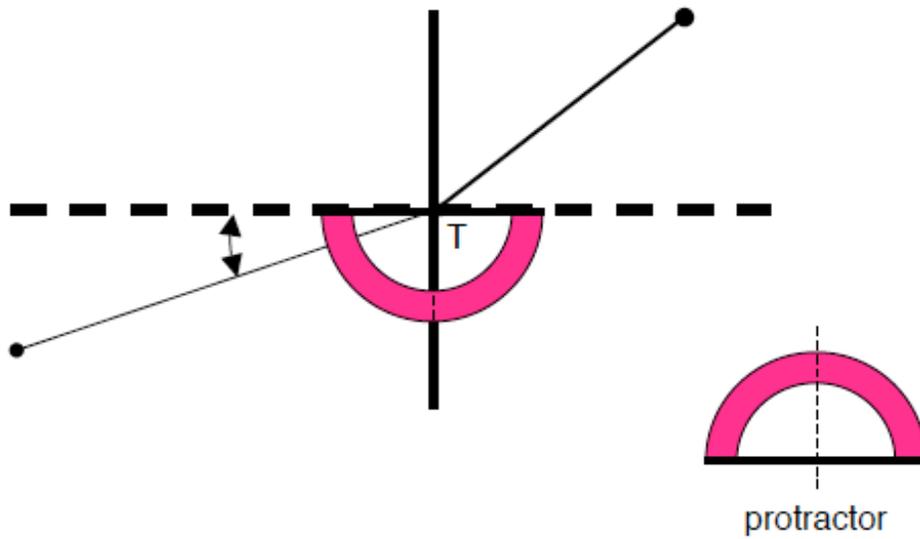


1. Pick three positions to fire the beam into the gelatin above the normal and below the normal, for a total of six positions.
2. Stand the laser and point it at the gelatin.
3. Clamp the laser "on" then align the beam so that it enters the gelatin directly over point "T."
4. Carefully hold down the laser pointer with one finger, and trace the sides of the binder clip on the graph paper. Label it "i-1." Later, you will use these reference lines to mark the position of the laser beam.
5. Mark the location where the refracted beam exits the gelatin. Label it "r-1."
 *Be careful not to nudge the gelatin. If you accidentally move the gelatin a bit, just realign it with the vertical line. Or, you may decide to redo your measurements.
6. Move the laser to a new incident beam position.
7. Repeat the above steps (2 – 6) for the remaining positions.
8. Remove the gelatin from the graph paper.
9. At each of the incident beam positions, mark a midpoint between the reference lines.
10. Lightly draw a line segment between each incident beam point (i-1, i-2, i-3) and the point "T."
11. Measure the angle between each incident line and the normal. Write down your data in you data table.
 *Alternative: measure the x and y coordinates for the point, with "T" as the origin.
12. Lightly draw a line segment between each refracted beam point (r-1, r-2, r-3 ...) and "T."
13. Measure the angle between the refracted line and the normal. Write down your data in your data table.
 * Alternative: measure the x and y coordinates for the point, with "T" as the origin.

Measure the incident angle



Measure the refraction angle



1. What variables should you plot?

Think about what you are trying to find (n_{gel}), and the mathematical relationship among the variables:

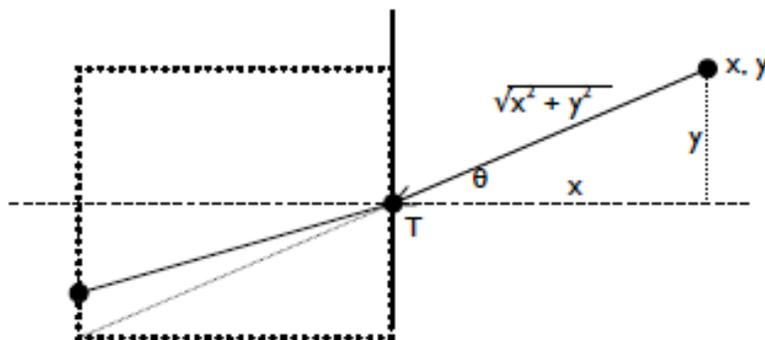
$$n_{\text{air}} \sin(\theta_i) = n_{\text{gel}} \sin(\theta_r)$$

You already know $n_{\text{air}} = 1$, and have just measured six different values for θ_i and θ_r .

$\sin(\theta_i) = n_{\text{gel}} \sin(\theta_r)$ looks like an equation for a line $y = mX$, where m is the slope. In this case, the x-axis represents the values for $\sin(\theta_r)$ and on the y-axis are values for $\sin(\theta_i)$.

2. Calculate the sine of each angle using the sine function on your scientific calculator.

$$\text{Alternative: } \sin(\theta) = \frac{\text{opposite side}}{\text{hypotenuse}} = \frac{|y|}{\sqrt{x^2 + y^2}}$$



Above: x and y are the coordinates for each incident or refracted point on the graph paper, with "T" as the origin.

$|y|$ is the absolute value of y . Here's why:

You are measuring angles between the normal line and incident or refraction line. In this case, these angles are less than 90° and positive.

3. Plot your $[\sin(\theta_r), \sin(\theta_i)]$ coordinate pairs on the graph paper below your data sheet.

4. Draw a straight line that best fits the data points.

If your students are using Microsoft Excel to record and plot their data, they can add a linear trend line to their plot and display the linear equation.

Explain

1. As the angle of incidence changes, what happens to the refraction angle?
The refraction angle increases and decreases with the incident angle. The refraction angle is less than the incident angle.

2. What does the slope of your best fit line represent?
The slope of the best fit line represents the index of refraction for the gelatin.

3. List at least three reasons why you think the data points do not perfectly line up.

This is an opportunity for students to identify and explain sources of error in their experiment. Examples:

a. nudging the gelatin: if students accidentally push the gelatin while marking refraction points, then realign the gelatin, they slightly change the conditions of the experiment. They may decide that this source of error is small enough to ignore, or they may decide to redo their measurements.

b. marking the incident and refraction points: the laser beam spreads out through the gelatin, and students must judge where the beam exits the gelatin.

c. accuracy of measuring the angle or (x,y) position with the protractor: the smallest angular unit on the protractor is 1°, thus the accuracy of each measurement is limited to 0.5°. The smallest metric unit is 1 millimeter, so the accuracy of measuring x or y is 0.5 mm.

d. irregularity of the gelatin surface at "T": a bump or bubble hole on the gelatin surface at "T" will act like a tiny lens that refracts the incident beam at odd angles.

e. gelatin misalignment with the vertical reference line: if the gelatin surface is not on the reference line, the measured refraction angles will be systematically higher or lower than their true value.

f. precision of lining up the protractor: every time an angle is measured, the student must realign the protractor to a new line and point.

4. What value did you find for the gelatin index of refraction?

Following the gelatin recipe and procedures in this activity, the author calculated 1.36 for the yellow gelatin, 1.33 for the red gelatin, and 1.19 for the clear gelatin.

5. Choose an Elaborate activity.

Now that students have completed the "Explain" section, choose one of the two possible "Elaborate" activities.

Elaborate: The "Super" in Super Gelatin

By experiment, you know the index of refraction for your sample of gelatin. But what else does that number mean?

If you think of light as an electromagnetic wave composed of electric and magnetic fields, you can mathematically model it as a wave. Three basic properties of a wave are:

Wavelength (λ or lamda) is the distance between electric or magnetic wave maximum expressed in meters (m). This is distance over one period, or oscillation, of the wave.

Frequency (ν or nu) cycles or oscillations per second, expressed in units called Hertz (Hz).

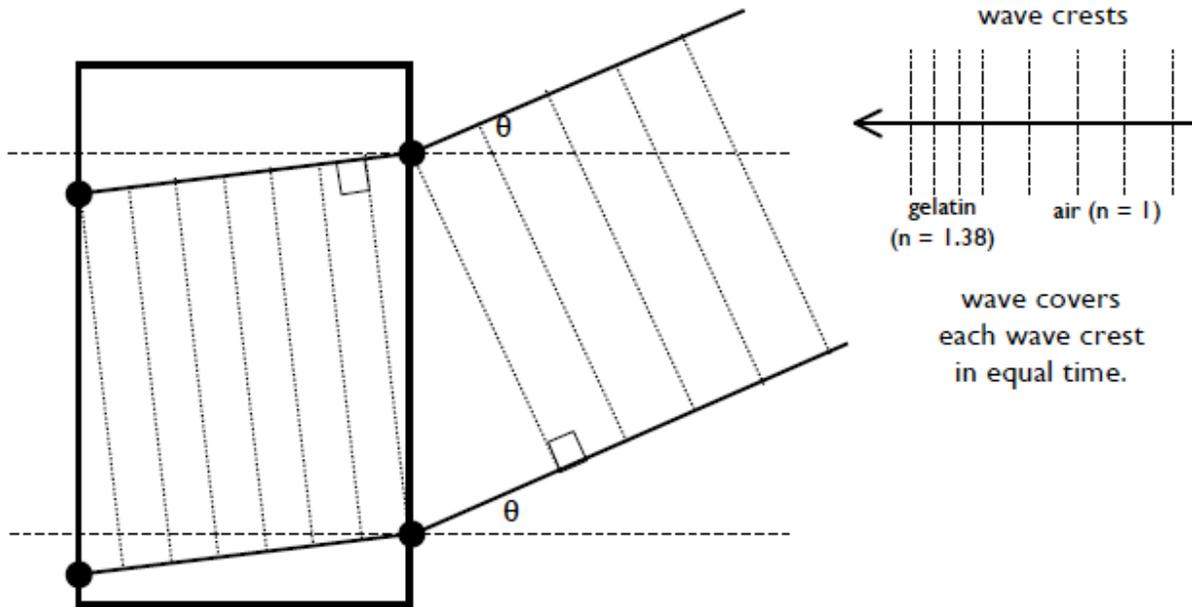
Velocity (v) expressed in meters per second (m/s)
 For a light wave, these three properties are related:

$$v = \lambda\nu = \frac{c}{n}$$

"c" is the speed of light in a vacuum (a constant), and "n" is the index of refraction for the medium light is traveling through.

The light's frequency does not change as it enters the gelatin – that is set by the source emitting the light. But what does change in the medium is the index of refraction. As a result, how does the wavelength and speed of the light change as it travels through the gelatin?

Below: The gelatin changes both the speed and wavelength of the light. Light does not travel at "c" through the gelatin. Instead it travels at a slower speed, and thus a shorter wavelength. As a result the light changes direction once it enters the gelatin. That's the super in Super Gelatin.



Elaborate: Gelatin Stack

Based on the situation below, students formulate a hypothesis and design an experiment to test it.

The three gelatin samples are stacked one on top of the other. What path do you think the laser beam will take through the gelatin stack?

