Thermochemistry

This experiment has three parts. In part A you will determine the calorimeter constant (heat capacity) for your calorimeter. In part B you will use your calorimeter to determine the specific heat capacity of an unknown metal, and from that you will estimate the atomic mass of the metal allowing you to find out which metal it is. In part C you will use Hess's law to determine the heat of reaction for the reaction between solid citric acid monohydrate and solid sodium bicarbonate.

STOCKROOM

You will need your unknown. **Make sure to record your unknown number in your data table and conclusion.**

You will also need one digital thermometer, a LabQuest with temperature probe, a computer, a calorimeter, a hot plate, a magnetic stirrer, a magnetic stir bar, beaker tongs, a small square of aluminum foil, a ring stand, a clamp, and a 125–mL Erlenmeyer flask.

CHEMICALS

You will need D.I. water as well as your unknown. You will need about 3 grams of citric acid monohydrate, $H_3C_6H_5O_7 \cdot H_2O$, and about 2 grams of sodium bicarbonate, $NaHCO_3$.

OTHER EQUIPMENT

You will need your 50-mL graduated cylinder, a 600-mL beaker, a 400 mL beaker, a 150 mL beaker, your wash bottle full of D.I. water, and your goggles.

WASTE DISPOSAL

All solutions may go down the drain. All solid waste may go in the garbage.

Do not throw out your metal shot!

SAFETY

Wear your goggles the entire time. Do not touch any hot metal or glass.

PROCEDURE

CALORIMETER CONSTANT – PART A

1.) Put about 500 mL of tap water in your 600 mL beaker and put it on your hot plate. Turn the hot plate on high. This is your hot water bath.

2.) Place the 125 mL Erlenmeyer flask on a balance and tare the balance. Remove the flask from the balance and add about 70 mL of D.I. water to it, place the flask with water in it back on the balance, and record the mass of the water to three places past the decimal in your data table.

This is m_{hot} for part A.

3.) Place your 150 mL beaker on the balance and tare the balance. Remove the beaker from the balance and add all of your metal shot for Part 2 to the beaker.

Do this carefully so as not to break your beaker!

Place the 150 mL beaker back on the tared balance. Record the mass of the metal shot to three places past the decimal in your data table.

This is m_{hot} for Part B.

Place the metal shot back into the test tube it came in.

Do this carefully so as not to break your test tube!

4.) Place a square of aluminum foil tightly over the mouth of the 125 mL Erlenmeyer flask.

Using the test tube clamp, suspend the 125 mL Erlenmeyer flask in the hot water bath making sure that the level of the water in the Erlenmeyer flask is below the level of the water in the hot water bath.

5.) Place the digital thermometer in the Erlenmeyer flask through the aluminum foil. Monitor the temperature, the water is ready when the temperature reaches about 95°C or higher.

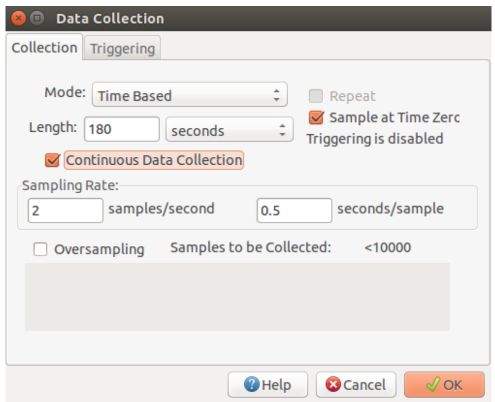
6.) Remove the inner metal cup from your calorimeter and place it on the balance. Tare the balance with the metal cup on it, and remove the cup. Add about 80 mL of D.I. water to the cup and place it back on the balance. Record the mass of the water to three places past the decimal in your data table. **This is m_{cold} for part A.**

7.) Add a magnetic stir bar to the calorimeter cup and place the cup in the calorimeter. Place the calorimeter on a stir plate. Turn the magnetic stirrer on so that the water I the cup has a vortex, but not too fast so as to avoid splashing.

8.) Turn on the LabQuest, connect the temperature probe to it, and connect the LabQuest to the computer. Start LoggerPro on the computer. Place the temperature probe through the one hole rubber stopper in the calorimeter.

9.) Read the temperature of the water in the calorimeter in LoggerPro, and record it in your data table. **This is T_i(cold) for Part A.**

10.) In LoggerPro, go to Experiment → Data Collection and select Continuous Data Collection. Start collecting data (click the arrow on the top).



11.) Once the temperature of the water in the 125 mL Erlenmeyer flask reaches about 92 °C, remove the test tube clamp from the ring stand with the Erlenmeyer flask still in the clamp.

12.) Measure the temperature of the water in the Erlenmeyer flask with the digital thermometer just before pouring the hot water into the calorimeter, then immediately add the hot water to the calorimeter.

13.) Immediately place the lid on the calorimeter.

14.) Record the temperature of the water in the Erlenmeyer flask in your data table. **This is T_i(hot) for Part A.**

15.) Once the temperature of the water in the calorimeter has reached it's maximum and either has started decreasing or is remaining constant, stop data collection in LoggerPro by clicking on the arrow at the top of the screen.

17.) Record the highest temperature reached in your data table.**This is T_F for Part A.**

18.) Empty the calorimeter cup and dry completely with a paper towel.

19.) In LoggerPro, go to Experiment, then Clear Latest Run.

UNKNOWN METAL – PART B

1.) Using a clamp on your ring stand place the test tube with your unknown metal in your hot water bath making sure that the level of the water is at or above the level of the metal.

Now go to Part C and complete that portion of the experiment before completing part B!

2.) Once part C is complete, place the dry calorimeter cup on the balance and tare the balance. Add about 80 mL of D.I. water to the cup and record the mass of the water to three places past the decimal in your data table. **This is m_{cold} for part B.**

3.) Add the magnetic stir bar to the calorimeter cup. Please note that although you will not be able to use the stir bar to stir the metal shot, the magnetic stir bar is included in the calorimeter constant from part A, and thus must remain in the cup.

4.) Measure the temperature of the hot water bath to one place past the decimal and record it in your data table. **This will be T_i(hot) for part B.**

5.) Start data collection in LoggerPro by clicking on the arrow at the top of the screen.

6.) Record the temperature of the water in the calorimeter in your data table by reading it from LoggerPro in the box beneath the data table. **This is T_i(cold) for part B.**

7.) Using the test tube clamp, remove the test tube with the metal in it from the hot water bath. Pour all of the hot metal into the cold water in the calorimeter.

8.) Immediately place the lid back on the calorimeter and continuously agitate until the end of the run.

9.) Once the temperature has peaked and started to decline, stop the run by clicking on the arrow at the top of the screen in LoggerPro.

10.) Record the maximum temperature reached in your data table. **This is T_F for Part B.**

11.) Remove the unknown metal from the calorimeter cup, pour the water out.

12.) Dry the calorimeter cup and the metal shot thoroughly.

13.) Place the metal shot back in the test tube it came in and return to the appropriate test tube rack.

HESS'S LAW – PART C (Perform this part of the experiment while waiting for the unknown metal for part B to heat up)

Heat of Solution of Citric Acid – Part C(1)

1.) Place the calorimeter cup on the balance and tare the balance. Remove the cup from the balance at add about 50 mL of D.I. water to it (do not try to get exactly 50 mL, it does not matter).

2.) Place the calorimeter cup with D.I. water back on the balance and record the mass of the water in your data table. **This is m_{water} for part C(1).**

3.) Place an empty weigh boat on the balance and tare the balance. Remove the weigh boat from the balance and add citric acid monohydrate to the weigh boat until you have about 1.5 grams. Record this mass in your data table. **This is m_{acid} for part C(1).**

4.) Add the stir bar to the calorimeter cup, place the cup in the calorimeter, place the temperature probe in the calorimeter, and place the calorimeter on the stir plate. Turn on the magnetic stirrer.

5.) Start data collection in LoggerPro by clicking on the arrow at the top of the screen.

6.) Record the temperature of the water in the calorimeter in your data table by reading it from LoggerPro in the box beneath the data table. **This will be T_i(solution) for part C(1).**

7.) Add the citric acid monohydrate to the calorimeter, and immediately place the lid back on the calorimeter.

8.) Once the temperature has reached a minimum and started to go back up, stop the run by clicking on the arrow at the top of the screen in LoggerPro.

9.) Record the minimum temperature reached in your data table. **This is T_F for Part C(1).**

10.) Empty the solution in the calorimeter cup down the drain, rinse the cup with D.I. water, and dry it with a paper towel.

Heat of Solution of Sodium Bicarbonate – Part C(2)

1.) Place the calorimeter cup on the balance and tare the balance. Remove the cup from the balance at add about 50 mL of D.I. water to it (do not try to get exactly 50 mL, it does not matter).

2.) Place the calorimeter cup with D.I. water back on the balance and record the mass of the water in your data table. **This is m_{water} for part C(2).**

3.) Place an empty weigh boat on the balance and tare the balance. Remove the weigh boat from the balance and add sodium bicarbonate to the weigh boat until you have about 1.5 grams. Record this mass in your data table. **This is m_{salt} for part C(2).**

4.) Add the stir bar to the calorimeter cup, place the cup in the calorimeter, place the temperature probe in the calorimeter, and place the calorimeter on the stir plate. Turn on the magnetic stirrer.

5.) Start data collection in LoggerPro by clicking on the arrow at the top of the screen.

6.) Record the temperature of the water in the calorimeter in your data table by reading it from LoggerPro in the box beneath the data table. **This will be T_i(solution) for part C(2).**

7.) Add the sodium bicarbonate to the calorimeter, and immediately place the lid back on the calorimeter.

8.) Once the temperature has reached a minimum and started to go back up, stop the run by clicking on the arrow at the top of the screen in LoggerPro.

9.) Record the minimum temperature reached in your data table. **This is T_F for Part C(2).**

10.) Empty the solution in the calorimeter cup down the drain, rinse the cup with D.I. water, and dry it with a paper towel.

Heat of Reaction Between Citric Acid and Sodium Bicarbonate – Part C(3)

1.) Place the calorimeter cup on the balance and tare the balance. Remove the cup from the balance at add about 50 mL of D.I. water to it (do not try to get exactly 50 mL, it does not matter).

2.) Place the calorimeter cup with D.I. water back on the balance and record the mass of the water in your data table. **This is m_{water} for part C(3).**

3.) Place an empty weigh boat on the balance and tare the balance. Remove the weigh boat from the balance and add citric acid monohydrate to the weigh boat until you have about 1 gram. Record this mass in your data table. **This is m_{acid} for part C(3).**

4.) Place another empty weigh boat on the balance and tare the balance. Remove the weigh boat from the balance and add sodium bicarbonate to the weigh boat until you have about 1.5 gram. Record this mass in your data table. **This is m_{salt} for part C(3).**

4.) Add the stir bar to the calorimeter cup, place the cup in the calorimeter, place the temperature probe in the calorimeter, and place the calorimeter on the stir plate. Turn on the magnetic stirrer.

5.) Start data collection in LoggerPro by clicking on the arrow at the top of the screen.

6.) Record the temperature of the water in the calorimeter in your data table by reading it from LoggerPro in the box beneath the data table. **This will be T_i(solution) for part C(3).**

7.) Combine the citric acid monohydrate and the sodium bicarbonate into the same weigh boat. Add those reactants to the calorimeter, and immediately place the lid back on the calorimeter.

8.) Once the temperature has reached a minimum and started to go back up, stop the run by clicking on the arrow at the top of the screen in LoggerPro.

9.) Record the minimum temperature reached in your data table. **This is T_F for Part C(3).**

10.) Empty the solution in the calorimeter cup down the drain, rinse the cup with D.I. water, and dry it with a paper towel.

NOW GO BACK AND COMPLETE PART B!

CALCULATIONS

Calculate:

1.) Your calorimeter constant, $\mathbf{C_{cal}}$, from part A.

2.) The specific heat capacity of your unknown metal from part B.

3.) The molar mass and identity of your unknown metal from part B. The possibilities are W, Mg, Al, Ti, Co, Ni, Zn, Sn, Zr, and Pb.

Use the law of Dulong and Petit to find the molar mass, and thus identity, of your unknown metal. The law of Dulong and Petit is:

$$\text{M.M.} = \frac{24.9435}{\text{s}}$$

Here M.M. is the molar mass of the metal in g/mol and s is the specific heat capacity of the metal in J/g·°C.

4.) Calculate the heat of solution of solid citric acid monohydrate.

$$H_3C_6H_5O_7 \cdot H_2O(s) \rightarrow H_3C_6H_5O_7(aq) + H_2O(l)$$

5.) Calculate the heat of solution of sodium bicarbonate.

$$NaHCO_3(s) \rightarrow Na^+(aq) + HCO_3^-(aq)$$

6.) Calculate the heat of reaction of citric acid and sodium bicarbonate.

$$H_3C_6H_5O_7(aq) + 3\ HCO_3^-(aq) \rightarrow 3\ CO_2(g) + 3\ H_2O(l) + C_6H_5O_7^-(aq)$$

[Here] is a video explaining the calculations for this experiment.

CONCLUSION

REPORT YOUR UNKNOWN NUMBER!!!

Report your calorimeter constant, **C**.

Report the specific heat capacity and molar mass of your unknown metal.

Report the identity of your unknown metal.

Report the heat of solution of citric acid monohydrate in kJ/mol.

Report the heat of solution of sodium bicarbonate in kJ/mol.

Report the heat of reaction between solid citric acid monohydrate and solid sodium bicarbonate in kJ/mol.

Determine and analyze a source of potential experimental error. Please see "How to Determine and Analyze a Source of Experimental Error".