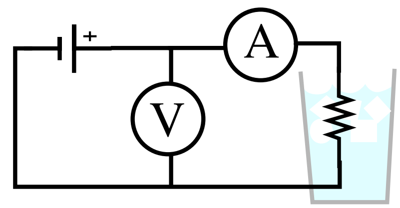
In this lab, we will be measuring how much energy it takes to melt ice and heat water.

Instructor's guide Students will set up a Styrofoam cup with heating element and a thermometer in it. They will measure the temperature as a function of time, and thus the energy transferred from the power supply.

Materials:



- Styrofoam cup
- Heating element
- Scale
- 2 digital multimeters
- Temperature guage
- Ice and water

Instructor's guide

Introduction This lab is very simple to run, but to get it done in one period you'll need to get students working quickly to measure the ice and water and get their heating started. Once their labs are going, there is time to give a middle-of-lab lecture introducing thermodynamics and thermal measurements.

There are two things to keep in mind for this lab. One is that the ice-water cups need to be vigorously stirred, otherwise the hot water (around 4 degrees Celsius) will settle at the bottom while the cold ice floats on the top. The other is that the ice should be cubes (not crushed) and the water should be ice-cold before it is massed out, otherwise too much ice will melt immediately on being added to the water.

Once the measurements are taken, I asked the students a couple of small-whiteboard-questions, "What is heat?" and "What is entropy?". I then lecture on what the heat capacity C_p is, and how they could extract it from their data, and on how they can calculate entropy from their measurements: $\Delta S = \int \frac{dQ}{T}$.

Student Conversations Many students have difficulties simply measuring the water and ice correctly. Perhaps smaller containers for retrieving water would be good (around the same size as necessary). Or perhaps some basic lab procedures need to be gone over at some point in the Paradigms. Once the basic lab setup was accomplished, students seemed able to do the rest of the lab with no difficulty. -Amanda Abbott

Wrap-up At the end of the lab, students should know how to calculate the entropy from the change in temperature. Students should be given a few days to do the analysis, and the data that they collect should be distributed to each member of the group.

The setup

You will put some mass of ice (about 30g) and ice-cold water (about 100g) into your styrofoam cup. Use the scale to record the mass of the ice and water as you add them to the cup. Finally, add your ice-cold heating element and thermometer through the lid of the cup.

Collect data

We will be measuring the temperature of the water and the power dissipated in the heating element (which is just a resistor). Thus we can find out how much energy was added to the water, and how this changes the temperature. In order to keep the temperature measurement reasonable, we will need to periodically stir the cup and heat it moderately slowly.

You will be collecting temperature data using the computer, so before you turn on the heater, you should make sure the computer is taking data. Turn on the heater, and write down the time you do so as well as the current and voltage, from which you can find the power dissipated in the resistor. If the current or voltage changes during the course of the experiment, take note of the new values—and the time.

Question 1: Plot your data I Plot the temperature versus total energy added to the system (which you can call Q). To do this, you will need to integrate the power. Discuss this curve and any interesting features you notice on it.

Question 2: Plot your data II Plot the heat capacity versus temperature. This will be a bit trickier. You can find the heat capacity from the previous plot by looking at the slope.

$$C_p = \left(\frac{\partial Q}{\partial T}\right)_p \tag{1}$$

This is what is called the *heat capacity*, which is the amount of energy needed to change the temperature by a given amount. The p subscript means that your measurement was made at constant pressure. This heat capacity is actually the total heat capacity of everything you put in the calorimeter, which includes the resistor and thermometer.

Question 3: Specific heat From your plot of $C_p(T)$, work out the heat capacity per unit mass of water. You may assume the effect of the resistor and thermometer are negligible. How does your answer compare with the prediction of the Dulong-Petit law?

Question 4: Latent heat of fusion

1. What did the temperature do while the ice was melting? How much energy was required to melt the ice in your calorimeter? How much energy was required per unit mass? per molecule?

2. The change in *entropy* is easy to measure for a reversible isothermal process (such as the slow melting of ice), it is just

$$\Delta S = \frac{Q}{T} \tag{2}$$

where Q is the energy thermally added to the system and T is the temperature in Kelvin. What is was change in the entropy of the ice you melted? What was the change in entropy *per molecule*? What was the change in entropy per molecule divided by Boltzmann's constant?

Question 5: Entropy for a temperature change Choose two temperatures that your water reached (after the ice melted), and find the change in the entropy of your water. This change is given by

$$\Delta S = \int \frac{đQ}{T} \tag{3}$$

$$= \int_{t_i}^{t_f} \frac{P(t)}{T(t)} dt \tag{4}$$

where $P(t)$ is the heater power as a function of time and $T(t)$ is the temperature, also as a function of time.