**Heating and Cooling Substances with a Microwave Oven**

***Background:***

The temperature of substance is an indication of the motion of the molecules that make up the substance. These molecules are attracted to each other by forces of various strengths so the rate at which different substances heat up and cool down gives us an indication of the strength of the forces that hold molecules together. Microwave ovens heat substances by using specific wavelengths of the electromagnetic spectrum to cause molecules to vibrate and move faster. Because the energy waves vary throughout the microwave oven, substances heat differently in different regions of the microwave oven and can often be mapped.

**Goals of the Experiment:**

1. Gain experience with preparation and analysis of graphical data

2. Use trends to predict future measured values from existing data

3. Relate macroscopic observations to molecular-scale phenomena

4. Appreciate sources of error in the design of an experiment

5. Design experiments with safety considerations in mind

***SAFETY NOTE:*** **Be extremely careful handling hot liquids, especially hot oil. Severe burns can result. If your container needs to be moved while hot, use an appropriate hot pad to prevent burns. Always think about the *end* of the experiment before you start! Do you have a safe place to set a (potentially dangerously) hot container to cool for 30 minutes or more? Do you have appropriate personal protective equipment (hot pads, etc) within reach?**

***Required Equipment and Supplies:***

1. Microwave oven

2. A few identical microwave-safe ***glass*** containers with a volume of at least 400mL

3. Thermometer (range up to at least ~250°F/120°C

4. 200.0mL water

5. 200.0mL vegetable oil (be sure to note type and brand)

***PART 1: Heating different substances***

Place 200.0mL of water in a microwave-safe glass container. Use a kitchen scale to measure the mass of the water. Record the initial temperature of the water. Place the container in the microwave, noting the exact position of the container. Microwave on high for 15 seconds, quickly stir the water, and record the temperature. Microwave an additional 15 seconds, stir, and record the temperature. **Repeat until the liquid boils OR for a total of 5 minutes** **OR until the thermometer reaches its maximum temperature**, whichever comes first. Remove the container from the microwave and continue to record the temperature every 15 seconds for at least another 5 minutes as the water cools. Repeat this procedure with 200.0mL of vegetable oil. Be sure to place the container in the same place in the microwave.

***Data Analysis:***

## Calculate the density (grams per milliliter) of your water and vegetable oil. Prepare a single plot of temperature vs. time which includes data for both water and vegetable oil. For each substance, determine the rate of temperature increase for the heating portion of the plot and the rate of temperature decrease for the data after the container was removed from the microwave. There are multiple ways to calculate the rate of change, be sure to explain how *you* calculated it in your assignment.

1. Which substance heats faster, water or vegetable oil? How much faster?

2. Which substance cools faster, water or vegetable oil? How much faster?

3. Did the substance that heats up faster also cool down faster?

4. What do the rates of heating and cooling tell you about the relative strength of the intermolecular forces holding molecules together in water vs. vegetable oil?

5. Did the more dense substance heat faster or slower than the less dense substance? Propose an explanation for this. Given that you are basing your explanation on the observation of only 2 substances, how reliable do you feel your explanation is?

***PART 2: Mapping Microwaves:***

*If the microwave has an automatic turntable:*

In 3 identical containers, place equal amounts of water. Place one container at the center of the turntable, one container at the edge, and the third container midway between the first two. (If your microwave is small, just use 2 containers; 1 in the middle, the other near the edge.) Record the initial temperature, heat for 15 seconds, stir quickly, and record the temperature in each container. Continue to heat and record the temperature 15 seconds at a time for 5 minutes or until one of the samples boils. Be sure to note the brand and power of the microwave you use for this experiment.

*If the microwave does not have an automatic turntable:*

In 3 (or more) identical containers, place equal amounts of water. Place one container at the center of the microwave, and spread the remaining containers out around the interior of the microwave oven. Record the initial temperature, heat for 15 seconds, stir quickly, and record the temperature in each container. Continue to heat and record the temperature 15 seconds at a time for 5 minutes or until one of the samples boils. Be sure to note the brand and power of the microwave you use for this experiment.

NOTE: Take the temperature of the samples in the same order every time you measure. Measure the temperatures as quickly as safety and your equipment will allow.

***Data Analysis:***

Draw a diagram of your “sample map” showing the position of each of your samples in the microwave. Prepare a single plot of temperature vs. time which includes data for all samples. For each sample, determine the rate of temperature increase.

1. What is the rate of heating in each of the positions?

2. Is the rate of heating the same in all positions?

3. If the rates are different, how can you use this information to change how you use this microwave to heat foods in the future?

4. How will measuring the samples in the same order affect the error in your results? Will it make your results more accurate (minimize error) or less accurate (increase error)? How might your results be different if you measured the samples in random order each time?

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Example Data Collection Sheet

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| ***Water*** | | | |  | ***Vegetable Oil*** | | | |
| *Heating* | | *Cooling* | |  | *Heating* | | *Cooling* | |
| Time  (seconds) | Temperature  (°F or °C) | Time  (seconds) | Temperature  (°F or °C) |  | Time  (seconds) | Temperature  (°F or °C) | Time  (seconds) | Temperature  (°F or °C) |
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Example Data Collection Sheet

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| --- | --- | --- | --- | --- | --- | --- | --- |
| *Location 1* | | *Location 2* | | *Location 3* | | *Location 4* | |
| Time  (seconds) | Temperature  (°F or °C) | Time  (seconds) | Temperature  (°F or °C) | Time  (seconds) | Temperature  (°F or °C) | Time  (seconds) | Temperature  (°F or °C) |
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**Grading Rubric:**

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| --- | --- | --- | --- | --- |
| ***Criterion*** | ***Poor*** | ***Average*** | ***Good*** | ***Score*** |
| PART 1: Data Collection | Data collection is incomplete and not recorded.  0 points | Data collection is complete and recorded.  1-2 points | Data collection is complete and clearly recorded.  3 points | 3pts |
| PART 1: Graphs | Graphs are missing.  Trendlines are missing  0-1 point | Graphs are included.  Trendlines are shown.  2-4 points | Graphs are properly prepared and labelled.  Trendlines are correct and clearly shown.  5-6 points | 6pts |
| PART 1: Analysis of Graphical Data | Little or no analysis.  0-1 point | Slopes are included and reasonable.  Relationship between rates and intermolecular forces are addressed.  Density and error is mentioned.  2-4 points | Slopes and rates are correctly interpreted.  Rates are related to intermolecular forces in a reasonable way.  Density and error are appropriately addressed  5-6 points | 6pts |
| PART 2: Data Collection | Data collection is incomplete and not recorded.  0 points | Data collection is complete and recorded.  1 point | Data collection is complete and clearly recorded.  2 points | 2pts |
| PART 2: Graphs | Graphs are missing.  Trendlines are missing  0-1 point | Graphs are included.  Trendlines are shown.  2-3 points | Graphs are properly prepared and labelled.  Trendlines are correct and clearly shown.  4 points | 4pts |
| PART 2: Analysis of Graphical Data | Little or no analysis.  0-1 point | Slopes are included and reasonable.  Differences in rates are noted.  Experimental design and error are addressed.  2-3 points | Slopes and rates are correctly interpreted.  Differences in rates are addressed.  Experimental design factors are explained with regard to measurement error  4 points | 4pts |