Names and Picture:

3 *EVAPORATION, CONDENSATION, AND HUMIDITY*

At this point, you should have a pretty good understanding of temperature and thermal energy transfer. In this section, we will be taking a look at some situations where a transfer of energy does *not* result in a temperature change. This will lead us to consider how substances can change from one phase into another. In particular, water is a substance that readily changes from a liquid into a gas. In this section we will investigate how this phenomenon can be understood in the context of energy transfer. Specifically we will try to answer the question: is the transfer of energy necessary for a substance to change phase?

You may need some of the following equipment for the activities in this section:

- Styrofoam (or other insulated) cups [3.1 – 3.2]
- Temperature sensors [3.1 – 3.3]
- Immersion heater [3.1]
- Heat pulsers (optional) [3.1]
- MBL system [3.1 – 3.3]
- Mass balance [3.1]
- Hot and cold water [3.1 – 3.3]
- Paper towels [3.2]
- Relative humidity sensors [3.3]
- Plastic, seal-able containers [3.3]

3.1 HEAT OF TRANSFORMATION

We saw in the last section that adding one calorie of thermal energy resulted in one gram of water changing temperature by one degree. Thermal energy is almost always discussed in the context of *transfer* from one object to another. Based on this observation, we might conclude that if we continue to add energy to water its temperature will continue to rise. Let's find out if this is true. We know that if we add thermal energy to a container of water it will eventually begin to boil. The question we want to ask is what happens to the temperature of the water if we continue to add energy to it while is boiling? **Caution:** Be very careful in the following activity. Boiling water can cause severe burns.

Activity 3.1.1 Watching Water Boil

Figure C-10: When water is heated to 100 °C, it begins to boil. What happens to the water when it boils? (Eye Ubiquitous /Corbis Images)

a) Begin by measuring the mass of an empty cup. Now put about 150 grams (it doesn't have to be exact) of room temperature water in the cup and measure the mass of the cup/water system. Report your results below.

You'll record the mass, in grams, of

1.the empty cup,

2. the mass of the cup with water in it, and

3. the *difference* between 1 and 2, which will be the mass of the water in the cup.

b) Set up the temperature sensing software so that it will take readings once per second for about 15 minutes ~~and make sure the temperature range goes from 0°C to 110°C~~. Next, place the temperature sensor and immersion heater (without plugging it in) into the water. Have your instructor check out your setup ***before*** starting the software. Once you have been checked out, start the software and begin stirring the water with the temperature sensor, being careful not to touch it to the heating unit. After 20 seconds or so, plug in the heating unit and continue stirring (without splashing) until the water begins to boil vigorously. At this point, you can stop stirring the water, but you still need to make sure that the temperature sensor doesn't come into contact with the heating unit.

Logger Pro will autoscale the temperature.

Additional instructions:

1.) Place your styrofoam cup inside of one of the ceramic mugs to stabilize it.

2.) *Immerse* the immersion heater fully in the water. (Don't clip it on to the side).

After the water has been boiling vigorously for at least five minutes, ~~unplug~~ turn off the heating unit and remove the temperature sensor from the water. Then, as quickly as possible (but being as careful as possible), remove the heating unit from the cup and measure the mass of the cup/water system. Report your result below. *Do not throw out the water remaining in the cup!* If there is less water in your cup than before you boiled it, where do you think the water went?

Take the thermometer out at the same time as you turn off the heat, but let Logger Pro keep running.

Logger Pro will record a sudden drop in temp when your thermometer comes out, and that will mark on your graph the end of the time that you heated the water.

c) After about 10 minutes (when the water has cooled off substantially) measure the mass of the cup/water system again. In the meantime, ~~you should print out a copy of your data~~ for your activity guide. How much water was lost while cooling down? Do you think any water was lost as the water was heating up (but not yet boiling)? Using this information, determine how much liquid water was lost during the boiling process alone. Show all you work.

take a screen shot of your graph and paste it below

But keep your graph and data up on the screen. You'll need to do more with the graph and the data in the sections below.

d) Briefly describe the main features of your graph, specifically what happened to the temperature of the water once it started boiling. What does this mean about how quickly the water molecules are moving? Are they moving faster and faster as you add energy to the boiling liquid? Explain briefly.

e) Although you continued to add energy into the water, its temperature stopped increasing. Where did the energy that you added to the water go?

At this point, you might have noticed that our definition of "heat" is a bit flawed. We defined our unit of thermal energy (the calorie) as the amount of energy needed to increase the temperature of one gram of water by one degree Celsius. Thermal energy was studied by its affect on the temperature of a substance. As the previous activity just showed, the temperature of water did not increase beyond 100°C, even though we were still adding energy. Thus, adding one calorie of thermal energy to one gram of water that is already at 100°C will *not* increase its temperature by one degree, which makes it important to specify what temperature the water is at when we try to increase its temperature. The accepted definition for one calorie is the amount of thermal energy needed to increase the temperature of one gram of water from 14.5 ºC to 15.5 ºC.

The fact that the temperature of the water stopped rising at 100 degrees Celsius may not have been a real surprise to you. However, you may not have realized that this temperature actually tells you something about the interaction between the molecules of water. Since temperature is a measure of the average speed of the molecules, it seems like there will be a point when the water molecules are moving so vigorously that they can "break away" from each other. This is what's referred to as the *boiling point* of the material. At this point, the liquid molecules are breaking their bonds with each other and becoming gas molecules. The bubbles you see when boiling water are bubbles of *gaseous* water (not air), also called steam.[6]

This is an example of what scientists call a *phase change*; the state of matter is being changed from one phase into another. In this case, liquid water is being turned into gaseous water. This happens at a well-defined temperature called the *boiling point*.

[6] It is worth pointing out that when people say they see "steam" rising from a pot of boiling water, they are not actually seeing steam. We will discuss this in more detail when we talk about cloud formation.

Another example is when solid water (ice) is turned into liquid water. This happens at a well defined temperature called the *melting* (or freezing) point. Because the inter-molecular forces are different for different molecules, each substance has its own unique melting and boiling points.

Determining the Energy of a Phase Change

The fact that it takes some energy to “break apart” a solid into a liquid or a liquid into a gas should not be completely surprising. This energy is called a *latent heat,* although latent energy is probably a better term. The latent heat of substances is very important in many areas of science and engineering. With our data from the last activity, we can calculate the *latent heat of vaporization*, which tells you how much energy must be transferred to one gram of water to break the molecules apart and create steam. In the next activity you will determine the latent heat of vaporization of water.

Activity 3.1.2 Heat of Vaporization

a) Examine your graph of the boiling water again. Notice that once the temperature reaches about 60 ºC, the line starts to curve down a little bit (can you explain why?) Before that, it looks like a very straight line. Fit a straight line (either by hand or with the computer) to the portion of the graph that looks like a straight line (up to about 50 ºC). Write down the value for the slope of this line (including units) and interpret what this slope means physically. **Hint:** Remember that the slope is the “rise” over “run.” What does the “rise” (the change in *y*) tell you *physically*? What does the “run” (the change in *x*) tell you *physically*?

Ask your instructor to show you how to fit *just a portion of your data* to a line in Logger Pro.

Display your “line of best fit” until the line has reached the boiling temperature of water.

b) Knowing how much water you had at the beginning of the experiment, use the slope of this line to determine how much energy is being transferred to the water every second (or minute). **Hint:** How many calories does it take to increase the temperature of your cup of water by 1ºC and how many degrees Celsius is the temperature increasing every second (or minute)? Show your calculations!

c) Now that you know how much energy is being delivered to the water every second (or minute), determine how much total energy was delivered to the water during the time it was boiling. **Note:** You will need to determine from your graph exactly how long the water was boiling.

d) Finally, knowing how much energy was delivered during the boiling process and how much liquid water was turned into steam during the boiling process, you should be able to determine how much energy it takes to turn *one gram* of liquid water into steam. **Hint:** Remember that some water might have been turned into steam before or after the water was actually boiling.

e) This quantity is called the *latent heat of vaporization* of water, and is given the symbol L_v. The accepted value for water is 539 cal/g. Compare your result to this and comment on any difference?

Your measurements for the heat of vaporization of water should be reasonably good. There may be some small experimental errors, but if you are careful, you should get a result that is within 5% of the accepted value. It should be pointed out that there is an analogous quantity called the *latent heat of fusion*, which tells you how much energy it takes to *melt* one gram of a substance. Although we won't actually measure this quantity (it would make a nice project), the procedure would be similar to the experiment done here. As already mentioned, the latent heat of vaporization, L_v, tells you how much energy it takes to vaporize one gram of water. Thus the quantity mL_v tells you how much energy it will take to vaporize m grams of water. For example, if you have 10 grams of water, (10 g)(539 cal/g) = 5390 calories will be required to vaporize the water.