The Super Coolest Physics Project at BYU!

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Objective: To determine experimentally the heat capacity of water that is below 0˚C. As we began the experiment, we expected to see the heat capacity of a volume of subzero water very near that of water at 15˚C, which is about 4186 J/kg*˚C. To our surprise, we quickly found out that the heat capacity of water sky rockets below 0˚C.

Materials:

Distilled Water

Tap Water

Digital Thermometer

Lots of Ice

Test Tubes

Sieve

Metal Bucket

Table Salt

Empty Plastic Ice Cream Pales

Newspaper

Funnel

Explanation of Phenomenon:

As a volume of water cools in a uniform and slow manner, a phenomenon known as supercooling can occur. This happens mainly because the latent heat of fusion of water (3.33x10^5 J/kg) is so much greater than the heat capacity of water around 0˚C (which is about 4186 J/(kg˚C)). Thus as the water cools uniformly, there is no potential nucleation site for ice to start forming; that is, because all the water is roughly the same temperature, the water would “rather” continue to decrease in temperature than initiate crystallization, because it requires such a greater loss of energy to initiate crystallization. When the necessary conditions are met, the temperature of liquid water can go below its actual freezing point (we even got it as low as -7˚C or -8˚C at one point).

When water is in a supercooled state, it is in a very unstable equilibrium. If disturbed, ice will start to form at a very rapid rate. The formation of ice crystals may be initiated by stirring the supercooled water with a foreign object, such as a pen or pencil, or dropping a small piece of ice into it. (At the onset of this project, we thought that we could even initiate crystallization by just shaking the water; however, we soon found out that this was not the case.)

Procedure:

We put a tin bucket into an empty plastic ice cream pale and filled the gaps between the bucket and ice cream pale with newspaper to insulate the system so that minimal heat would flow into the bucket (see figure 1). We then prepared a solution of subzero salt water/ice by putting a lot of ice in the metal bucket then pouring a minimal amount of cold tap water over the ice. We then dumped table salt over top of the solution. This depressed the freezing point of the water, causing the ice to melt. In order for ice to melt, a lot of energy is required (the latent heat of fusion of ice is 4186 J/(kg˚C)). Thus as the ice melted it sucked heat out of the salt water/ice system causing the overall temperature of the system to decrease. Using the thermometer, we measured how cold the system got and when the temperature was low enough (usually around -5˚C or -6˚C) we immersed test tubes filled with a known volume of distilled water into the superchilled system, suspending them from the test tube holder. Because the test tubes were so thin and because the distilled water inside the test tubes was only touching glass that was immersed in the chilled water, the temperature of the distilled water decreased very uniformly, making the conditions just right for supercooling.

Figure 1: Tin bucket in ice cream pale, surrounded by newspaper, holding chilled solution of salt water/ice.

When the distilled water had reached a sufficiently low temperature, we removed the test tubes from the superchilled system and initiated crystallization. (This was the fun part and we had to be sure we recorded this part of the experiment with a digital camera.) Shortly after the distilled water had finished crystallizing, we poured out the ice and water through a sieve and into another test tube in order to measure how much water had crystallized and how much water had not. By knowing how much of the known volume turned to ice and how much did not, and the supercooled temperature, we were able to calculate the heat capacity of supercooled water.

Data Table and Analysis:
At the end of the report.

Difficulties:

Before we began this project, we thought it would be rather easy to get the water into a supercooled state. As we started to actually experiment and play around with the water, we realized, however, that it was much more difficult to achieve than we had expected.

At first, we could not get the water to cool below 0˚C without freezing. We finally figured out that this was because the water was not cooling uniformly enough. If part of the test tube was touching the bottom or the side of the tin can, then the heat would flow out of the test tube at different rates and the distilled water would not cool at the same rate. This happened quite a few times until we obtained a test tube holder from which we could suspend the test tubes in the subzero system so that the test tubes would not touch anything but the chilled water. Prior to this, we would just lean the test tubes against the side of the metal bucket.

We also tried to achieve the supercooled state by suspending water in the freezer, but up to this point we have failed to do so. All the times we have tried the water has frozen normally. We believe this is because either the water does not cool slowly enough (we measured Peter's freezer to have a temperature of -1˚F which is about -18.3˚C!) or because the air at the back of the freezer seems to be colder than the air at the front of the freezer, thus the water cannot cool uniformly.

We also had many difficulties trying to measure how much ice formed after we initiated crystallization of a supercooled volume of water. At first, we wanted to measure the increase in volume of the whole volume of water/ice, knowing that ice at 0˚C has a lower density than water at 0˚C. However, the amount of ice that forms is so small that it was impossible to measure any noticeable increase in volume.

We then figured that if we could separate the water and ice after crystallization had finished, we could measure the volume of water that did not turn to ice and easily find out how much water did turn to ice. We therefore used a sieve and a filter to pour the water that did not form back into a test tube where we could measure its volume. While this is probably not the most accurate method, we did find that the procedure yielded fairly consistent results.

Extra Media:

Supercooling Movie (watch while listening to your favorite type of music)

Data Collected During Supercooling Experiment:

Temperature in °F	Temp in °C	Height from the Top in cm	Volume of Ice Frozen in mL or cm^3	Mass of Ice Frozen in g	Mass of Remaining Water g	Percent Frozen	Calculated Heat Capacity J/°C kg	Calculated Heat Capacity J/°C mol	Experimentally Found Data
21.2	-6.00	2.20	3.15	3.15	14.19	18.2%	10091	161.7	4785.2
21.0	-6.11	2.60	3.73	3.73	13.62	21.5%	6559	105.1	4786.1
21.0	-6.11	2.30	3.30	3.30	14.05	19.0%	5723	91.7	4786.1
20.5	-6.39	2.60	3.73	3.73	13.62	21.5%	6274	100.5	4788.4
20.1	-6.61	3.65	5.23	5.23	12.11	30.2%	8946	143.3	4790.3
18.7	-7.39	3.75	5.38	5.38	11.97	31.0%	8264	132.4	4797.2
18.7	-7.39	3.70	5.30	5.30	12.04	30.6%	8134	130.3	4797.2
18.1	-7.72	3.90	5.59	5.59	11.75	32.2%	8285	132.7	4800.2

Equations used for Calculated Data:

Δenergy = mass*specific heat*Δtemperature

Δenergy = latent heat of fusion*mass

Fit Equation for Experimentally Found Data[1]

$c_p(T) = (0.044*(T/222-1)$^$(-2.5)+74.3)*(1000/16.02)$

with c_p in J/°C kg and T in Kelvin

Constants From Equipment and Lab location:

Height of Test tubes in cm	12.1
Inner Diameter of Test tubes in cm	1.35
Volume of Water Used in mL	17.344
Density of Water in g/mL	1.00
Density of Ice in g/mL	0.92
Elevation of Experiment in feet	4512
Latent Heat of Fusion for Water in J/g	333
Freezing Point of Water in °F	32

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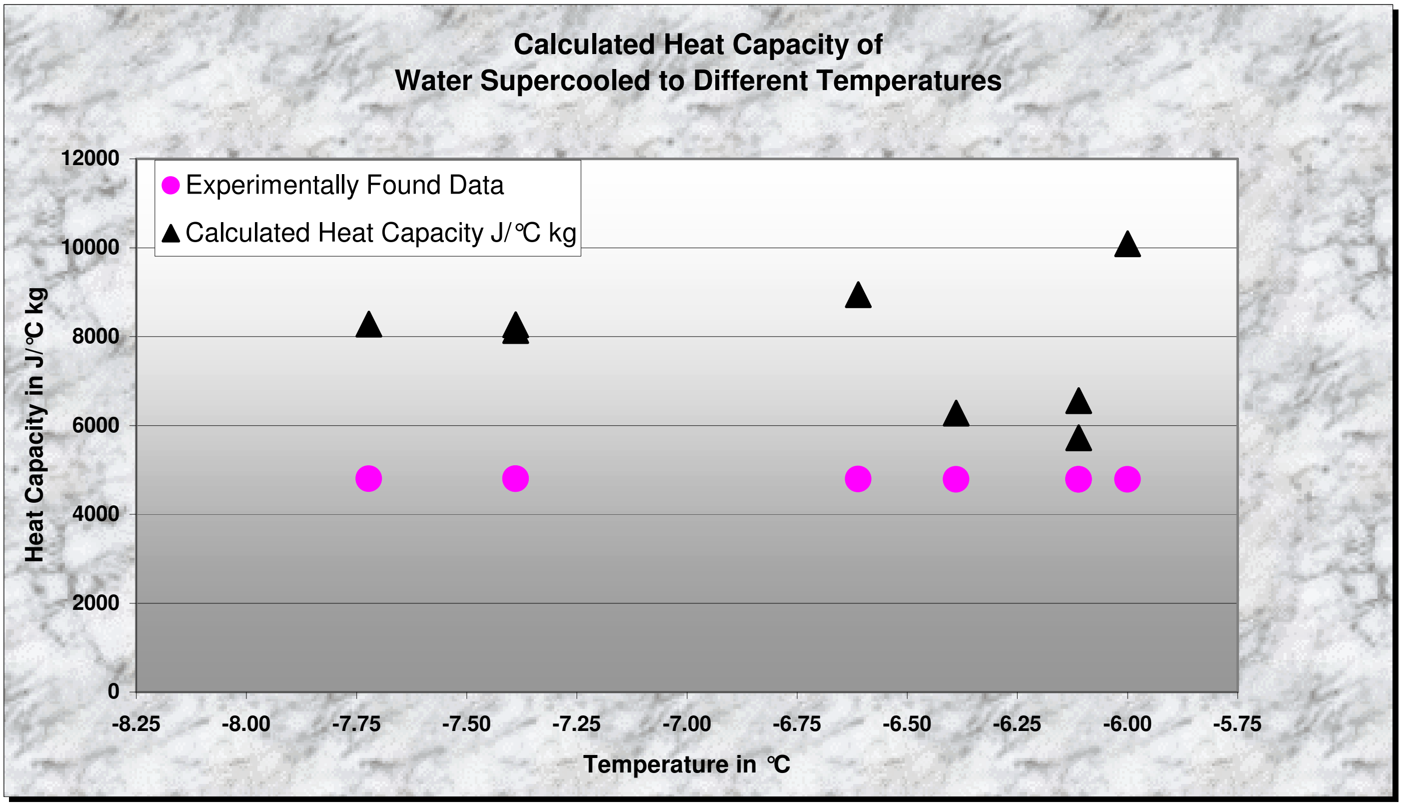
[1] E. Tobari, C. Ferrari, G. Salvetti. "Heat capacity anomaly in a large sample of supercooled water." Chemical Physics Letters 300 (1999) 749-751.


Calculated Heat Capacity of
Water Supercooled to Different Temperatures
● Experimentally Found Data
▲ Calculated Heat Capacity J/°C kg
Heat Capacity in J/°C kg
12000
10000
8000
6000
4000
2000
0
-8.25
-8.00
-7.75
-7.50
-7.25
-7.00
-6.75
-6.50
-6.25
-6.00
-5.75
Temperature in °C