Specific Heat of Solids and Liquids

Part I

Have you noticed that when it is really cold outside, lakes in this area may freeze, but Puget Sound does not freeze? This also happens around the Great Lakes, which are large freshwater lakes. Although the surface of these lakes may sometimes freeze, this only happens when it is very cold for a prolonged period of time. But the air temperature can be less than –10 °C in Chicago for a week straight, but Lake Michigan doesn’t freeze solid. (Recall that the freezing point of water is 0 °C.)

► Propose an explanation for the fact that large bodies of water don’t freeze as soon as air temperature drop below 0 °C. (Be sure to include both what you think and why you think it. It doesn’t matter if your explanation turns out to be wrong.)

Part of the reason that lakes don’t freeze during the first cold snap is because they have a lot of matter. But that’s only half of the answer. To see why, think about this. As before, let’s imagine a week in Chicago where the air temperature has been < –10 °C for the entire week. As we mentioned above, even in these conditions Lake Michigan doesn’t freeze. But here’s the interesting thing. If you took a thermometer and measured the temperature of both the lake and the surrounding ground (soil & rock), you would find that the ground was colder than the lake. The ground temperature might be as low as –5 °C or even lower! There is more ground in the Chicago area than there is water in Lake Michigan, so the size of the lake alone does not explain this observation. The same thing happens in the summer. It can get to be 38 °C (100 °F) in Chicago in the summer, and still Lake Michigan will never get warmer than 27 °C (80 °F). Yet the sidewalks, roads and highways are all roasting hot. There is something different about the water!

► Make a prediction that explains why the temperature of the lake is never as cold as or as warm as that of the surrounding air and ground? Write down your hypothesis before continuing.
Once you know the answer to these questions, you should have a good understanding of a concept called **specific heat**. The best way to understand a concept like specific heat is to do a few experiments. Since we can’t travel to Chicago to experiment with Lake Michigan, we’ll have to improvise a bit. Our “Lake Michigan” will be some water in a Styrofoam cup. For the ground, we’ll use some rocks, since we happen to have a few around the lab. The experiment will involve investigating heat transfer between the rock and the water.

► Do you remember the difference between heat and temperature? Just to refresh your memory, write down your best recollection in the space below.

In this experiment we’ll be looking at the factors that affect heat transfer between the rock and the water. First, think back to a previous experiment where you mixed different amounts of water at different temperatures and measured the final temperature.

► Refresher Question: If 100 g. of water at 80 °C is mixed with 50 g of water at 60 °C, will the final temperature of the water be 70 °C (halfway in between)? Why or why not?

Hopefully you recall that the amount of heat transferred between the two samples of water depends on two things: the **temperature** of the water and the **mass** of the water. However, when we investigate heat transfer between **two different types** of material we have to account for a third factor, which has to do with the kind of material involved (or the **identity** of the substance transferring the heat). In your experiments with the water you didn’t observe this effect because you only experimented with one substance (water). Today’s experiments introduce this third variable by looking at heat transfer between **different** substances.
Now it’s time to get started on the experiment. Here’s what you’ll need. Before starting, assemble the following items at your desk.

- A Styrofoam cup.
- A rock
- A graduated cylinder
- A thermometer
- A piece of string

Experiments often begin with questions, so here’s our question:

“Which substance can hold (or retain) more heat, rock or water?”

After establishing the question to be investigated, it is common to make a hypothesis (an educated guess) about the possible results of the experiment.

► What is your hypothesis: Which substance can hold (or retain) more heat, rock or water?”  
(Be sure to include both what you think and why you think it. And remember: it doesn’t matter if your explanation turns out to be wrong.)

Now it’s time to design the experiment. Remember that we want to investigate and compare heat transfer between two different substances (rock and water). But heat transfer also depends on the mass of the substance. One way to simplify our experiment is to make the mass of the water equal to the mass of the rock. Because the masses are the same, the mass of the object will not affect the results of the experiment. We’ll learn other ways to account for mass difference later.

In order to look at heat transfer, the rock and the water will need to be at different temperatures. We will use room temperature water. The rock will be heated and then added to the water.

► Describe how can you heat the rock up to a known temperature using the equipment provided  
(By the way…It won’t work to put the rock on the hot plate measure the temperature of the rock with the thermometer. ☺)
Experimental Procedure:

- Use the balances to determine the mass of your rock, and record the mass in the data table.

Since we want the mass of the rock to equal the mass of the water, you’ll need to obtain an equivalent mass of water. Remember that 1 ml of water = 1 gm and use the graduated cylinder to measure out a mass of water equal to the mass of the rock. Once you have measured out the proper amount of water, add it to the Styrofoam cup.
  - Remember to record the mass of the water in the data table.
  - Record the temperature of the water in the cup. Record this value in your data table as the initial temperature of the water.

You are going to heat up the rock by submerging it in hot water for a few minutes. To make it easy to get the rock in and out of the water, tie a string around it. (You’ll need to make sure you remember which rock is yours!) Put the rock in the hot water and leave it there for 5 minutes or so.

- Record the temperature of hot water (in °C):

- If the rock sits in the hot water for five minutes, what is the temperature of the rock? (Explain your reasoning). Record this value in your data table as the initial temperature of the rock.

Once the rock has been in the hot water for a while, use the string to quickly transfer the hot rock to the water in the cup and cover with a lid. Use the thermometer to monitor the temperature of the water. Stir constantly so that the heat is evenly distributed.

- Note the highest temperature reached and record this in the data table as the final temperature of the water.

- Question: When the temperature of the water stops changing, what is the temperature of the rock? Explain your reasoning and record this value in your data table as the final temperature of the rock.
• Repeat the experiment two more times.

**Data Table:**

<table>
<thead>
<tr>
<th></th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description of Rock</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass of Rock (g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass of Water (g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial Temperature of Water (°C)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial Temperature of Rock (°C)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final Temperature of Water (°C)</td>
<td></td>
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</tr>
</tbody>
</table>

Now that you have collected a bunch of data, it’s time to see what they tell us. Take a minute to look at the data.

- Compare the results from your three trials. Were the results the same or different? If they were different- they suggest a reason why they were not the same.

- Which changed temperature more: the water or the rock? How did this compare with your predictions?

Remember that in this experiment, both the water and the rock had the same mass. Think back again the previous experiment where you mixed equal masses of water at different temperatures.

- In that case, what was true about the final temperature of the water, compared to the initial temperature of each water sample?
In this experiment, perhaps you noticed that the rock’s temperature changed more than the water’s temperature, even though the rock and the water had the same mass. (Isn’t that strange?) Let’s calculate the change to really see the difference.

- Complete the table below (remember that “ΔT” means “the change in temperature.”)

<table>
<thead>
<tr>
<th></th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔT_{water}</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ΔT_{rock}</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Now try these questions:
- Compare the average temperature change of the rock and the water in this experiment.
- How are the results of this experiment different from the results of the experiments we did in with both of the materials (the hot one and the cold one) were water?
- If you use the equation we gave you for water, what is the amount of heat transferred by the rock and the water in this experiment?

Check with an instructor before continuing.

An important concept to have at this point is that even though temperature of the rock and the water change by different amounts, the amount of heat lost by the rock equals the amount of heat gained by the water. This has to be true - otherwise where would the heat go? (Of course to make this statement we are assuming that none of the heat in this experiment escaped to the surrounding air. That’s why we used a Styrofoam cup and tried to quickly transfer the rock to the water.)

So why did the rock’s temperature change more than that of the water? It’s because there is something fundamentally different about rock and water. Not all substances hold (retain) heat in the same way. Scientists use the term specific heat to refer to the ability of a substance to hold heat. Be careful – the “specific heat” of an object is defined differently from “heat”. They sound the same, but they mean different things!
Here is a somewhat technical definition of specific heat:

**Specific Heat:** The amount of heat required to change (raise or lower) the temperature of 1 gram of a substance by 1 °C.

So we can now restate the equation about heat to read:

\[
\text{Heat transfer (H)} = \text{[specific heat (s)]} \times \text{[mass (m)]} \times \text{[change (Δ) in temperature (T)]}
\]

Or

\[
H = s \times m \times ΔT
\]

All substances have different specific heats. The specific heat of water, for example, is 1.0 cal/g°C. This means that it takes one calorie to raise the temperature of 1 gram of water by 1 °C. (Remember that the calorie is a unit for heat or energy).

➢ Describe in your own words what “1.0 cal/g°C” means. You may want to refer to the definition of specific heat listed above.

Test your understanding of this concept by answering the questions below. Include units with your answers.

► How much heat would it take to raise the temperature of 1.0 g of water by 1 °C? (Show your work or explain your reasoning).

► How much heat would it take to raise the temperature of 2.0 g of water by 1 °C? (Show your work or explain your reasoning).

► How much heat would it take to raise the temperature of 5.0 g of water by 3 °C? (Show your work or explain your reasoning).
Now suppose that instead of water, you were investigating another substance with a specific heat of **0.5 cal/g°C**. In other words, for this new substance, it requires only **0.5 cal** to raise the temperature of 1 gram of the substance by 1 °C.

- How would your answers to the previous three questions if we were recording the changes in the new substance rather than water? Explain using numbers, words or equations.

**Check your answers with an instructor before continuing.**

- Which do you think has a higher specific heat: your rock sample or the water? Take a minute to look again at your experimental data and the definition of specific heat, and explain your answer.

- Based on your data, do you think that the specific heat of your rock was greater than, less than or equal to the specific heat of the water? How can you tell just by looking at your data?

Did you conclude that the specific heat of the rock was *less than* that of the water (or to put it another way: the lower the specific heat of an object, the easier it is to change its temperature). If this concept is still a bit fuzzy, you should consult with an instructor before continuing.
Using your experimental data, you are now ready to calculate the specific heat of your rock samples. You will need to use the equation for specific heat given on page 7.

- Using your equation, calculate the amount of heat gained by the water in each of your three trials. Show your work and record your answers in the table below.

**Trial 1:**

**Trial 2:**

**Trial 3:**

In this experiment, the rock lost heat and the water gained heat. We can say that these items had a thermal interaction. Remember that the amount of heat gained by the water equals the amount of heat lost by the rock. Now that you have calculated the amount of heat gained by the water, you also know the amount of heat lost by the rock. (They are equal). You can use this information to find the specific heat of the rock.

- Rearrange your equation on page 8 to solve for \( s \), the specific heat of the substance. (But don’t solve the equation yet. Check your work with an instructor before continuing).

In order to solve for the specific heat of the rock you will need to know both the mass of the rock and its change in temperature. These quantities can be found in your data table on page 6. You will also need to know the amount of heat lost by the rock. (If you don’t remember how to figure this out- ask one of your instructors)
Calculate the specific heat of the rock for each of your three trials. Record your answers (including units!) and show your work below.

Trial 1:

Trial 2:

Trial 3:

Check with an instructor before continuing.

If you can remember all the way back to page 1 when you started this exercise, you might recall that this experiment had something to do with the temperature of Lake Michigan compared to the temperature of the ground.

In your experiments, the water in the cup represented Lake Michigan and the rock represented the surrounding ground. Before starting the experiment, you made a hypothesis about which substance would retain more heat. Go back to p. 3 and have a look at what you wrote.

► Were your experimental results consistent with your hypothesis? Why or why not?
Based on the results of your experiment, why is it that the ground in the Chicago area is colder than the lake during winter, and warmer than the lake during summer? You should use the term specific heat in your answer. You should also explain how your experimental results prove your answer.

We can use the same concepts to think about regional climate here in the Pacific Northwest. Of course climate is influenced by many factors (altitude, topography, air currents etc.), but specific heat plays a role too.

- Compare the summer and winter temperature in Western Washington to the summer and winter climates in Eastern Washington.

- What is different about Eastern and Western Washington that might account for this difference? There are many possible answers here, but try to think of an answer that applies the concepts you have learned in this module.