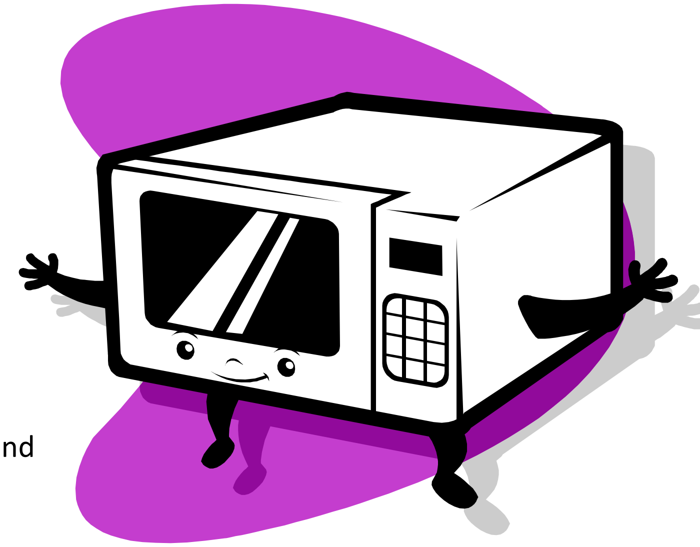
Nuke it!



Primary Learning Objectives:
Students will:

- Understand that microwaves are waves of energy.
- Know that water molecules are polar, one end having a positive charge and the other end having a negative charge.
- Determine that microwaves cause water molecules to vibrate which heats and cooks food.
- Fully understand the equation c = fλ and relate it to things that they use.
- Identify the parts of a standing wave (node, antinode, etc) and be able to describe them and their properties.
- Be aware that Dr. Percy Spenser discovered the technology in the 1940s that would lead to the development of the microwave oven.

Examples of TN State Standards to Incorporate:
Kindergarten:

- Inq.1 Observe the world of familiar objects using the senses and tools.
- T/E.1 Recognize that both natural materials and human-made tools have specific characteristics that determine their use.

1st Grade:

- Inq.2 Ask questions, make logical predictions, plan investigations, and represent data.
- Inq.3 Explain the data from an investigation.

2nd Grade:

- T/E.1 Explain how simple tools are used to extend the senses, make life easier, and solve everyday problems.
- 7.9.2 Investigate how temperature changes affect the state of matter.

3rd Grade:

- Inq.1 Explore different scientific phenomena by asking questions, making logical predictions, planning investigations, and recording data.
- 7.10.1 Investigate phenomena that produce heat.

4th Grade:

- T/E.2 Recognize the connection between a scientific advance and the development of a new tool or technology.

- T/E.4 Recognize the connection between scientific advances, new knowledge, and the availability of new tools and technologies.
- 7.10.2 Investigate how light travels and is influenced by different types of materials and surfaces.

5th Grade:

- Inq.1 Explore different scientific phenomena by asking questions, making logical predictions, planning investigations, and recording data.
- 7.10.2 Use data from an investigation to determine the method by which heat energy is transferred from one object or material to another.

6th Grade:

- Inq.3 Synthesize information to determine cause and effect relationships between evidence and explanations.
- T/E.3 Distinguish between the intended benefits and the unintended consequences of a new technology.
- T/E.2 Know that the engineering design process involves an ongoing series of events that incorporate design constraints, model building, testing, evaluating, modifying, and retesting.

7th Grade:

- 7.11.6 Investigate the types and fundamental properties of waves.
- 7.11.5 Compare and contrast the basic parts of a wave.
- Inq.4 Draw a conclusion that establishes a cause and effect relationship supported by evidence.

8th Grade:

- T/E.1 Explore how technology responds to social, political, and economic needs.
- T/E.2 Know that the engineering design process involves an ongoing series of events that incorporate design constraints, model building, testing, evaluating, modifying, and retesting.
- Inq.5 Design a method to explain the results of an investigation using descriptions, explanations, or models.

High School Course Standards--Physics:

- 1.3.1 Identify the components of standing waves; including nodes, antinodes
- 1.3.2 Investigate and analyze wavelength, frequency, period, and amplitude of longitudinal and transverse waves.
- 1.4.1 Explore properties of electromagnetic radiation.
- 1.4.2 Examine properties of light waves.

High School Course Standards--Physical World Concepts:

- 7.3.11 Examine properties of light waves.
- 7.3.10 Explore properties of the electromagnetic spectrum.

- 3237.3.3 Investigate and analyze wavelength, frequency and amplitude of longitudinal and transverse waves.

High School Course Standards—Physical Science:

- Inq.1 Recognize that science is a progressive endeavor that reevaluates and extends what is already accepted.
- Inq.1 Trace the historical development of a scientific principle or theory.
- T/E.1 Explore the impact of technology on social, political, and economic systems.
- T/E.3 Explore how the unintended consequences of new technologies can impact human and non-human communities.
- 2.2.2 Explore and explain the nature of sound and light energy.
- 2.2.1 Investigate energy transfer through waves and particles.
- 2.2.5 Explore heat as a form of energy that may be transferred between materials.

Examples of Academic Vocabulary to Incorporate:

Kindergarten: beginning, ending, retell, difference, location, position, air, change, collect, observe, parts, senses, tools, job

1st Grade: question, reality, information, summarize, predict, sequence, classify, compare, data, direction, even, greater than/less than, balance, classify, environment, investigate, location, matter, prediction, property, push/pull, technology

2nd Grade: discussion, predicting, distance, interpret, likely, unlikely, outcome, unknown, compare, contrast, depend, distance, energy, infer, investigate, observation, reasoning, scientific inquiry, scientist, similarities/differences, type, decision, conflict

3rd Grade: cause, effect, fact, possessive, sequential, summarize, supporting details, change, conclusion, reasonableness, orbit, conductor

4th Grade: prediction, make inferences, drawing conclusions, compare, contrast, analogy, range, relationship, convert, accuracy, electricity, friction, distribution

5th Grade: implied, main idea, visual image, data collection methods, edge, variable, dissipate,

6th Grade: inference, relevant, relevancy, sequential order, experimental probability, random, similarity, cause and effect, conductivity, control, criteria, protocol, variable

7th Grade: inferences, paraphrase, phenomenon, speed

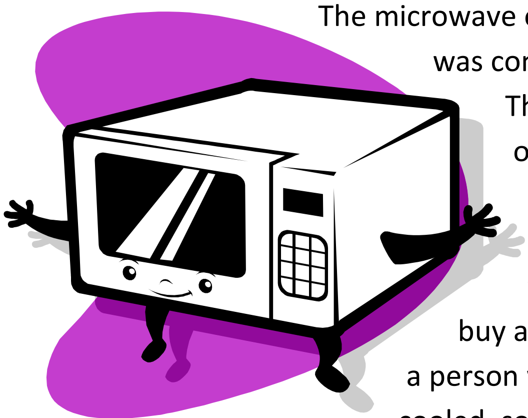
8th Grade: debate, elaborate, inferring, facilitator, rate, inductive reasoning, deductive reasoning, reliability, infinite, sequence, particle motion, variation

9th Grade: questioning, research, paraphrase, friction, energy, resistance

10th Grade: research, reasoning, shift, incongruity, ambiguity, deductive reasoning, inductive reasoning, independent and dependant events, property

High School: Instructors, please note that though there are no specific Academic Vocabulary lists for upper grade high school students, they will be expected to be familiar with and understand the key scientific terms and concepts covered within the following lesson. Familiarize yourself with the proper terms for all of the following concepts and make sure that you use them with and explain them to your students.

Nuke It!

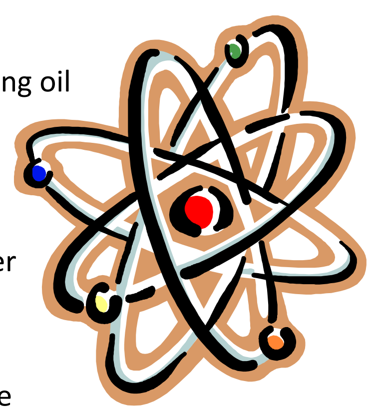


The microwave oven is now an essential part of most kitchens when once it was considered a luxury only the very wealthy could afford. They've changed since their invention, the first microwave ovens, in 1947, were gigantic and enormously expensive, standing 5 1/2 feet tall, weighing over 750 pounds, and costing about $5000 each. To give some perspective, at the time the average annual salary was $3,500, you could buy a brand new car for $1,500.00. A microwave cost more than a person would earn in a year! Microwaves also had to be water-cooled, so additional plumbing installations were also required.

Now, everybody likes to use the microwave to pop popcorn, melt butter, or make hot chocolate. Unfortunately, most people still have no idea how their favorite popcorn popping machine even works! We're going to do a few experiments that will help us figure out how this miracle machine does its job.

For this experiment, you will need:

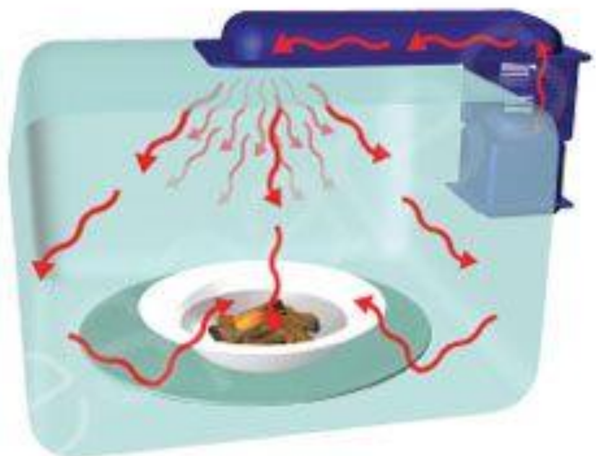
- 3 identical, **microwave safe** containers
- water
- cooking oil
- a microwave oven
- Hot pads



Any microwave safe containers should work, for example, small drinking glasses. Put about an inch of water into one glass, about an inch of cooking oil into another and leave the third glass empty. Place all three glasses into the microwave oven. Set the time for 15 seconds and start the oven. When the oven stops, open the door and carefully remove all three glasses. Carefully feel the outside of the glass of water, at the water level. It should feel quite warm. Making sure not to burn yourself, carefully touch the surface of the water. It should also be quite warm, possibly even hot. Do the same thing with the glass of cooking oil and the empty glass. What do you notice?

The glass of water heated up nicely, but the glass of oil, and the empty glass did not. Why? It has to do with how a microwave oven works. Inside the oven is a tube called a magnetron. This magnetron broadcasts microwave radiation. RADIATION!!!! Oh, no! Is our food radioactive? No. There are many kinds of electromagnetic radiation, such as radio, television, radar, and light. Microwaves do not make your food radioactive.

So how do the microwaves cook our food?



The microwave works when the high voltage from the plug is converted to waves of electromagnetic energy, which is a combination of electrical and magnetic energy. This energy is closer to radio waves, which are safe, not x-rays which can harm you if you have too many. When the door is opened or the timer reaches zero, the energy automatically stops, so no microwave radiation leaves the oven.

These waves cause the water molecules in the food to vibrate. Why just the water molecules? Water molecules are polar. That means that one end of the water molecule has a positive charge and the other end has a negative charge. (Remember protons and electrons?)

As the name suggests, microwaves are waves. They are not waves of water, but waves of electromagnetic energy. Just as a wave in water can cause an object to bob up and down as it rises and falls, the microwaves can cause a molecule of water to vibrate first one way and then the other. As the wave approaches the molecule, the positive end is pulled one way and the negative end is pulled in the opposite direction. Like an invisible game of tug-o-war. As the wave passes, the pulls are reversed. Because lots of waves keep coming and pulling this causes the water molecule to vibrate back and forth rapidly, with all the other water molecules doing the same thing. All of this vibrating makes them heat up (which is why your food steams). The water molecules then pass some of their vibration to surrounding non-water molecules, making them hot too.

That's why foods that have a lot of water, like fruits and vegetables, cook more quickly. Metal reflects/bounces back the microwaves, but the energy passes through glass, plastic and paper.

The microwaves make the water molecules contained in food vibrate and 'wiggle', which produces heat. Although heat is produced directly in the food, microwave energy doesn't cook food from the inside out. More dense foods like meat are cooked primarily by conduction of heat from the outer layers, which are heated by microwaves.

Why Didn't the Oil Heat Up?

Oil is not a polar molecule. That is the reason that oil and water do not mix easily. Polar molecules stick to other polar molecules, but not to non-polar ones. Because the oil is not polar, it is not heated by the microwaves. They just stay put and don't vibrate. That is why we cannot fry things in the microwave. But wait a minute. You might have had bacon cooked in the microwave. What about that? The bacon contains water as well as the fat. The water in the strip of bacon provides the heat to cook it. The fat just drains away. It will be hot, having been heated by the water in the bacon, but it will not continue heating once it drains away.

Dry foods do not cook well in the microwave oven. Remember that the empty glass did not get hot. You need the polar molecules in the water to get the heat for cooking.

Now, lets get back to the RADIATION. You might have heard that microwaves change the chemical structure of the food. Yes, cooking food with microwaves does change the chemical structure of the food. So does any kind of cooking. That is the reason we cook food. If you don't want the chemical structure of your food changed, eat it raw. Food cooked in a microwave oven is just as nutritious as food cooked by other means. It is not radioactive and not dangerous, as long as you don't burn yourself with it or drop it on your foot.

Who invented the Microwave Oven?

Like many of today's great inventions, the microwave oven was a by-product of another technology (and inspired through chocolate.) It was during a radar-related research project around 1946 that Dr. Percy Spencer, a self-taught engineer with the Raytheon Corporation, noticed something very unusual. He was testing a new vacuum tube called a magnetron when he discovered that the candy bar in his pocket had melted. This intrigued Dr. Spencer, so he tried another experiment. This time he placed some popcorn kernels near the tube and, perhaps standing a little farther away, he watched with an inventive sparkle in his eye as the popcorn sputtered, cracked and popped all over his lab.

The next morning, Scientist Spencer decided to put the magnetron tube near an egg. Spencer was joined by a curious colleague, and they both watched as the egg began to tremor and quake. The rapid temperature rise within the egg was causing tremendous internal pressure. Evidently the curious colleague moved in for a closer look just as the egg exploded and splattered hot yolk all over his amazed face. The melted candy bar, the popcorn, and now the exploding egg, were all attributable to exposure to the microwave energy. Thus, if an egg can be cooked that quickly, why not other foods? Experimentation began...

Dr. Spencer fashioned a metal box with an opening into which he fed microwave power. The energy entering the box was unable to escape, thereby creating a higher density electromagnetic field. When food was placed in the box and microwave energy fed in, the temperature of the food rose very rapidly. Dr. Spencer had invented what was (after further experimentation and refinement by other engineers and himself) to revolutionize cooking, and form the basis of a multimillion dollar industry, the microwave oven.

Microwaves, Chocolate, and the Speed of Light

An Experiment Inspired by Spenser

How often do you get a chance to examine electromagnetic radiation and even measure its wavelength (and the speed of light) while melting and eating chocolate? Thanks Spencer!

To try this, you will need:

1. a microwave oven
2. waxed paper
3. several chocolate bars
4. a large plastic, glass, or paper plate. Do not use metal!

Start by looking at the inside of the oven. If it has a turntable to rotate the food (most do), remove it. We want the chocolate to stay in one place, not move around.

Cover the plate with waxed paper, and then place the chocolate bars (unwrapped) on the plate to form a solid layer. You want the layer of chocolate to be as flat and even as possible.

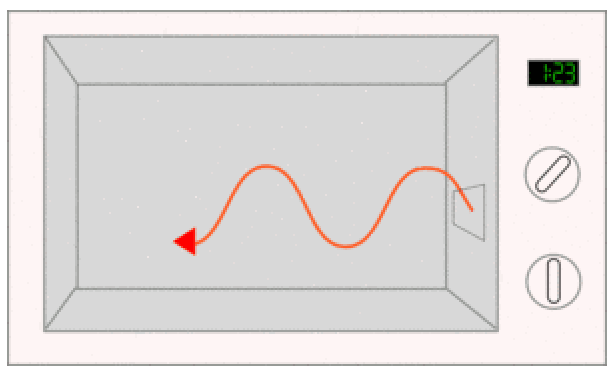
Place the plate of chocolate in the microwave and set the timer for at the most, 30 seconds. Depending on your oven, you may have to cook it a bit longer, but you don't want to learn from experience that cooking too long gives you a LOT of smoke and a mess.

After 15-30 seconds of cooking, check the results. You should find that there are spots where the chocolate is melted, and maybe burned, and other places where it is not melted at all.

Why?

Your microwave oven works by producing microwave radiation. No, its not radioactive! This is electromagnetic radiation, which also includes visible light, radio waves, ultraviolet light, radar, etc. As you know, microwaves cause water molecules to vibrate, producing heat to cook your food. OK, so why does your oven have hot spots, instead of cooking evenly?

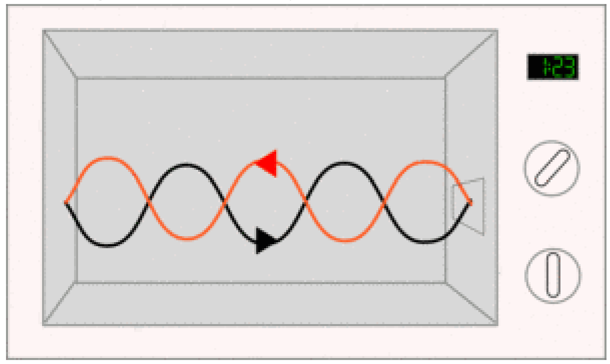
Microwave images and explanation are from Naked Scientists Kitchen Science 2007. (http://www.thenakedscientists.com/HTML/content/kitchenscience/exp/measuring-the-speed-of-light/) © The Naked Scientists® 2000-2010. The Naked Scientists® and Naked Science® are registered trademarks.



When you turn on your microwave oven, electrical circuits inside start generating microwaves – The waves are produced by a device called a magnetron and leave from a hole in the right.

If you look on the back of your microwave oven you should see a number in GHz (billion vibrations a second) or MHz (million vibrations a second), this is the number of waves the microwave produces every second - the frequency. Most microwaves produce electromagnetic waves with frequencies around 2.5 gigahertz – 2,500,000,000 Hz. Two billion, five hundred million vibrations every second.

These waves bounce back and forth between the walls of the oven. Instead of just blasting microwaves around, 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"**. This is where you get two waves, one going in each direction, these interact to make some areas where the microwaves are very intense, where the molecules will be vibrated very powerfully, so they are heated strongly. Then there other places, where the microwaves are weak and do not move much at all. These areas separated by half a wavelength. This is why there is a turntable in a microwave oven, otherwise parts of your food will be overcooked and others will still be raw.

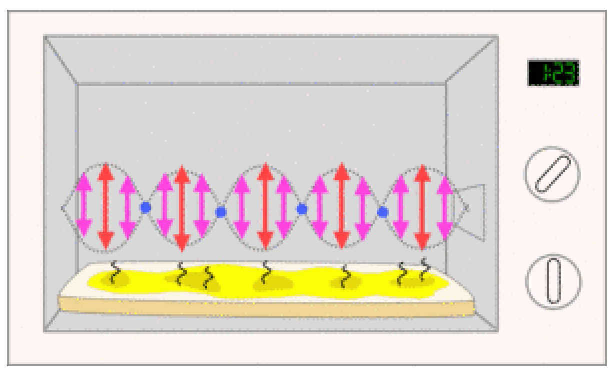


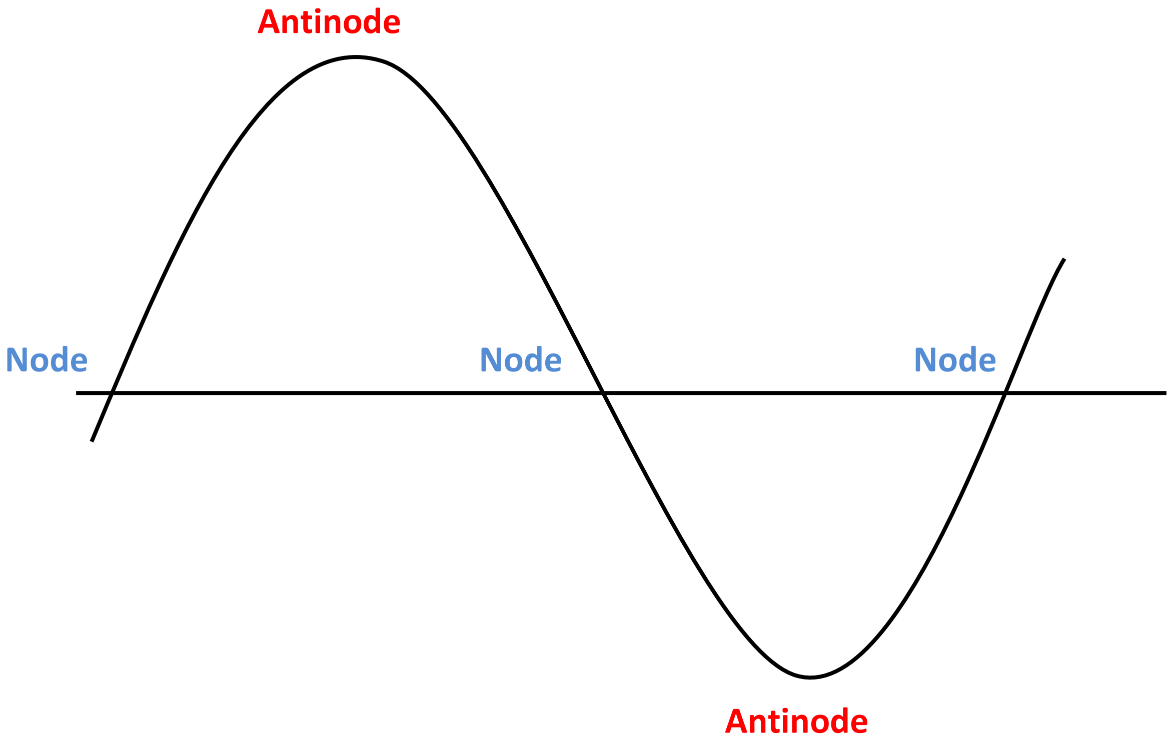
The easiest way to for your students to imagine a standing wave is to look at one and make one.

- Get several feet of rope, and tie one end to a doorknob.
- Hold the other end move back to take up most of the slack. You don't want the rope tight.
- Start shaking the rope up and down, and notice the way the rope wiggles. By adjusting how fast you shake the rope, you can find the point where it produces a stable pattern.
- Some parts of the rope will always be moving up and down, while other points will not move much at all. You should recognize the pattern when you see it.

That is a standing wave.

The electromagnetic field inside the microwave behaves in roughly the same way as our rope, except the vibrations are in "the electromagnetic field". Where the vibrations are greatest (the points where the wave is moving up and down a lot, called the **antinodes**), you will see the greatest heating, producing the burned spots. At the **nodes**, the part of the wave that does not move much and would not produce much heat, the chocolate will only melt slowly as heat diffuses into those areas, giving you the cooler spots in the oven. That is why you need a turntable to move the food through the hot spots, to heat it evenly. If you put the chocolate (or buttered bread) in the microwave the chocolate will first melt where the microwaves are the most intense, so the distance between these will be half a wavelength.





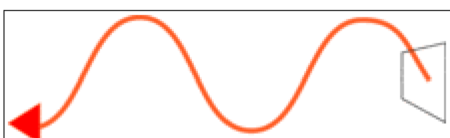
So, what has the wavelength got to do with the speed of light?

Anyone can measure the **speed of light (c)** - with chocolate (or buttered bread) and a microwave oven! The only equipment you need for this experiment is a microwave, a ruler and chocolate.

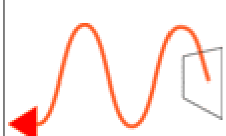
The speed of light is equal to the **wavelength (λ)** multiplied by the **frequency (f)** of an electromagnetic wave (microwaves and visible light are both examples of electromagnetic waves).

$c=\lambda*f$

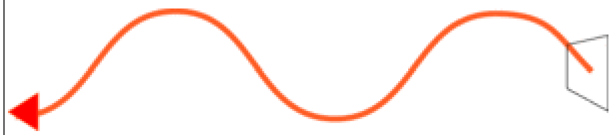
Your microwave oven is producing microwaves vibrating at a certain frequency – remember, this is written on the back of your microwave. The wavelength depends on how rapidly the wave is vibrating (the frequency) and how fast it is moving - as it is a type of light, the speed of light.



If you have a wave traveling at a fixed frequency (a certain number of vibrations a second).



If it is moving more slowly it will travel less far between vibrations so the wavelength will be less

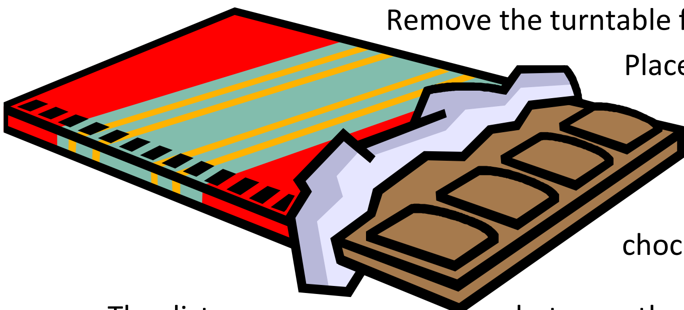


If it moves faster then the wavelength will be longer.

So this means that if the wave has a frequency of 100Hz it will travel it's wavelength 100 times in a second. So a wave's speed is frequency × wavelength.

Because microwaves are a type of light you have just measured the speed of light in your kitchen!

You do it.



Remove the turntable from the microwave (so the plate does not rotate). Place chocolate bars evenly on a plate inside the microwave. Heat the chocolate until it just starts to melt - about 20 seconds. There will be some melted hot spots and some cold spots in the chocolate.

The distance between the melted areas is half the wavelength of the microwaves or the distance between the antinodes. So, from this simple experiment, and some easy math, you can work out the speed of light!

c=2*x*f

Option: If you are out of chocolate, you can try this experiment using butter or margarine and some bread. Take the turntable out of the microwave. Put an upside down plate over the rotating parts so it won't rotate. Spread the butter evenly on all 4 pieces of bread, right out to the edges. Lay the four slices on another plate or the turntable plate, and add some butter at the joints.

Put this in the microwave, heat until the butter starts to melt (10-15 seconds) it is probably worth checking every 4-5 seconds.

What Is Happening?

Just like the chocolate, you should find that the butter melts in splodgy bands. If you measure the distance between these on either the chocolate or the butter and multiply it by two you will find the wavelength of the microwaves that the microwave oven is using to cook with.

If you multiply the wavelength you found by this frequency you will find the speed of light.

Distance between the hot spots _______________________________cm

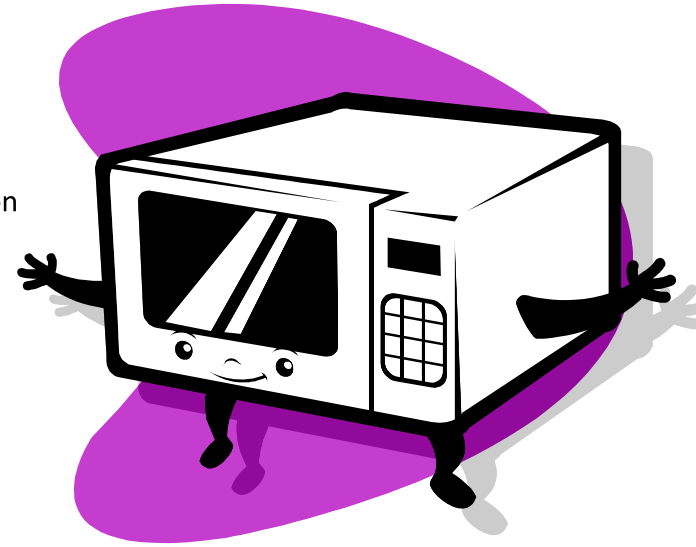
Wavelength ____cm

Wavelength ____m

Frequency of the microwave _________________________________m

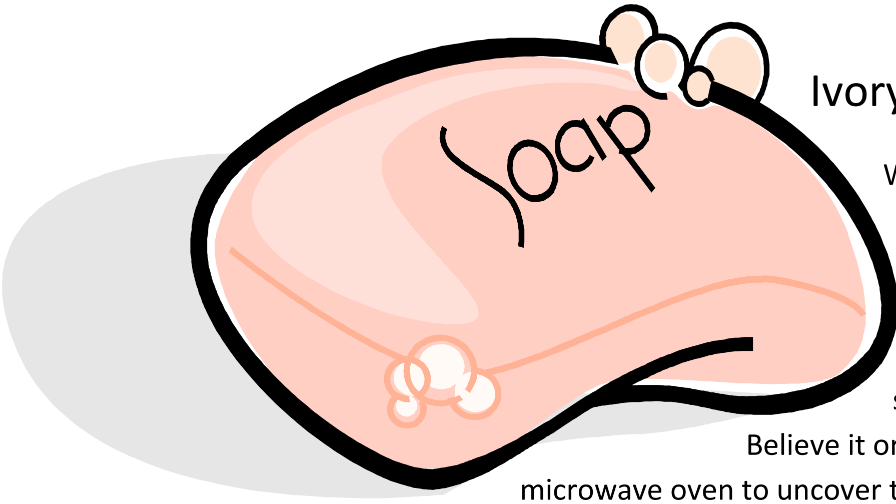
EQUATION ____

Your calculated speed of light ________________________________m/s



1. A standing wave is where you get . . .
   a. two waves, one going in each direction
   b. one wave, that stays in the same place
2. What kinds of foods do NOT cook well in a microwave?
   a. Greasy foods
   b. Dry foods
   c. Wet foods
3. Microwaves cause the water molecules in the food to _____________.
   a. Freeze
   b. Stay still
   c. Vibrate
4. Polar means that means that one end of the water molecule has a _______________ and the other end has a ________________.
   a. Positive Charge/Negative Charge
   b. Positive Charge/Neutral Charge
   c. Neutral Charge/Negative Charge
5. If the **antinodes** are where the vibrations are biggest and you will see the greatest heating, then at the **nodes**
   a. The vibrations are the smallest and you will see a lot of heating
   b. The vibrations are the smallest and you will see little heating
6. Why do microwaves have turntables that spin?
   a. Makes sure the food cooks evenly, preventing burned spots and raw spots
   b. Spreads the water out in the food
   c. The turntable creates a standing wave

What else can we do with a microwave?



Ivory Soap Science

Walk down the detergent isle and you'll see dozens of different kinds of soap. Green soap, smelly soap, big soap, even soap that floats. Ivory soap is famous for floating. How do they make some bars of soap float and others sink? Believe it or not, we're going to cook the soap in the microwave oven to uncover the secret. Just wait until you see what happens when the soap that floats also cooks. You get a bar of soap that grows bigger than a football.

Materials

- Bar of Ivory soap
- Various bars of another brands of soap
- Deep bowl of water (or a plastic tub)
- Paper towel
- Microwave oven

1. Fill the bowl with water.
2. Drop the bars of soap in the bowl of water. Notice how all of the bars of soap sink except for the Ivory brand soap. Why?
3. Remove the Ivory soap from the water and break it in half to see if there are any pockets of air hiding in the middle of the bar. (By the way, there are no pockets of air! Hmmmm?)
4. Place the bar of Ivory soap in the middle of a piece of paper towel and place the whole thing in the center of the microwave oven.
5. Cook the bar of soap on HIGH for 2 minutes. Don't take your eyes off the bar of soap as it begins to expand and erupt into beautiful puffy clouds. Be careful not to over cook your soap souffle.

6. Allow the soap to cool for a minute or so before touching it. Amazing... it's puffy but rigid.

How does it work?

Ivory soap is one of the few brands of bar soap that floats in water. If it floats in water, it must mean that it's less dense than water. When you broke the bar of soap into several pieces, no large pockets of air were discovered. Ivory soap floats because it has air pumped into it during the manufacturing process. The air-filled soap was actually discovered by accident in 1890 by an employee at Proctor and Gamble. While mixing up a batch of soap, the employee forgot to turn off his mixing machine before taking his lunch break. This caused so much air to be whipped into the soap that the bars floated in water. The response by the public was so favorable that Proctor and Gamble continued to whip air into the soap and capitalized on the mistake by marketing their new creation as The Soap that Floats!

Why does the soap expand in the microwave?

This is actually very similar to what happens when popcorn pops or when you try to microwave a marshmallow. Here's the secret: All soap contains water, both in the form of water vapor inside trapped air bubbles (particularly important in the case of Ivory) and water that is caught up in the matrix of the soap itself. The expanding effect is caused by the heating of the water that is inside the soap. The water vaporizes, forming bubbles, and the heat also causes trapped air to expand. Likewise, the heat causes the soap itself to soften and become pliable.

This effect is actually a demonstration of Charles' Law. When the soap is heated, the molecules of air in the soap move faster, causing them to move far away from each other. This causes the soap to puff up and expand to an enormous size. Charles' Law states that as the temperature of a gas increases so does its volume. Other brands of soap without whipped air tend to heat up and melt in the microwave.

Extensions:

Perform the experiment with additional bar soaps like Dove, Dial and Irish Spring and see if anyone else has discovered whipped air since 1890.