Lab 5: Thermal Equilibrium

1. *Imagine* (don't do it yet) that some water is placed into a metal cup (about 3/4 full), a thermometer placed into the water, and a lightbulb is turned on and placed very close to the cup. *Predict* how the reading of the thermometer will change with time as the lightbulb is left to heat the water for a very long time. Sketch your prediction on the handout your instructor gave you. Your sketch doesn't need to be exact, just a rough estimate of what you think it will look like.

   (a) Explain why you drew your graph the way you did.

2. *Imagine* that you now have the same metal cup filled about 3/4 full with water that is almost boiling. *Predict* how the reading of the thermometer will change with time as the water cools down. Again, sketch your prediction on your handout.

   (a) Explain why you drew your graph the way you did.

3. You are now going to team up with another lab group to do these experiments. Since both of these will take a while, one group will perform the heating experiment and the other will perform the cooling experiment. Your instructor will inform you which experiment your group will be doing and which other group to partner with.

   Heating: Fill your metal cup approximately 3/4 full with water from the sink at the back of the room. Place the temperature probe in the water. Open **SPARKVue** application in the **PASCO SPARK LXi** interface. Open **PASCO** Experiment. Select **PHYS101L**. Open **Thermal Equilibrium** file to start data collection. Place the lightbulb of your lamp as close as possible to the cup (you may need to elevate it with some textbooks) and start data collection. Record data for about 45- 60 minutes then ask your instructor to look at your data, but do not stop until your instructor tells you that it is ok.

   Cooling: Fill your metal cup approximately 3/4 full with water from the electric kettles (be very careful not to burn yourselves!). Place the temperature probe in the water. Open **SPARKVue** application in the **PASCO SPARK LXi** interface. Open **PASCO** Experiment. Select **PHYS101L**. Open **Thermal Equilibrium** file to start data collection. Record data for about 45-60 minutes then ask your instructor to look at your data, but do not stop until your instructor tells you that it is ok.

   Share your data once you are done. Sketch the results on your handout.

(a) Were your predictions correct? If not, re-examine your ideas that led to your predictions and modify your thinking as needed.

(b) Is the slope of the *heating* graph near the end of your experiment greater than, smaller than, or equal to the slope near the beginning?

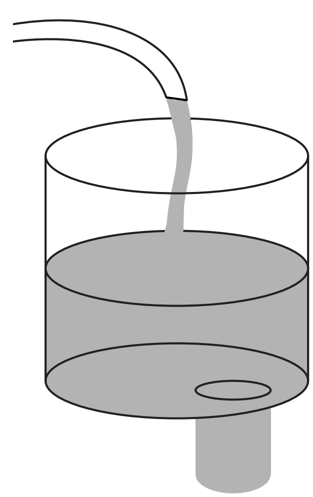
(c) Is the slope of the *cooling* graph near the end of your experiment greater than, smaller than, or equal to the slope near the beginning?

(d) What does it mean that the slopes of the graphs are different at different times?

(e) If you continued either experiment for a very long time, what do you think would happen?

4. While trying to make sense of the black cup heating experiment, a student offers the following analogy:

The flow of energy in the form of heat into (heating) or out of (cooling) water can be considered to be analogous to filling a cylindrical bucket that has a hole in the bottom. The constant input of water from the faucet represents the constant energy being transferred from the lightbulb to the water in the metal cup. Water pouring out from a hole in the bottom represents heat flow out of the cup. The temperature versus time graph in the heating experiment can be understood by thinking of filling this bucket.



Assume that the hole at the bottom of the bucket is closed. On your handout, sketch a graph of the height of the water versus time as the bucket is filled. On the same set of axes, sketch what the graph would look like if the hole in the bottom of the bucket was not closed while it was being filled (Assume the water is flowing into the bucket at a faster rate than if is flowing out of it). Label your sketches so you can tell them apart.

(a) Explain your reasoning behind your sketches and compare the two slopes.

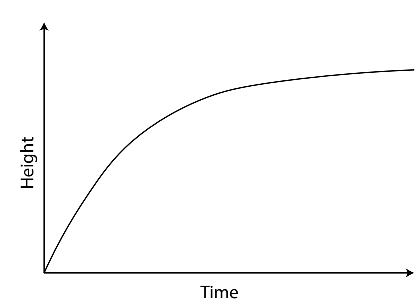
5. Now imagine that the bucket is already filled with water. With the faucet off, the water is allowed to drain through the open hole in the bottom. Sketch a graph of what this would look like. On the same set of axes, sketch what it would look like if the faucet was on while the bucket was draining (Assume the water is flowing out of the bucket at a faster rate than it is flowing in). Label your sketches so you can tell them apart.

   (a) Explain your reasoning behind your sketches and compare the two slopes.

6. Again, start with a bucket that already has water in it and sketch a graph of the height of the water in the bucket versus time if the water pours out of the hole at the same rate at which water pours in from the faucet.

   (a) All of your sketches for water pouring into/out of the bucket should be straight lines. Why?

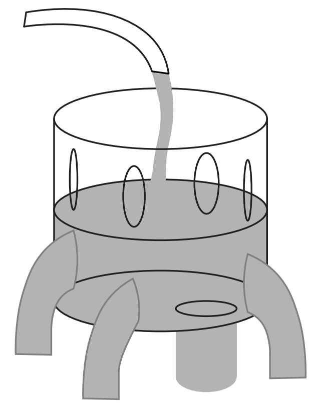
   (b) Suppose that your graphs looked like the figure below. What would that suggest about the rate at which water is filling the bucket? Explain.



   (c) In your heating and cooling experiments the temperature vs. time graphs were not straight lines, but curved like the graph shown previously. What does the shape of the heating curve suggest about the rate at which thermal energy is entering the water in the can as it is heated?

7. After realizing that the heating curve is shaped like the graph above rather than a straight line, the student who created the bucket analogy modifies it. They now suggest the following:

The heating experiment is analogous to filling a cylindrical bucket that has a hole in the bottom but also has holes leading up the sides of the bucket. As in the earlier version of the bucket analogy, the faucet represents the light bulb which provides constant energy input and water pouring out from the holes in the bucket represent heat flowing out of the cup. The temperature versus time graph in the heating experiment can be understood by thinking of filling this hole-riddled bucket.



(a) Consider the case when this hole-riddled bucket is nearly filled compared to when the bucket is nearly empty. In which case will the water flow out of the bucket through the holes be greater? Explain.

(b) As the lightbulb heats the black cup, is there any energy *leaving* the cup at the same time? How can you tell? What aspect of the student's analogy deals with this?

(c) Considering this analogy, what do you think causes the heating/cooling curve to level out on the temperature vs. time graph?

(d) When a body radiates energy at the same rate that it absorbs energy, a physicist would say it is in *thermal equilibrium*. In each experiment, when is the cup in thermal equilibrium - near the beginning, in the middle, or near the end? Explain.