Speed of Light in a Microwave Experiment

AP Physics 2/EM Radiation/grades 11-12

Materials: Students will need access to the class Moodle, to their Google Drive, and to a microwave oven. Students will also need a camera (cell phone is great), calculator (cell phone works), a ruler, and food that will melt in a microwave (such as cheese or chocolate). Students are expected to supply their own experimental materials.

The teacher will need a computer with internet access hooked up to a projector.

Instructions for the teacher: This experiment is to be performed by students at home during the EM radiation unit to verify that the microwave radiation in the oven does indeed travel at the speed of light. This experiment should be assigned after going over the equation: $c = \lambda f$ and the EM spectrum.

- To introduce this experiment, I review the EM spectrum with students. Then I ask them why microwave ovens are called, well, microwave ovens. We then discuss how microwave ovens cook food.
- I then display the experiment instructions on the board using a projector. Students can access the instructions through the class Moodle but a link could be provided on the teacher/class website instead. The instructions can also be found on page 3 of this document.
- I go over the instructions, and answer any questions. Students can work alone or in groups of 2 or 3.
- Students then have two weeks to design, perform, and write up their experiment as a Google doc which will be submitted through the Moodle. If the students work in groups, they are expected to use the group feature on Google docs to collaboratively write one report for the group.
- The lab reports are then graded according to the grading rubric which students can view through a link on the Moodle. The rubric is also given on page 5 of this document. I will use the rubric feature on the Moodle, but an online rubric could be created using Google Forms instead.

Resources: Students may wish to refer to their textbook to review standing waves.

Standards: This assignment addresses the following standards for AP Physics 2 as written by the College Board. The standards can be found in the AP Physics 2 course description.

- Big idea 5: Changes that occur as a result of interactions are constrained by conservation laws.
- Big idea 6: Waves can transfer energy and momentum from one location to another without the permanent transfer of mass and serve as a mathematical model for the description of other phenomena.
- Science practice 2: The student can use mathematics appropriately.
- Science practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.
- Science practice 4: The student can plan and implement data collection strategies in relation to a particular scientific question.

- Science practice 5: The student can perform data analysis and evaluation of evidence.

AP Physics 2
Speed of Light in a Microwave Experiment

Due to the fact that the classroom has but one microwave, this experiment will be performed at home. Read through all of the information below and let me know if you have any questions or concerns. Remember to use common sense and to use appropriate safety precautions.

Purpose: To measure the speed of light using a microwave oven.

Theory: Microwave ovens use light in the microwave part of the EM spectrum to cook food. The microwave photons reflect off the walls of the oven and can interfere with one another. The result is the formation of a standing wave (made of EM radiation!). Hot spots will form at the antinodes (max energy) and cold spots will form at the nodes (zero energy) of the standing wave formed by the microwave light. This is why microwaves have turntables. If the food in the oven does not rotate, you will find that there are hot spots and cold spots in the food. Two consecutive hot spots or two consecutive cold spots are a half wavelength apart. If the wavelength and frequency are known, then the speed of the wave can be calculated using $c = \lambda f$.

Hints and Tips: Most microwaves have the frequency printed on the back. If not, try using 2.5 GHz, which is a typical frequency for microwave ovens. You can also try an internet search for your specific microwave oven. Foods that melt, such as chocolate or cheese, are the best to use. Be wary of marshmallows. While fun and yummy, they will expand during the microwaving and contract when removed so getting an accurate measurement is difficult. Empty paper plates also work; burn marks will appear in the location of the antinodes.

Materials: microwave oven, ruler, something to put in the microwave (cheese, chocolate, etc.), camera, calculator

Safety: Do NOT put anything in the microwave that is NOT supposed to go in the microwave. No metals, toys, pets, siblings, etc.

Procedure:

1. Develop a procedure and then perform your experiment. Consider how many trials you want to make and whether you want to vary foods, heating times, etc. You are welcome (and encouraged!) to work with another physics student or even two. Lab groups should not exceed three people. You will want to keep track of all data and measurements. You will also want to take pictures as you perform the experiment.

2. Write up your experiment as a Google Doc. Only one lab report per group will be submitted so use the group feature on Google Drive to write your report. If you have a lab partner, each

person is expected to contribute equally to the report. Include your procedure, data, calculations, pictures and results. The procedure should be detailed enough that someone else could exactly recreate your experiment and obtain the same results. The data, calculations, and pictures should be clearly labeled and identifiable. The entire report should be neat and logical. Remember to check for spelling and grammar.

3. In the results section, compare your experimental value with the accepted value for the speed of light. (Remember in air, the speed of light is essentially c.) Then, discuss possible sources of error and suggest how this error could be reduced.

$$\% \text{ difference} = \frac{|\text{accepted} - \text{experimental}|}{\text{accepted}} \times 100$$

4. Before you submit your report, be sure to look at the grading rubric to make sure that you have everything covered.

5. When your report is finished, submit your report through the Moodle. The report is due by 11 pm on the due date. The Moodle will accept submissions after 11 pm, but the report will be LATE.

AP Physics 2
Speed of Light in a Microwave Experiment Grading Rubric

Procedure	Nothing submitted 0points	Vague procedure, little detail, missed steps. 1-2points	Procedure is mostly complete, has a few omissions or is out of order. 3-4points	Complete, detailed procedure that would allow someone else to duplicate the results of the experiment. 5points
Data	Nothing submitted 0points	One trial. 1-2points	Multiple trials. Missing unit labels. 3points	Multiple (minimum of 3) trials. Labeled with units. 4-5points
Calculations	Nothing submitted 0points	Only final result is given with or without units. 1points	Some work is shown. 3-4 points	ALL work is shown, including any necessary unit conversions. Units are labeled. 5points
Pictures	Nothing submitted 0points	Only one picture of food either before or after. 1points	More than one picture but pictures are not relevant.	Pictures document experiment, show food before and

			2points	after being microwaved. 3points
Results	Nothing submitted 0points	Vague or incorrect summary. 2points	Missing either the comparison or the discussion of error. 3points	Complete summary of results, including a comparison with the speed of light and a discussion of error. 5points
Logical flow	Nothing submitted 0points	Sections are jumbled or difficult to distinguish. 1points	Section labels are missing or one section is out of order. 2points	Report goes in order and each section is clearly labeled. 3points
Grammar/Punctuation	Nothing submitted 0points	Unnecessary number of punctuation, formatting and spelling errors which make report difficult to read. Spell check would have fixed many of these mistakes. 1points	Some punctuation, formatting, and spelling errors. Spell check may not catch the difference between, say, "form" and "from" but proofreading would have helped. 3points	No or few punctuation, formatting, and spelling errors. Writing is clear and conforms to standard grammar and spelling conventions. Words are used correctly. 4points

Equal Contribution from all lab partners	Nothing submitted 0points	One partner wrote the entire report. (not an issue if person worked alone) 1 pts	Each partner contributed something. 3 pts	Equal contribution by all partners. 5 pts