

Synchrotron Investigations

10.3 The efficiency of a microwave oven

Background

Synchrotrons produce high intensity EMR including, at the far end of their emission range, microwaves. Microwaves interfere with molecules causing them to oscillate. The shape and size of the molecule determines at which microwave frequency it will start to oscillate continuously.

We all know that if we put matter that contains water (such as food) into a microwave oven and expose it to microwaves it heats and cooks. The microwaves cause the water molecules in the food to oscillate. This motion leads to friction, and friction results in heating and therefore cooking. Most foods we consume consist of over 70 per cent water (by weight), making this an effective way for heating foods. Foods with low water content take longer to heat in a microwave. Frozen foods take longer to heat than defrosted foods because the water molecules in them cannot move as much as in liquid water. Food heated in a microwave cannot become hotter than the boiling point of water (100°C), this is why foods cannot be browned in microwave ovens and pies and pastries reheated in microwave ovens do not have a crisp crust like a freshly baked pie would have.

The microwaves used in a microwave oven need to be in the region of the natural frequency of water molecules. This allows them to oscillate in a regular manner. As a result, all microwave ovens are manufactured to produce EMR of the same frequency. Globally, household microwave ovens operate at a frequency of 2458 MHz and this produces a wavelength of 12.2 cm.

Radiation with longer wavelengths tends to penetrate deeper into matter. An example of this is that radio waves can travel through concrete walls. Microwaves have a much shorter wavelength than radio waves but can still penetrate about five centimeters into food. Microwaves can heat foods faster than heating through conduction by boiling water on the outer surface. If food is thicker than five centimeters, the middle of the food will still need to be heated by conduction.

Use these websites to gain an understanding of the principles involved before moving on.

- www.colorado.edu/physics/2000/microwaves/index.html
- http://en.wikipedia.org/wiki/Microwave_oven

One of the major drawbacks of microwave ovens are areas in them termed hot spots. As it reflects around the metal interior of the oven, microwave radiation interacts with reflected radiation in a way that results in the formation of hot and cold spots. To alleviate this as much as possible the base plate (or turntable) rotates to reduce uneven cooking.



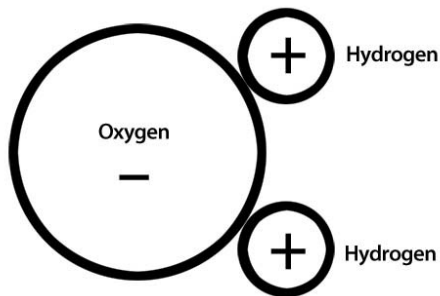
Microwave oven
Image courtesy: DUIT Multimedia

The efficiency of a microwave oven

Background on microwaves

We know that microwaves interact with different types of matter in different ways.

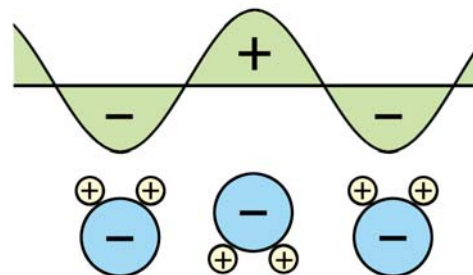
- They are reflected by metal. This is why the inside of the microwave oven is made of metal and the door is made of metal mesh.
- Radar uses microwaves because it can pass through cloud and dust and is reflected back by the metal surfaces of planes.
- Microwaves can cause molecules to oscillate causing heating through friction. This means microwaves can be used for cooking.
- They can penetrate non-metallic matter to a depth of around five centimeters. This means cooking is quicker because it is not relying on conduction.



Water molecules (H₂O) are polar molecules; this means its charge is not evenly distributed.

Microwave radiation, like all other EMR, consists of oscillating electric and magnetic fields. If you pass or move a microwave electric field over a water molecule the positive and negative areas of the molecule will interact with the positive and negative areas of the moving field.

This forces the water molecules to oscillate resulting in friction between the molecules. This friction then leads to heating.



If you have not visited the Colorado physics web site yet, do so now before you move on <http://www.colorado.edu/physics/2000/microwaves/index.html>

Experiment background information

You are going to measure the efficiency of your microwave oven by calculating how much of the electrical energy used by the microwave actually heats the water.

The electrical energy used is calculated using the relationship

$$P = \frac{E}{t}$$

where P is the power rating of the microwave oven (read off the compliance plate, watts)
 E is the electrical energy used by the microwave oven in time (joules)
 t is the time the microwave oven was turned on for (seconds)

The amount of energy converted into heat energy is calculated using the following relationship.

$$Q = mc_{\text{water}}(T_{\text{final}} - T_{\text{initial}})$$

where Q is the heat transferred to the water

m is mass of water being heated (kg)

T_{final} is the final temperature

T_{initial} is the initial temperature

c_{water} is the specific heat of water (4186 J kg⁻¹ C⁻¹)

By subtracting one from the other, you can calculate how much useful work has been done and therefore work out the efficiency of the microwave oven.

The percentage efficiency is worked out using the following relationship.

$$\text{Percentage efficiency} = \frac{E - Q}{E} \times \frac{100}{1}$$

where Q is the heat transferred to the water (joules)

E is the electrical energy used by the microwave oven in time (joules)

Materials

- a microwave oven
- 100 mL beaker
- a thermometer
- a watch to measure seconds with

Method

1. Place about 80 mL of water in a beaker, making sure you have weighed the water to get an accurate measure of the amount in kilograms.
2. Measure and record the initial temperature of the water.
3. Place the beaker of water in the microwave oven, on the turntable.
4. Run the oven for 30 seconds.
5. Take care when removing the heated water.
6. Measure and record the final temperature of the water.

NOTE: If the temperature has not increased by at least 30°C, start the experiment again from the beginning with a new sample of water and heat for a longer period of time.

7. Repeat the experiment a total of three times. Each time use fresh water and place the beaker a different distance from the centre of the turntable.

Data

Trial	Mass of water (kg)	Initial temperature (°C)	Final temperature (°C)
1			
2			
3			

Processing data

Task 1

List, in order, the calculations you need to complete to find the efficiency of the microwave oven you are testing. Have your teacher check your sequence before moving onto **Task 2**.

Teacher's check

Task 2

Complete your calculations, setting them out neatly and in the correct sequence to find the efficiency of your microwave oven.

Results

Microwave oven brand and name	Microwave oven rating	Percentage efficiency

Concept understanding

1. Explain how microwaves can heat water. To do this properly you will need to get the sequence of what happens in the correct order. Start with the microwave EMR penetrating into the water and finish with the water increasing in temperature. You should have already visited this site, but if not go to the Colorado physics site, it will help you.

www.colorado.edu/physics/2000/microwaves/index.html

2. What has happened to the energy that has been lost in this experiment?
3. A typical direction for microwaveable frozen food reads 'Heat on high for two minutes, then let stand for one additional minute'. Why is the second step necessary?

