Calorimetry and Specific Heat Capacity

Partner(s) _____   Date _____   Section: 001 002 003 004

Purpose: This experiment will demonstrate the relationship between matter and energy involving heat, mass, specific heat, and temperature. Calorimetry is the <u>science</u> of measuring the <u>heat</u> of <u>chemical reactions</u> or <u>physical changes</u>. Heat is the transfer of energy. Temperature is a <u>physical property</u> of matter that quantitatively expresses the common notions of <u>hot</u> and <u>cold</u>.

In the experiment you will measure heat changes and calculate unknown specific heat of two solids.

Theory/Concepts: Calorimeters are designed to be well-insulated, so no heat is gained from or lost to the surroundings. If no heating element is used to introduce heat in the system, and no heat escapes, then total heat transferred (q) for the entire calorimeter system must equal zero. The total heat can be split into heats for each component in the system. When two substances, one cold and one hot, are placed into the calorimeter, heat flows from the hot substance to the cold substance.

Heat Lost (by warm substance)   +   Heat Gained (by cold substance) = 0

$$m_{hot} \text{sp ht}_{H2O}\, \Delta T + m_{cold}\text{sp ht}_{H2O}\Delta T = 0$$
$$m_{hot}\ \text{sp ht}_{H2O}\ (T_f\ -\ T_i) + m_{cold}\text{sp ht}_{H2O}(T_f\ -\ T_i\ )\ = 0$$

$\Delta T = T_f\ -\ T_i$ $\qquad\qquad\qquad$ sp ht$_{H2O}$ = 1 cal/g $^{\circ}$C = 4.184 J/g $^{\circ}$C

Note: Specific heats, masses, or temperatures may be determined.

Exercise 1:   General Data Sheet for Calorimetry – heat in a system

	Trial 1		Trial 2	
Formula/Symbol for Cold Substance	water, H_2O		water, H_2O	
a. Mass	_____	g	_____	g
b. Specific Heat (c_{water})	_____	$\frac{Cal}{g:C}$	_____	$\frac{Cal}{g:C}$
c. Initial Temperature	_____	°C	_____	°C
d. Final Temperature	_____	°C	_____	°C
e. q_{cold} = m* sp ht$_{water}$*ΔT = a*b*(d-c)	_____	cal	_____	cal
Formula/Symbol for Hot Substance	water, H_2O		water, H_2O	
f. Mass	_____	g	_____	g
g. Specific Heat (c_{water})	_____	$\frac{Cal}{g:C}$	_____	$\frac{Cal}{g:C}$
h. Initial Temperature	_____	°C	_____	°C
i. Final Temperature (same as d)	_____	°C	_____	°C
j. q_{hot} = m*sp ht$_{water}$*ΔT = f*g*(i-h)	_____	cal	_____	cal
q_{cold} + q_{hot} = e + j	_____	cal	_____	cal

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Exercise 2: Calculating the specific heat

$$0 = q_{metal} + q_{H2O}$$

$$q_{metal} = m_{metal}\, sp\, ht_{metal}\, (T_f - T_{i,metal})\qquad q_w = m_w\, sp\, ht_w\, (T_f - T_i)$$

$$Sp\, ht_{metal} = \frac{-(m_w\, sp\, ht_w)(T_f - T_i)}{m_{Cu}(T_f - T_{metal})}$$

	Trial 1	Trial 2
H₂O, water (select one)	Cold or hot	Cold or hot
a. Mass	_____ g	_____ g
b. Initial Temperature	_____ °C	_____ °C
c. Final Temperature (same as metal T_f)	_____ °C	_____ °C
d. Specific Heat (sp ht_water)	____1____ $\frac{Cal}{g:C}$	____1____ $\frac{Cal}{g:C}$
e. Q_{H2O} = a*d*(c-b)	_____ Cal	_____ Cal
Room temperature metal (Cu or Al)	_____	_____
f. Mass	_____ g	_____ g
g. Initial Temperature (room temp)	_____ °C	_____ °C
h. Final Temperature (same as water T_f)	_____ °C	_____ °C
i. Specific Heat (Solid) = $^e/_{[f(h-g)]}$	_____ $\frac{Cal}{g:C}$	_____ $\frac{Cal}{g:C}$

Average Specific Heat   (Trial 1 value i + Trial 2 value i)/2 = _____ Cal/g:C

Calculations:

Theory/Concepts: Calorimeters are designed to be well-insulated, so no heat is gained from or lost to the surroundings. If no heating element is used to introduce heat in the system, and no heat escapes, then total heat transferred (q) for the entire calorimeter system must equal zero. The total heat can be split into heats for each component in the system. When two substances, one cold and one hot, are placed into the calorimeter, heat flows from the hot substance to the cold substance. Note that these heat changes will have different signs, representing loss and gain of heat. By convention, a + sign indicates heat gain (by a cold substance). The final temperature will be greater than the initial temperature so that the temperature change will be positive. A negative sign (-) denotes the heat being lost from that component. The magnitude of the heat change for each substance will depend on the properties of the substance (its mass, specific heat, initial and final temperatures). Initial temperatures vary but the final equilibrium temperature is the same for both substances. The units of heat energy will be calories. The specific heat, a value unique to each substance, will have the units of calories per gram-degree C.

Heat Lost (by warm substance)   +   Heat Gained (by cold substance) = 0

$$m_{hot}sp\ ht_{H2O}\ \Delta T + m_{cold}sp\ ht_{H2O}\Delta T = 0$$
$$m_{hot}\ sp\ ht_{H2O}\ (T_f\ -\ T_i) + m_{cold}sp\ ht_{H2O}(T_f\ -\ T_i\ )\ = 0$$
$$\Delta T = T_f\ -\ T_i \qquad\qquad\qquad sp\ ht_{H2O} = 1\ cal/g\ ^oC = 4.184\ J/g\ ^oC$$

Note: Specific heats, masses, or temperatures may be determined.

Apparatus: Hot plate, tongs, 1- 100mL beakers, 1 @ 100 mL graduated cylinder, copper metal samples, Styrofoam calorimeter, temperature probe. Set up for 6 groups.

Procedure:

Exercise 1   Calculating the calorimeter constant

1. Calculate for each trial the sum of the heat lost and the heat gained using the general equation for calorimetry. This value should be zero but may be positive or negative depending on the experimental error in the experiment. The General Data Sheet for Calorimetry is designed for data collection.
2. Open data studio. Select create experiment. Select the temperature sensor. Display in digits and in graph mode. Use the data sheet provided to record your values.
3. Obtain a known volume of room temperature or cool water, between ~ 40.0 to 80.0 mL, measured in a graduated cylinder. Insert the temperature probe and record the temperature ($T_{i,\ cool}$).
4. Place a 100 mL beaker or Styrofoam calorimeter on the balance and tare it (zero it out). Fill the calorimeter/beaker with about the same volume of water as you have in the graduated cylinder. Record the resulting mass on the data sheet. Turn the hot plate to ~ level 5. Insert temperature probe and heat to about 60-80^oC.
5. Remove beaker from hot plate, record high temperature and immediately add cold water. Cover with the lid, if available, to prevent heat loss.
6. Gently swirl the calorimeter to mix the contents and distribute heat.
7. Allow 1-2 minutes for equilibration and temperature stabilization. When the new temperature has leveled off and become constant, you have reached T_f. Record the temperature. You **may stop the experiment.**
8. The final temperature should be the same for both.
9. Calculate $q_{hot} + q_{cold}$. Theoretically, the value would be zero, but our system has experimental error.

Exercise 2   Calculating the specific heat

Imagine an experiment in which a hot metal is dropped into a calorimeter containing water at room temperature. The metal will lose heat, which will be absorbed by the calorimeter and water. Because no heat enters or leaves the system the heat balance for this experiment is

$0 = q = q_{metal} + q_{H2O}$ $\qquad\qquad q_{metal} = m_{metal}\ sp\ ht_{metal}\ (\ T_f - T_{i,metal}\ )$ $\qquad\qquad q_w = m_w\ sp\ ht_{H2O}\ (\ T_f - T_i\ )$

The specific heat capacity of water is known (1 cal/g °C), and the temperatures T_{metal}, T_i, and T_f can be measured experimentally. The masses of the metal and water (m_{metal} and $m_{H2O)}$ can also be measured experimentally. The only unknown property in the above equations is the specific heat capacity of the metal.

$$sp\ htc_{metal} = \frac{-\ (m_w\ sp\ ht_w)\ (T_f - T_i)}{m_{Cu}\ (T_f - T_{metal})}$$

1. Measure a known volume of tap water (~ 30.0-50.0 mL) and transfer to the calorimeter. Measure the temperature and record the mass.
2. From the side shelf, obtain one of the weights. Ensure the water is boiling. The initial metal temperature will be 100°C.
3. Add the hot metal to the cold water. Record the heat rise until it stabilizes. This will be T_f.
4. Calculate the heat capacity of the metal.
5. Repeat for a second trial.

$$0 = q_{metal} + q_{cal} + q_{H2O} \qquad q_{cal} = C_{cal}\ (T_f - T_i) \qquad q_w = m_w\ sp\ ht_{H2O}\ (T_f - T_i)$$

In this case $q_{metal} < 0$, because the copper will lose heat to the calorimeter and water. Similarly, $q_{cal} > 0$ and $q_{H2O} > 0$, because both the calorimeter and the water will gain heat. In chemistry the thermodynamic sign convention is things *entering* the system a positive in value, and things *leaving* the system are negative in value.

The basic strategy in calorimetry is to use a temperature change and a heat capacity to determine a heat flow. In this experiment, all substances have the same final temperature (T_f), but not all substances have the same initial temperature. The metal is initially at temperature T_{metal} while the calorimeter and water are initially at temperature T_i.

The heat capacity of the calorimeter must be obtained from a separate calibration experiment (for example, a heating element can be used to introduce a known amount of heat). The specific heat capacity of water is known (4.184 J/g °C or 1 cal/g °C), and the temperatures T_{metal}, T_i, and T_f can be measured experimentally. The masses of the metal and water (m_{metal} and $m_{H2O)}$ can also be measured experimentally. The only unknown property in the above equations is the specific heat capacity of the metal.

6. Measure a known volume of tap water and transfer to a 100-mL beaker. Heat the water over medium heat for about 5 minutes. Do not let the water boil. Carefully transfer the hot water from the beaker to the calorimeter (Styrofoam cups) using beaker tongs or oven mitt. Place a thermometer or temperature probe in the calorimeter. Cover and allow it to reach equilibrium temperature for 2 minutes.
7. Once both initial temperatures are recorded, quickly remove the calorimeter lid, adding the cooler water. Close the lid quickly to minimize heat lost to the surroundings. (Note: Record these readings as these temperatures will represent the initial temperature readings for the warmer liquid in the calorimeter and the cooler liquid in the cup). Cover and begin to record the temperature of the mixture, to the nearest 0.1 C, every thirty seconds, with occasional stirring. When the temperature loss levels out, record this temperature as the T_{final}. This temperature will be used as the final temperature of the mixture for all calculations. (Note: The warmer liquid in the calorimeter and the cooler liquid in the cup both reach the same final temperature… the temperature of the mixture).
8. From the mass of the liquid, the specific heat of the liquid, and the initial and final temperatures of the liquid, the quantity of heat (in calories) that are transferred to or from the liquid may be calculated using the standard equation for heat:

Calorimetry: Specific Heat Capacity of Copper
Calorimetry Lab (Calculating the heat capacity of unkown metal ...
http://www.youtube.com/watch?v=XwCLvJdVrIs&feature=related
http://www.youtube.com/watch?v=v1zOnyC4RgQ&feature=related