A Student Self-Exploratory Laboratory: Determining the Average Specific Heat of Ice in the Temperature Range 77K to 273K

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Abstract

- Students are given equipment from the previous week where they measure the latent heat of vaporization of liquid nitrogen.
- The students are asked to design an experiment to measure the average specific heat of ice from 273K down to 77K.

- Students are asked to start by deriving any necessary equations and then devise an experiment to complete the exercise.

- They are asked to critique all suggestions and to discuss possible sources of error in the proposed experiment.

- As a group, students are to come to a consensus on the final experimental method.

- The instructor interacts minimally but in a way to provoke thought.

Background:
Review of Previous Week's Experiment

Latent Heat of Vaporization of Liquid Nitrogen

- An aluminum cylinder of known temperature is lowered into a Dewar of liquid nitrogen. The mass of the liquid nitrogen boiled off is measured.

- The cold cylinder is then put into a calorimeter and allowed to come to equilibrium. The equilibrium temperature, the mass and initial temperature of the cylinder, the mass and initial temperature of the water in the calorimeter, and the mass of the liquid nitrogen boiled off, are used to determine the latent heat of vaporization of liquid nitrogen.

» The students are told that they are to develop their experiment as a group, drawing their information from last week's experiment. This included both theory and experimental techniques.

» At first, they usually sit quietly without much interaction.

» In every lab, however, someone finally takes charge and goes to the white board and either starts suggesting an approach or asks for input from fellow students.

- It usually takes the first hour of the lab before the students come up with an acceptable workable experiment.

- The next phase usually involves developing the experimental technique which minimizes error, especially eliminating approaches which involve the knowledge of variables over which they have no control, e.g., the temperature of a sample of ice near the freezing point.

Student Generated Procedure:

1. Determine the mass of water in a 25-mL graduated cylinder and stirring rod. This water will later be poured down the rod into the liquid nitrogen.

2. Place a Dewar flask filled 3/4 full of liquid nitrogen on the beam balance and determine its mass. Since the mass is changing slowly and steadily, it will be necessary to specify the time at which a given mass measurement is made. Determine at least 15 consecutive mass-time values which can be plotted using Graphical Analysis. Time and mass measurements are taken for every 0.2 g loss of mass of the liquid nitrogen until 3.0 g of the nitrogen has evaporated.

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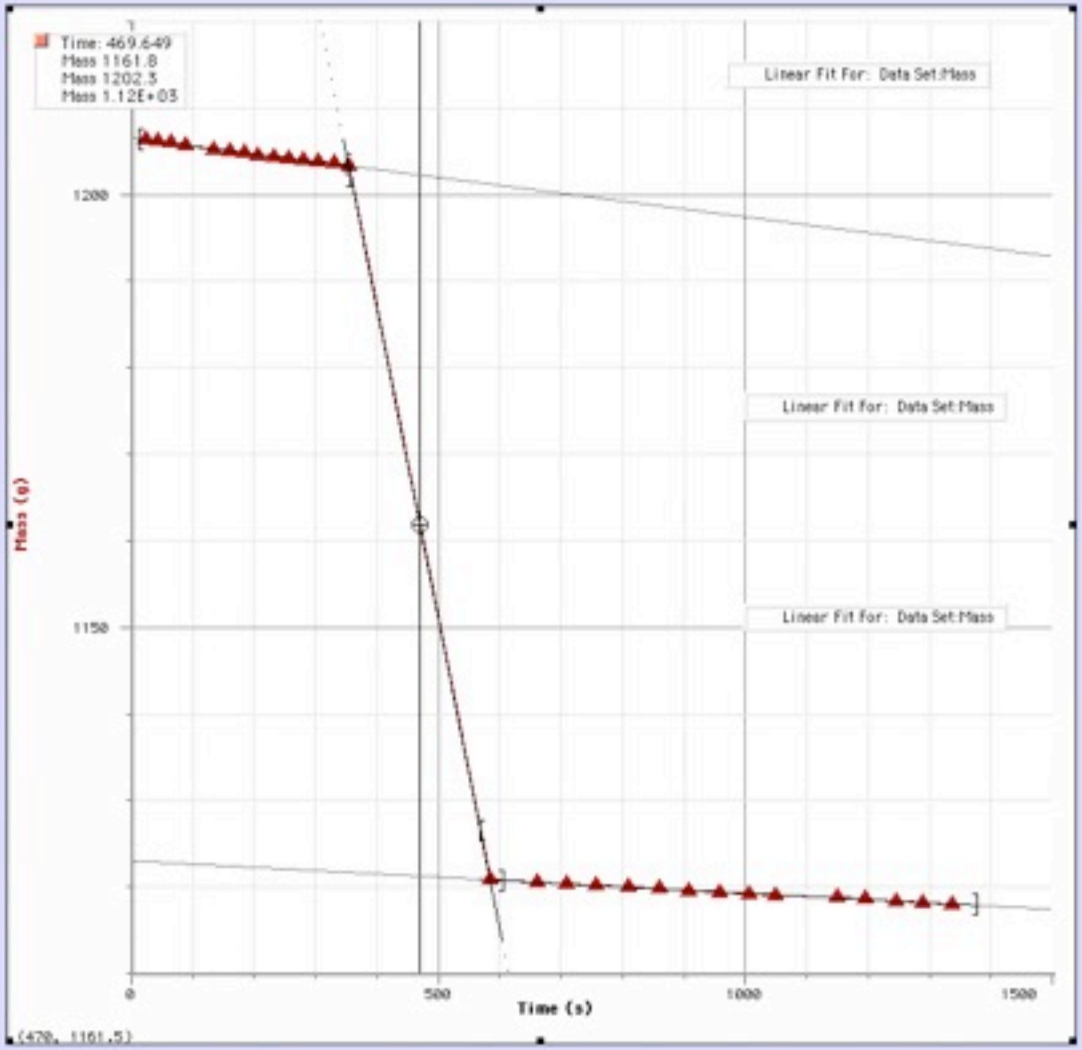
	Data Set	
	Time (s)	Mass (g)
11	280.000	1204.000
12	304.000	1203.800
13	329.500	1203.600
14	353.500	1203.400
15	584.000	1120.800
16	662.000	1120.600
17	708.500	1120.400
18	757.500	1120.200
19	810.000	1120.000
20	859.500	1119.800
21	907.000	1119.500
22	959.000	1119.400
23	1007.500	1119.200
24	1050.500	1119.000
25	1149.700	1118.800
26	1196.200	1118.600
27	1246.000	1118.400
28	1288.000	1118.200
29	1337.000	1118.000

Notes:

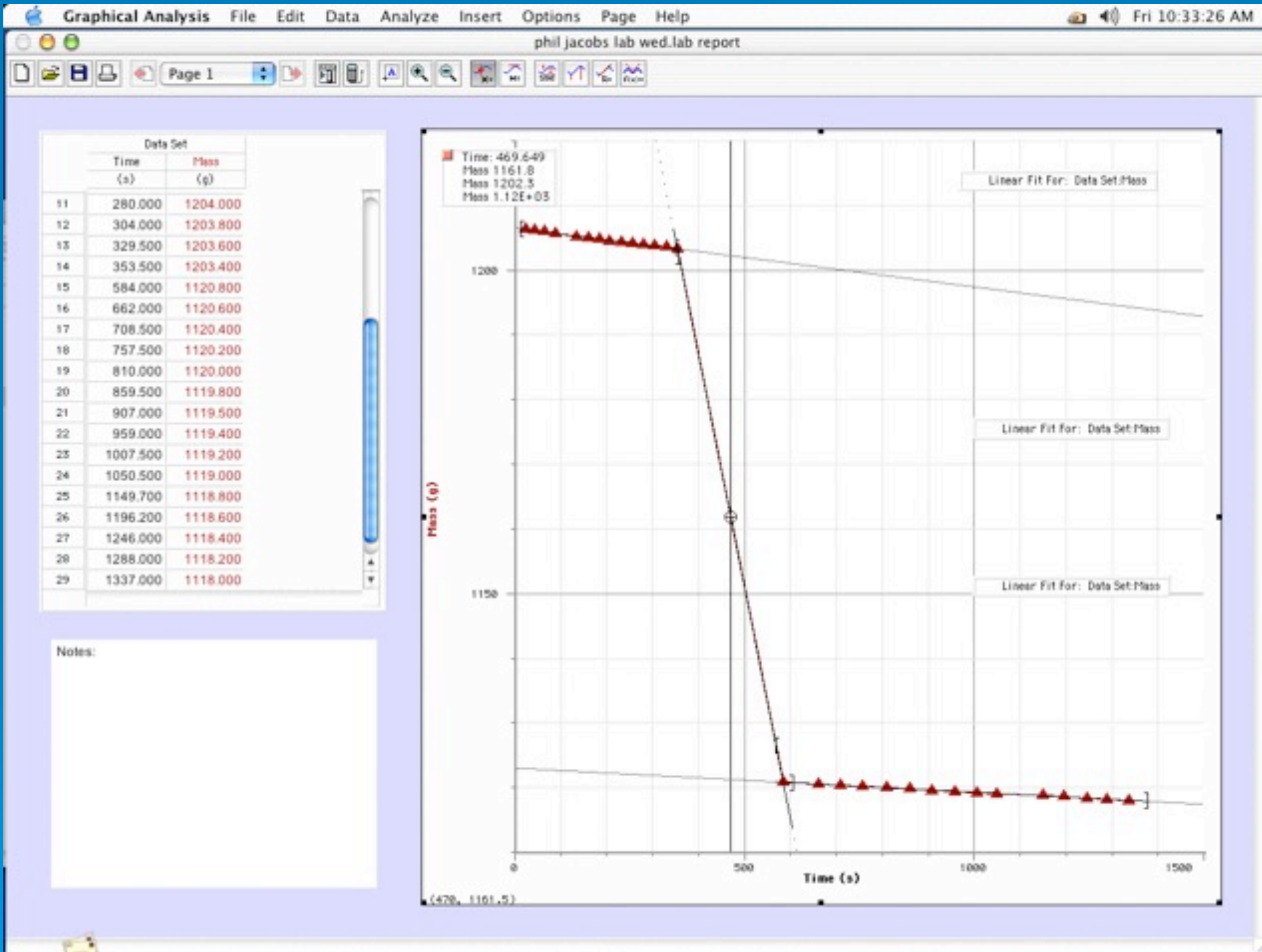


3. Leave the timer running and use a stirring rod to pour the water into the liquid nitrogen, allowing the water to pour in the middle of the Dewar so that there is no water lost to the sides of the Dewar. Allow the water-nitrogen system to come to equilibrium.

4. Use Graphical Analysis to plot 15 more consecutive mass-time measurements. As before, the time and mass are recorded for every 0.2 g of mass lost until a total of 3.0 g has evaporated.

5. Weigh the empty graduated cylinder and rod. Determine the mass of water used in the experiment by subtracting this measurement from that in step 1. Subtract this mass of water from each mass value in the second set of 15 mass-time measurements. Plot the mass measurements versus time.

6. Perform linear fits on both the upper and lower portions of the mass vs. time graph. Interpolate between these two lines and find the time and mass values at the mid-point of the interpolated line. Subtracting the smaller mass value from the larger mass value gives the mass of liquid nitrogen that evaporated during the experiment.



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7. The average value of the specific heat of ice can be calculated using the concept of the conservation of energy, as follows:

$$\Sigma Q = 0$$

$$\Delta Q_{water} + \Delta Q_{ice} + \Delta Q_{LN} = 0$$

$$m_w c_w \Delta T_w - m_w L_{f-w} + m_w c_{ice} \Delta T_{ice} + m_{LN} L_{v-LN} = 0$$

$$\bar{c}_{ice} = \frac{[-m_w c_w \Delta T_w + m_w L_{f-w} - m_{LN} L_{v-LN}]}{m_w \Delta T_{ice}}$$

For comparison, an average value for C_{ice} can be determined by integrating the values found in the *CRC Handbook of Chemistry and Physics*.

This provides an additional learning opportunity in that students can learn about numerical integration techniques for obtaining averages.

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	Data Set		
	C (cal/gm-K)	T (Celsius)	Temperature (K)
1	0.1620	-200.0	73.000
2	0.1990	-180.0	93.000
3	0.2300	-160.0	113.000
4	0.2460	-150.0	123.000
5	0.2620	-140.0	133.000
6	0.3290	-100.0	173.000
7	0.3920	-60.0	213.000
8	0.4346	-38.3	234.700
9	0.4411	-34.3	238.700
10	0.4488	-30.6	242.400
11	0.4454	-31.8	241.200
12	0.4599	-23.7	249.300
13	0.4605	-24.5	248.500
14	0.4668	-20.8	252.200
15	0.4779	-14.6	258.400
16	0.4896	-8.1	264.900
17	0.4989	-4.3	268.700
18	0.4984	-4.5	268.500
19	0.4932	-4.9	268.100
20	0.5003	-2.6	270.400
21	0.5018	-2.2	270.800
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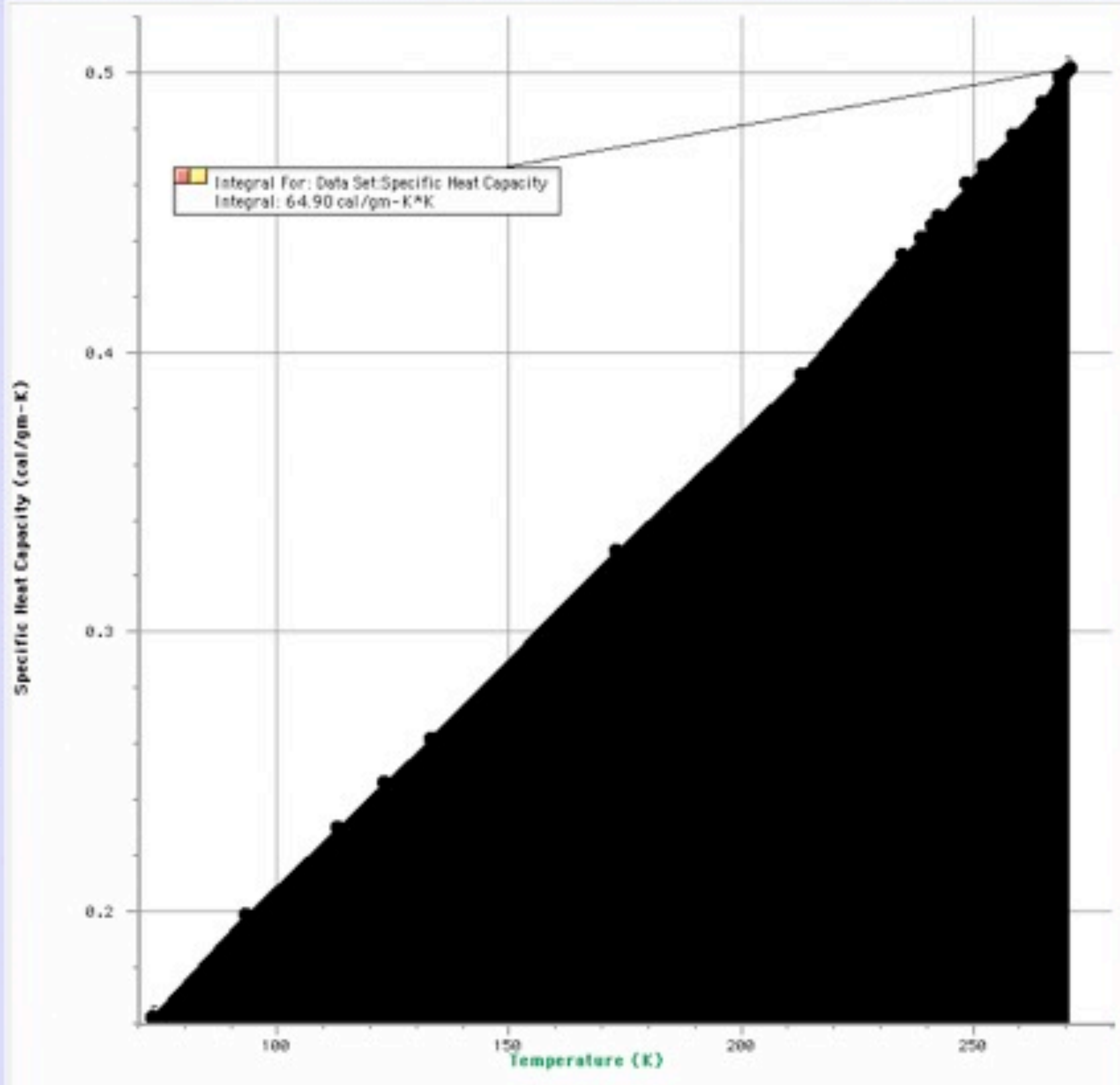
Notes: Values taken from the CRC Handbook of Chemistry and Physics

Average Specific Heal = 64.9/(270.8-73)

= 0.328 cal/gm-K



Observations and Conclusion:

» All the students seem to get involved and take a certain amount of ownership in the experiment as time proceeds.

» The students take over completely and try to perform a good experiment.

» The experiment is very popular and generates much student interest and involvement. Any experiment using liquid nitrogen is very appealing.

Pictures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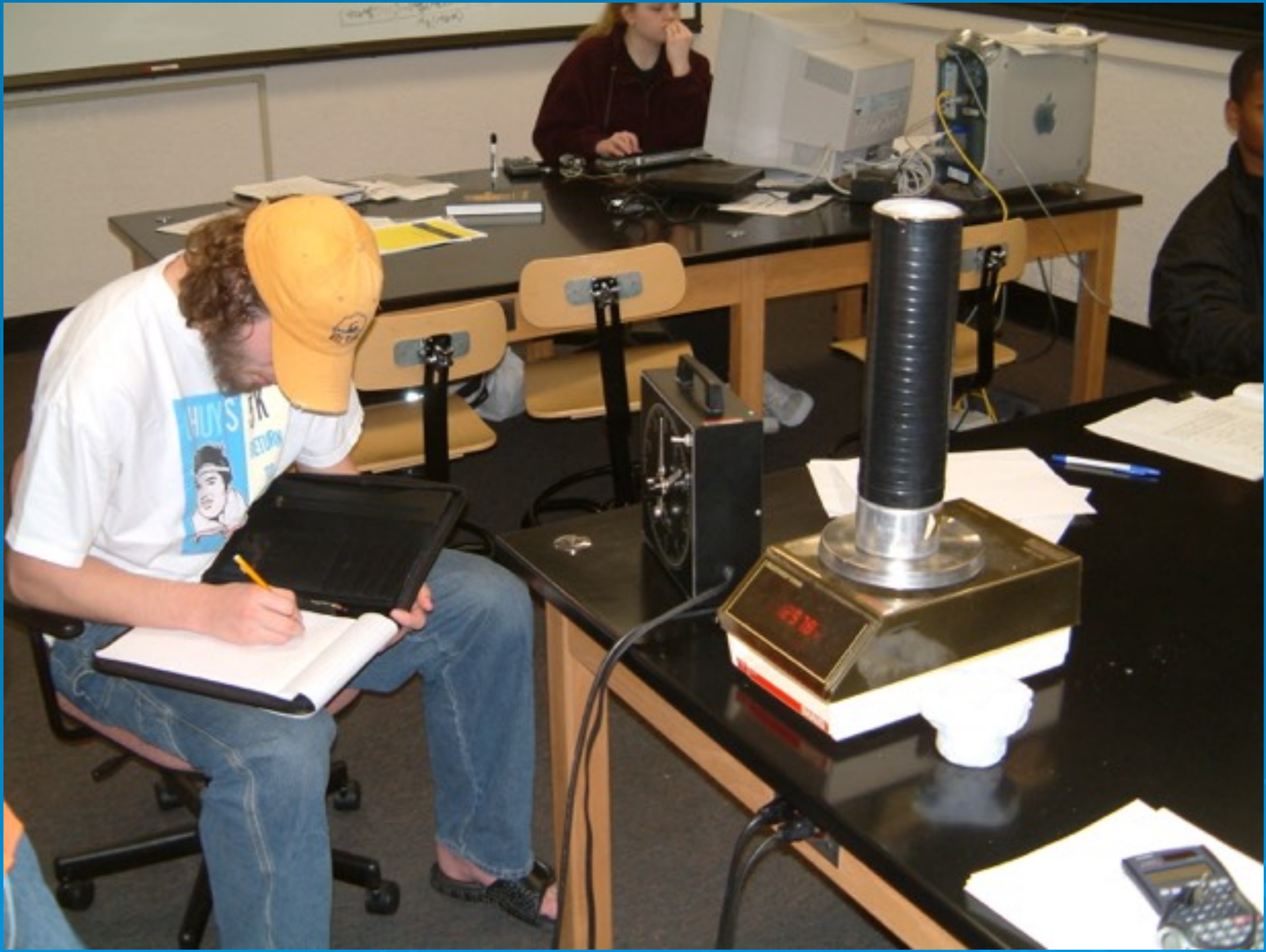

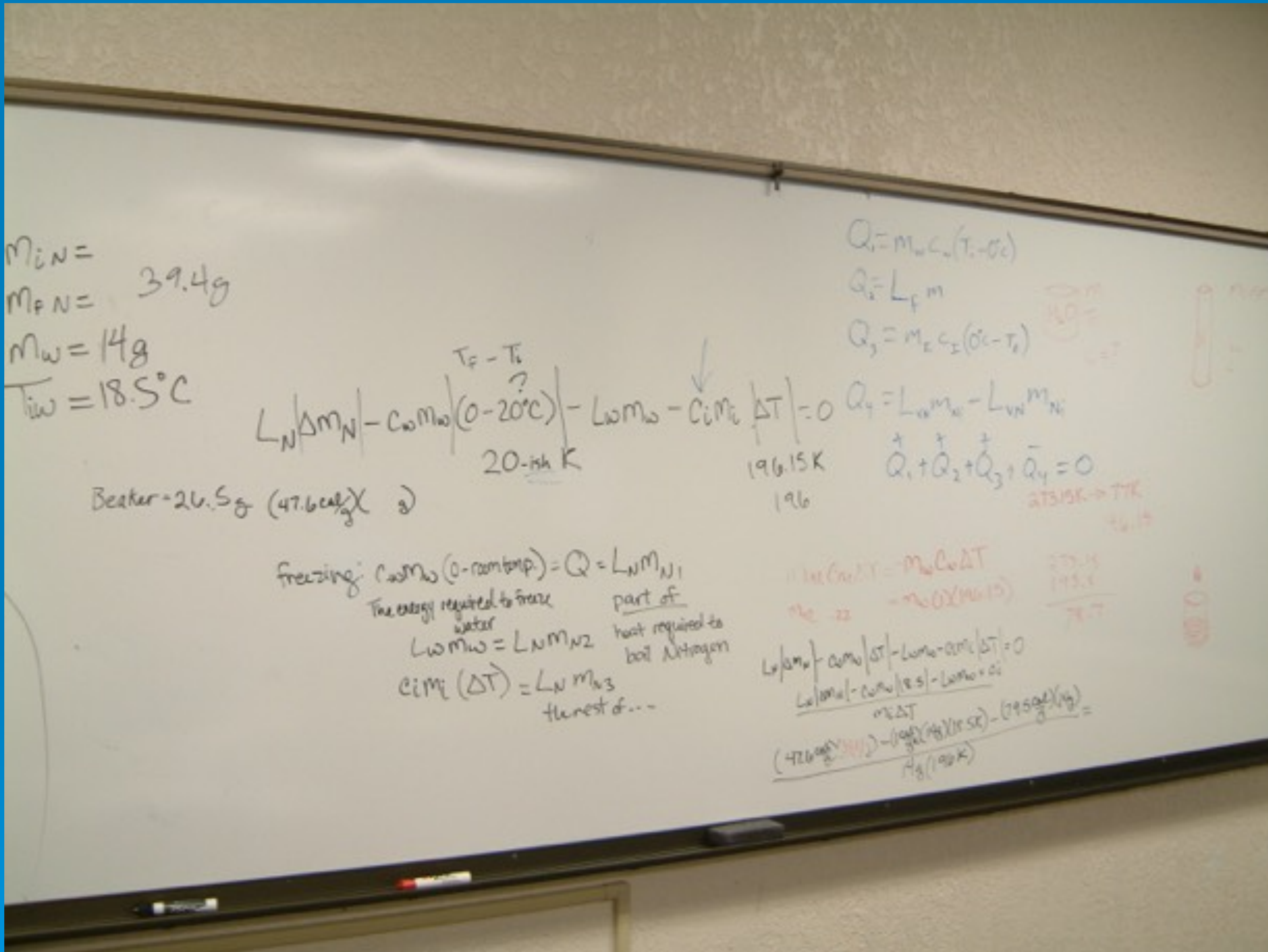

mi N =
mf N = 39.4g
mw = 14g
Tiw = 18.5°C
Tf - Ti
20-ish K
Beaker - 26.5g
196.15 K
196
freezing: cwmw (0-room temp.) = Q = LNmN1
The energy required to freeze water
part of
LwMw = LNmN2
heat required to boil Nitrogen
ciMi (ΔT) = LN mN3
the rest of...