Phase Change of Water

Measuring and Modeling the Absorbtion of Heat by Water Through Various States of Matter

SCH4U Chemistry - Ms. Grundy

Author: Jimmy Liu
Group members: Jeffery Hu, Rhea Sharma, and Mina Sagheb

Monday, February 6, 2023

1 Preamble

Purpose: The purpose of this experiment is to investigate the heat changes that result from phase changes in matter and to observe the different stages of heating as solid ice turns into water vapour.

Apparatus:

Digital scale	Wire gauze	Beaker (100 mL)
Analog thermometer	Digital stopwatch	
Hot plate	Beaker tongs	

Materials:

Ice cubes (around 50 g)

2 Diagram of Experiment

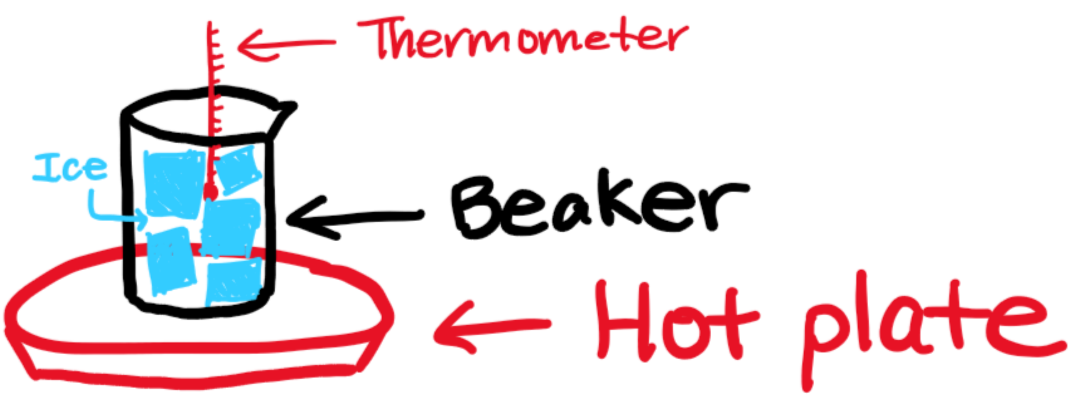


Figure 1: Diagram of experiment setup.

3 Final Experimental Procedure

1. Each group member was responsible for performing one specific task only. Each responsibility is described below:

   (a) A digital stopwatch was used by Person A to record the elapsed time, precise to the millisecond.

   (b) The data was recorded on the Observation Table by Person B, namely, **physical observations** of the experiment and the **quantitative data** needed.

(c) The analog thermometer was held by Person C. The thermometer was held vertically with its mercury pool positioned 1.5 centimetres above the bottom of the beaker.

2. The hot plate power was set to 7, and the hot plate was preheated until its indicator turned off, signifying that the hot plate had reached the maximum temperature at the respective power setting, and the preheating was successful. Step 6 was not started until the hot plate was successfully preheated, but steps 3 - 5 were performed while waiting for the hot plate to finish preheating.

3. The digital scale was zeroed so that it displays 0.00 g with no load. The 100 mL beaker was placed on the digital scale, and the beaker's mass was measured in grams, precise to a hundredth of a gram.

4. Roughly 50 grams of ice was placed into the beaker. The ice-filled beaker was placed onto the digital scale again, and the ice-filled beaker's mass was measured using the same scale and precision. The digital scale was not altered, zeroed, or turned off in any way between measurements.

5. The analog thermometer was inserted into the ice through the centre of the beaker opening, with the mercury pool positioned 1.5 centimetres above the bottom of the beaker. The thermometer was left in this position until there were no visible changes in the thermometer's temperature reading. The stabilised temperature was recorded in degrees Celsius precise to a tenth of a degree Celsius.

6. The ice-filled beaker was immediately placed onto the hot plate using beaker tongs with the thermometer continuously held at the same position described in Step 5. Upon the beaker making contact with the hot plate, the digital stopwatch was started by Person A.

7. The time was watched carefully by Person A, and the time was counted down out loud 3 seconds before every 20 seconds had elapsed on the stopwatch. Once the verbal countdown has reached 0, indicating that an interval of exactly 20 seconds has been reached, the 'lap' function on the stopwatch was pressed to record the exact time that the 20 seconds was indicated to the others. The thermometer's temperature was immediately read out loud by Person C. The quantitative temperature measurement dictated by Person C was recorded by Person B on the observation table. In addition, any new qualitative observations were also recorded on the observation table by Person B.

8. Step 7 was repeated for every 20-second interval until the water boiled for 4 minutes. Boiling was achieved when the temperature of the water reached 100 °C or no longer underwent significant increases in temperature.

9. The beaker was removed from the hot plate using beaker tongs and was set on wire gauze to cool for 10 minutes.

10. All materials were gathered and discarded. All apparatus were returned.

4 Experimental Data and Observations

Table 1: Changes in temperature in 20-second intervals of water when placed in a beaker on a hot plate until 4 minutes after boiling

Time Elapsed (s)	**Temperature of water** (°C)	**Qualitative Observations**
0.00	3.5	• Ice was melting slowly • Ice was still solid • Centre of beaker was becoming foggy • Small pool of water at bottom
20.61	4.0	• Ice melted slightly • Ice was mostly intact
44.63	5.5	• Water pool volume increased steadily
61.76	20.0	• Ice was melting significantly • Beaker contents consisted of approximately 40% water, 60% ice.
81.68	24.0	
102.16	23.0	
121.26	20.0	• Very small bubbles started to form in the water
142.39	19.0	
161.24	19.5	
180.83	17.0	• Ice continued to melt but the melting began to slow down • Now consisted of approximately 70% water, 30% ice.
200.75	19.5	

Table 1 (Continued)

Time Elapsed (s)	**Temperature of water** (°C)	**Qualitative Observations**
220.77	22.0	• Number of bubbles forming increased • Size of bubbles remained constant
242.14	23.0	
260.81	27.0	• Approximately 90% water, 10% ice • Bubbles gathered on the sides of the beaker.
281.33	30.5	
301.29	34.0	• Very little ice remained
321.33	38.5	• All ice has melted
340.78	44.0	
361.05	50.0	
384.83	58.0	
402.18	62.0	
420.58	67.0	
441.48	71.8	• Bubbles rose to water surface quickly
460.62	77.0	• Steam began to form from water • Bubbles collected at water surface
482.98	82.5	• Bubbles rising faster from the corners of the beaker
500.98	87.0	• Size of bubbles increased

Table 1 (Continued)

Time Elapsed (s)	**Temperature of water** (°C)	**Qualitative Observations**
523.13	92.0	
540.93	96.0	• Steam and bubbling reach maximum intensity • Water has achieved a rolling boil
560.58	99.0	
580.44	99.8	
602.38	99.0	
620.43	99.9	
640.59	100.0	• Condensation formed on the sides of the beaker
661.51	100.0	
683.05	100.0	
700.11	100.0	
719.88	100.0	• Condensation on the sides of the beaker started to drip back into the water
740.58	100.1	
760.27	100.5	
780.44	100.3	• Water has boiled for 4 minutes.

Measured Mass

Mass of beaker: 48.32 g
Initial mass of ice-filled beaker: 104.67 g
Initial mass of ice: $104.67\,\text{g} - 48.32\,\text{g} = \underline{56.35\,\text{g}}$

5 Analysis

5.1 Graph

Figure 2: Graph of temperature (in °C) at 20-second intervals of elapsed time.

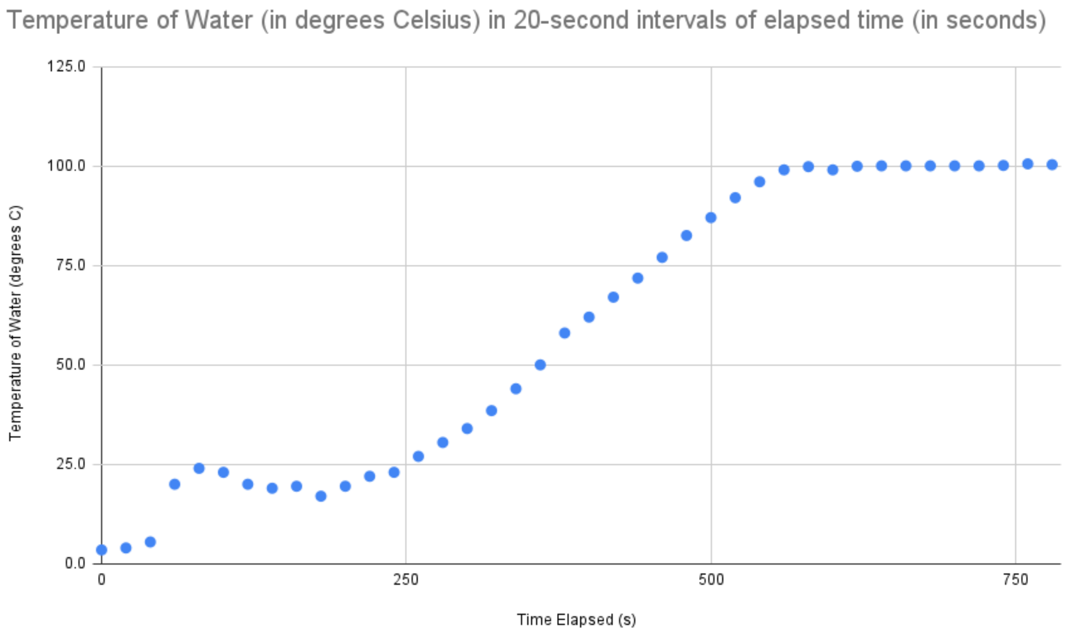
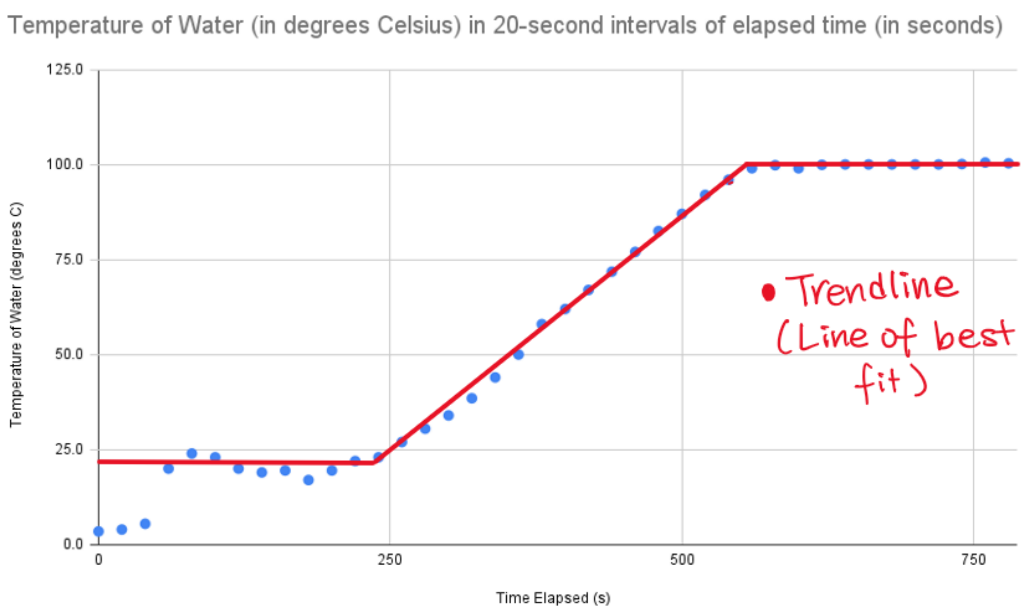


Figure 3: Graph of temperature of water (in °C) at 20-second intervals of elapsed time with a sketched trendline/line of best fit.



5.2 Heat Absorbtion

To determine the total energy absorbed by the system, the sum of enthalpies undergone by the system yields the requested result.

There are two types of heat changes that are experienced by the system in the experiment:

1. Standard heat transfer in a single state, given by

$$q = mc\Delta T$$

2. State change of the system, given by

$$q = n \cdot \Delta H^\circ$$

Variable	**Purpose/value**
q	Change in heat of the system
m	Mass of the system
c	Specific heat capacity
n	Molar quantity of system
l	Latent heat of the phase change
ΔT	Change in average temperature of the system
ΔH°	Enthalpy of phase change

Stages of Heating of the System

1. The solid ice melts into liquid water:

   (a) Enthalpy of melting of water is 6.01 kJ/mol

   (b) Molar mass of H_2O:

$$\begin{aligned}\text{molar mass of } \mathrm{H_2O} &= 2M_H + M_O \\ \text{molar mass of } \mathrm{H_2O} &= 1.01 \times 2 + 16.00 \\ \text{molar mass of } \mathrm{H_2O} &= 18.02\,\mathrm{g/mol}\end{aligned}$$

   (c) Molar quantity of the water:

$$\begin{aligned} n &= \frac{\text{mass}}{\text{molar mass}} && \text{formula for calculating molar quantity} \\ n &= 56.35\,\cancel{\mathrm{g}} \times \frac{\mathrm{mol}}{18.02\,\cancel{\mathrm{g}}} && \text{substituting values} \\ n &= 3.12\underline{7}081\,\mathrm{mol} \end{aligned}$$

(d) Change in heat from melting:

$$\begin{aligned} q_{\text{melt}} &= n \cdot \Delta H^{\circ}_{\text{melt}} && \text{formula for calculating molar quantity} \\ q_{\text{melt}} &= 3.12\underline{7}081\,\cancel{\text{mol}} \times 6.01\,\frac{\text{kJ}}{\cancel{\text{mol}}} && \text{substituting values} \\ q_{\text{melt}} &= 18.\underline{7}9375681\,\text{kJ} \end{aligned}$$

2. The system's temperature increases from 3.5 °C to 100 °C

$$\begin{aligned} q_{\text{liquid}} &= mc\Delta T && \text{Formula for heating at a single state} \\ q_{\text{liquid}} &= 56.35\,\text{g} \times 4.19\,\text{J/g°C} \times (100.0\,°\text{C} - 3.5\,°\text{C}) && \text{Substituting values} \\ q_{\text{liquid}} &= 22.\underline{7}84277\,\text{kJ} \end{aligned}$$

3. The water changes phase from a liquid to gaseous state.

   (a) Enthalpy of vapourization of water is 40.7 kJ/mol

   (b) Change in heat from vapourization:

$$\begin{aligned} q_{\text{vap}} &= n \cdot \Delta H^{\circ}_{\text{melt}} && \text{formula for energy required in a phase change} \\ q_{\text{vap}} &= 3.12\underline{7}081\,\cancel{\text{mol}} \times 40.7\,\frac{\text{kJ}}{\cancel{\text{mol}}} && \text{substituting values} \\ q_{\text{vap}} &= 12\underline{7}.27\,\text{kJ} \end{aligned}$$

4. The system's temperature increases from 100.0 °C to 100.5 °C

$$\begin{aligned} q_{\text{gas}} &= mc\Delta T && \text{Formula for heating at a single state} \\ q_{\text{gas}} &= 56.35\,\text{g} \times 2.02\,\text{J/g°C} \times (100.5\,°\text{C} - 100.0\,°\text{C}) && \text{Substituting values} \\ q_{\text{gas}} &= 56.\underline{9}135\,\text{kJ} \end{aligned}$$

In total, the heat absorbed by the system is calculated as:

$$\begin{aligned} \text{Total heat} = \Sigma q &= q_{\text{melt}} + q_{\text{liquid}} + q_{\text{vap}} + q_{\text{gas}} \\ \Sigma q &= 18.\underline{7}9375681\,\text{kJ} + 22.\underline{7}84277\,\text{kJ} + 12\underline{7}.27\,\text{kJ} + 56.\underline{9}135\,\text{kJ} \\ \Sigma q &= 22\underline{5}.76153381\,\text{kJ} \\ \Sigma q &\approx 2.26 \times 10^{2}\,\text{kJ} \end{aligned}$$

Therefore, the total heat absorbed by the system is 2.26×10^{2} kJ.

6 Sources of Error

Table 2: Experimental Sources of Error Affecting Accuracy of Results

Source of Error	**Impact on Results**	**Rectification in Experiment**
Inconsistent thermometer position	Because the thermometer is held by a human hand, the unsteadiness of the hand causes the position of the thermometer to shift up and down. Since the temperature of the water is different at different locations of the beaker, the inconsistent position of the thermometer causes erratic temperature reading results.	In order to achieve more accurate results the next time the experiment is performed, the thermometer should be held in place by a stable structure such as a pole which will ensure that the position of the thermometer is maintained. Ensuring that the temperature is always measured at a single location will reduce error in the experiment.
Not all of the water underwent evaporation	Since the water only boiled for 4 minutes, there was still significant liquid water remaining at the end of the experiment. However, the only mass value measured was the initial total mass. When analysing the heat absorbed by the system, we assume that the mass of water that underwent evaporation was equivalent to the total mass measured at the beginning of the experiment. In reality, only a small percentage of the water evaporated, meaning the data was inaccurate.	In order to more accurately determine the heat absorbed by water, we can either have the beaker of water kept on the hot plate until all the water has evaporated or measure the final mass of water at the end of the experiment to determine the exact mass of water that underwent evaporation. Implementing either of these improvements will reduce the error in the analysis.
Use of cubed ice	The type of ice that was used in the experiment was cubed ice which contains large gaps between the ice cubes. This means that rather than measuring the actual temperature of the ice itself, the thermometer is measuring the temperature of the air in the gaps between the ice. This temperature is different from the actual temperature which should be measured, which is the temperature of the ice itself.	Using finely crushed ice instead of cubed ice significantly reduces the size of the gaps between pieces of ice. This allows for maximum contact between the thermometer and the ice in order to achieve a temperature reading that is much closer to the actual temperature of the ice.

Table 2 (continued): Experimental Sources of Error Affecting Accuracy of Results

Source of Error	**Impact on Results**	**Rectification in Experiment**
Use of an analog mercury thermometer	Since mercury analog thermometers take a large amount of time to change between temperatures and adapt to a new temperature, the thermometer did not give accurate results at the exact time that the temperature reading was requested. This inaccuracy especially affected the initial temperature measurement of the ice since the thermometer had to start at room temperature and adapt to a below-zero temperature of the ice.	Using a digital or infrared thermometer greatly reduces the error produced from thermometer readings. The time it takes to display the correct temperature on a digital thermometer is significantly less than that of an analog thermometer.

7 Conclusion

This experiment was accomplished successfully as we were able to clearly investigate how water absorbs heat over time.

Overall, the experimental procedure was well-executed with the group members following the procedure's instructions very carefully and with very few mistakes. Aside from the experimental sources of error which cause significant inaccuracies in the data, there was very little human error that occurred during the experiment.

When observing the graph produced using the collected data, I noticed that the data points earlier in the experiment had the most inconsistent data. Theoretically, the temperature of the ice should have remained at $0\,^{\circ}\mathrm{C}$ throughout the phase change, but the trendline suggests that the temperature of the ice remained at around $23\,^{\circ}\mathrm{C}$. The cause of these results is likely the third source of error since the thermometer is measuring the temperature of the air between the ice cubes which is warmer than the ice itself due to convection from the surroundings.

In addition, the final experimental value for the total energy absorbed by the water is $2.26 \times 10^{2}\,\mathrm{kJ}$, which is a reasonable value for the amount of energy required to heat ice to a boiling temperature.

In conclusion, the experiment ran smoothly, and there were no major unexpected issues in the data collection, analysis, and the experiment itself.

8 Appendix

8.1 Rough Observation Table

Figure 4: Initial rough observation table (page 1)

Observation Table: "Observing the changes in temperature of a solid ice inside a beaker when placed on a hot plate in 20-second intervals until it has boiled for 4 minutes"

Mass of the ~~Ice~~ water (g)	Time (sec)	Temperature of ~~ice~~ water (°C)	Qualitative Observations
beaker : 48.32 ice + beaker : 104.67g	0	3.5°	- melting slowly, still solid, transparent w/ foggier center, small pool of water at bottom
	20.63	4.0°	Slightly melting; ice mostly intact
	44.63	5.5°	pool increasing "
	60 61.76	20.0°	ice melting significantly 40% water
	81.68	24.0°	
	102.16	~~23.50~~ 23.0°	tiny, start
	120 121.26	20.0°	there are bubbles that form in the water
	142.39	19.0°	
	161.24	19.5°	
	180 180.83	17.0°	70% water, continues melting. slows down a little
	200.75	19.5°	
	220.77	22.0°	bubbles slightly getting more
	240 242.14	23.0°	but constant in size
	260.81	27.0°	90% water bubbles form on
	281.33	30.5°	side of beaker
	300 301.29	34.0°	Almost all water (98% water)
	321.33	38.5°	No more ice
	340.78	44.0°	Most definitely melted.

Figure 5: Initial rough observation table (page 2)

	360 361.05	50.0	
	384.83	58.0	more bubbles
	402.18	62.0°	
	420 420.58	~~66~~ 67.0°	temp. rises quickly
	441.48	71.8	rising bubbles
	460.62	77.0	bubbles rising to top, steam, bubbles collect
	480 482.98	82.5°	bubbles rising faster, rising at corners
	500.98	87.0	bubbles getting larger, more steamer
	523.13	92.0	
	540 540.93	96.0	BOILING RAPIDLY
	560.58	99.0	
	580.44	99.8°	fairly loud boiling
	600 602.38	99.0°	
	620.43	99.9°	
	640.59	100.0°	condensation!
	660 661.51	100.0°	
	683.05	100.0°	
	700.11	100.0°	
	720 719.88	100.0°	some condensation dripping down
	740.58	100.1°	boiling quieter
	760.27	100.5°	
	780 780.44	100.3°	
	800.54	100.2°	
	820.31	100.1°	
ice + beaker	842.40	100.0°	
= 90.03g	861.65	100.0°	

Scanned with CamScanner

8.2 Initial Lab Procedure

Purpose: The purpose of this experiment is to investigate the heat changes that result from phase changes in matter and to observe the different stages of heating as solid ice turns into water vapour.

Apparatus:

Digital scale	Wire gauze	Beaker (100 mL)
Analog thermometer	Digital stopwatch	
Hot plate	Beaker tongs	

Materials:

Ice cubes (around 50 g)

Procedure:

1. Dedicate each person in the group to perform a specific task
   (a) Keeping track of time
   (b) Recording and observing the results
   (c) Holding the thermometer
2. Place the 100 mL beaker on a scale and either record the mass or tare the scale to 0 g. Place 50 g of ice and record the new mass, accounting for the mass of the beaker
3. Record the initial temperature of the ice.
4. Immediately place the beaker on the hot plate to heat the ice on medium to high heat. Ensure that the thermometer is in the ice but not touching the bottom of the beaker.
5. Record the temperature stated on the thermometer in 20-second intervals and the exact time in which the temperatures were recorded.
6. Continue step 4 until the water has boiled for 4 minutes.
7. Afterwards, use the beaker tongs to remove the beaker from the hot plate and let the beaker cool on wire gauze.
8. Clean up the lab bench and return materials.