COOKING AT THE SPEED OF LIGHT

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Annotation:
In this activity, students measure the speed of light using a microwave oven and the wave speed equation.

Primary Learning Outcomes:
Students will be able to identify the crest, trough, amplitude, and wavelength of a wave.

Students will be able to define the terms *frequency, period,* and *standing wave*.

Students will be able to solve problems involving wave speed, frequency, and wavelength.

Students will be able to describe the history of the measurement of the speed of light.

Students will be able to explain that the frequency and wavelength of light varies along the electromagnetic spectrum.

Georgia Performance Standards
Characteristics of Science
SCSh4. Students will use tools and instruments for observing, measuring, and manipulating scientific equipment and materials.

SCSh5. Students will demonstrate the computation and estimation skills necessary for analyzing data and developing reasonable scientific explanations.

SCSh7. Students will analyze how scientific knowledge is developed.

SCSh8. Students will understand important features of the process of scientific inquiry.

Physical Science Content
SPS9. Students will investigate the properties of waves.

Physics Content
SP4. Students will analyze the properties and applications of waves.

Duration:
Preparation: 15 minutes
Introduction: 15 minutes
Student Activity: 25 minutes
Conclusion: 10 minutes
Total Class Time: 50 minutes
Materials and Equipment:
Per Class

1. Microwave oven without turntable

Per Group

1. Paper plate
2. Chocolate chips
3. Ruler

Safety:
Chocolate chips may be hot when removed from the microwave oven. Students should use caution when handling.

Technology Connection:
Web Links – The following links provide background information related to this lesson plan.

- http://galileoandeinstein.physics.virginia.edu/lectures/spedlite.html
- http://physics.about.com/cs/opticsexperiments/a/290903.htm
- http://www.colorado.edu/physics/2000/waves_particles/lightspeed_evidence.html

Procedure:
Teacher Preparation:
Obtain microwave oven and remove turntable, if present. Obtain the operating frequency from the label on the back of the microwave oven. Most microwave ovens operate at 2,450 MHz. Obtain sufficient materials. Copy the *Cooking at the Speed of Light* student handout.

Estimated Time:
15 minutes

Introduction:
Review the introduction provided on the *Cooking at the Speed of Light* student handout.

Estimated Time:
15 minutes

Student Activity:
Students should follow the procedure provided on the *Cooking at the Speed of Light* student handout.

Estimated Time:
25 minutes

Conclusion:

Review the activity and calculations with students. Compile student results on the board and discuss variability of results. A sample calculation follows.

SAMPLE CALCULATION

1. Measure distance between the hot spots in cm
   x = Distance between the hot spots ___________6.2_____________cm

2. Multiply x by 2 to obtain wavelength
   2x = λ = Wavelength __________________12.4________________________cm

3. Convert λ from cm to m
   λ = Wavelength _______________0.124______________________________m

4. Determine the frequency of the microwave in MHz (Most are 2450 MHz)
   f = Frequency of the microwave _______2450_________________________MHz

5. Convert f in MHz to Hz
   f = Frequency of the microwave ____2450000000________________________Hz

6. Write the equation you will use (Values from #3 and #5 above) **c = λ *f**
   EQUATION ___c = 0.124 * 2450000000__________________________

7. Calculate the speed of light using equation in #6.
   Your calculated speed of light ____303800000______________________m/s

8. Calculate the percent difference = ((Observed – Expected)/Expected)*100%
   _((303800000 m/s – 299792458 m/s) / 299792458 m/s)*100=1.34%___________

Estimated Time:
10 minutes

Assessment:
Assessment should be based on completion of the *Cooking at the Speed of Light* student handout.

COOKING AT THE SPEED OF LIGHT *Student Handout*

Introduction:

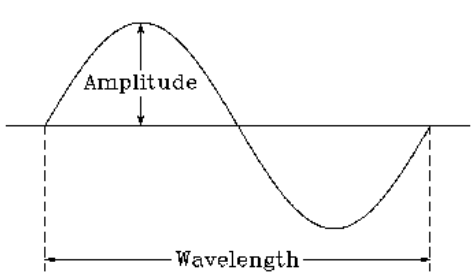
What is the speed of light? That's an easy question, isn't it? By flipping through our text book or pulling it up online, we can easily see that the speed of light is 3×10^8 m/s, right? In fact, the speed of light is so well known that it forms the basis for the SI units of length. Now for a trickier question…How do we know the speed of light? Speed, of course, is defined as distance traveled divided by time. So to calculate the speed of a car, for example, we simply measure the distance it covers during a given time interval and divide. Easy enough, right? Well imagine that the car is traveling over 100,000 miles each second. This makes things a little trickier. In order to accurately measure the speed of light, we must be able measure either very long distances or very short time intervals.

Galileo made the first attempts at measuring the speed of light in the early 17th century. He and an assistant attempted to use lanterns to measure the time that it took light to travel 1 mile. The time interval was much too short to be measured. Later in the same century, the Danish astronomer Ole Roemer calculated the speed of light based on observations of Jupiter's moon Io. In the 1850s, two French scientists, Fizeau and Foucalt, more accurately measured the speed of light by mechanically measuring the behavior of light beams. The Polish-American scientist Albert Michelson improved the measurement again in the late 1870s. Since then, the speed of light has been confirmed numerous times, including through use of a mirror placed on the moon by astronauts.

Today you will join the long line of great scientists who have measured the speed of light, and you will do it using chocolate chips, a ruler, and a microwave oven! After learning how a microwave oven works, we can use our knowledge of wave properties to measure the **speed of light (c)**.

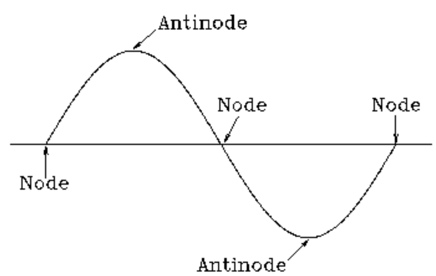
The speed of any wave is equal to the **wavelength (λ)** multiplied by the **frequency (f)** of the wave. Because light travels as an electromagnetic wave (microwaves and visible light are both examples of electromagnetic waves) the speed of light can be calculated by this formula.

$c=\lambda * f$



When you turn on your microwave oven, electrical circuits inside generate microwaves – electromagnetic waves with frequencies around 2.45 gigahertz (or 2.45×10^9 Hz). These waves bounce back and forth between the walls of the oven. The size of the oven is chosen so that the peaks and troughs of the reflected waves line up with the incoming waves and form a **standing wave**.

The electromagnetic field inside the microwave behaves in roughly the same way as a guitar string except the vibrations are in "the electromagnetic field." Where the vibrations are greatest (the **antinodes** – these correspond to the peaks and troughs of the wave), you will see the greatest heating, but at the **nodes**, the chocolate will only melt slowly as heat diffuses into those areas.



Purpose:
To use the wave properties of microwaves to calculate the speed of light.

Materials:
1. Paper plate
2. Chocolate chips
3. Ruler
4. Microwave oven

Procedures / Data:
1. Remove turntable from microwave oven, if present.
2. Cover plate with a single layer of chocolate chips.
3. Place plate in middle of the microwave.
4. Heat about 20 s until chips begin to melt in at least two different spots.
5. Remove the plate from the microwave and observe the melted spots.
6. Measure the distance between the melted spots. You will find that one distance repeats over and over. This distance will correspond to half the wavelength of the microwave and will be roughly 6 cm. Record this distance in the space provided below.
7. Obtain the operating frequency of the microwave used and record in the space provided below.
8. Complete the calculations outlined below.

Data & Calculations:

$$c = \lambda * f$$

Expected value for **c = 299792458 m/s**

1. Measure distance between the hot spots in cm

   x = Distance between the hot spots ________________________________cm

2. Multiply x by 2 to obtain wavelength

   2x = λ = Wavelength ____cm

3. Convert λ from cm to m

   λ = Wavelength ____m

4. Determine the frequency of the microwave in MHz (Most are 2450 MHz)

   f = Frequency of the microwave __________________________________MHz

5. Convert f in MHz to Hz

   f = Frequency of the microwave __________________________________Hz

6. Write the equation you will use (Values from #3 and #5 above) **c = λ *f**

   EQUATION ____

7. Calculate the speed of light using equation in #6.

   Your calculated speed of light _________________________________m/s

8. Calculate the percent difference = ((Observed – Expected)/Expected)*100%

   ____

Post-Laboratory Questions:

1. Calculate the wavelength of an X-ray with a frequency of 6×10^{19} Hz.
2. *Describe in your own words how a microwave oven cooks food.*