Name: Date:

§ 16.01a **Thermochemistry: Calorimetry**

Most Important Ideas:

1. specific heat (s) = amount of heat required to raise 1-g substance by 1^oC
   specific heat of H_2O = 4.184 J/(g ^oC)
2. heat capacity (C) = amount of heat required to raise specific amount by $1^oC \Rightarrow C = m * s$
3. heat change (q) = m * s * ΔT; in a system: $q_{released} + q_{absorbed} = 0$ (conservation energy)

Objective

The objective of this activity is to determine the heat exchanged in a reaction. For example: what is the final temperature of the water when 2.0 g of copper metal at 100^oC is placed in 50.-mL of water at 25^oC?

Background

Calorimetry is the study of heat or, more specifically, heat flow. As anyone who has walked barefoot on a hot day knows the amount of heat required to raise the temperature of street blacktop is different from that of grass. This difference is based on the **specific heat (s)** of a substance, the amount of heat required to raise 1-gram of substance by 1^oC.

Specific heat is an intensive property – e.g., used to identify a substance. The **heat capacity** of a substance is the amount of heat required to raise a given quantity of substance by 1^oC. The following are equations used in calorimetry calculations.

$$C = m\,s \qquad \text{(m = mass, grams)}$$
$$q = m\,s\,\Delta T \qquad (\Delta T = T_{final} - T_{initial})$$

N.B. (1) For a chemical reaction in an isolated system, the total heat change is zero. ($q_{rxn} = -q_{cal}$)
(2) Draw a picture whenever possible! It helps!

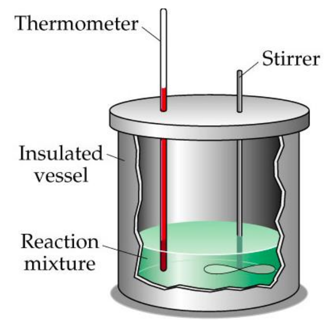
Everyday Application

Everyone who has eaten a hot apple pie knows the apple filling is more likely to burn your mouth than the crust, even though both are at the same temperature when the pie comes fresly out of the oven. Both parts have been in the oven for a period of time long enough for the two to have the same temperature: the molecules of each have the same average kinetic energy. Yet, your mouth is more likely to get burned from the filling. Why? The filling has a larger specific heat, i.e., more energy/mass. Although both crust and filling are at the same temperature, the filling has more energy/mass and will, therefore, raise the temperature of whatever contacts it more than the crust (given that both start at the same initial temperature.)[1]

[1] http://www4.hcmut.edu.vn/~huynhqlinh/olympicvl/tailieu/physlink_askexpert/ae463.cfm.htm

Types of Calorimeters
There are two types of calorimeters:

(1) Constant-Volume Calorimeter:



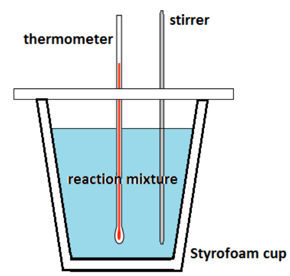
a. Used for combustible substances (e.g., determine the calories in food.

b. The heat of combustion is measured by placing a sealed container ('bomb') inside a steel container.

c. We need to know two of the three following variables:
   i. heat changes for calorimeter & the reaction ($q_{cal} = -q_{rxn}$)
   ii. heat capacity of the calorimeter (C_{cal})
   iii. temperature change (ΔT)

d. $q_{cal} = C_{cal}\ \Delta T$

(2) Constant-Pressure Calorimeter. (We use a constant-pressure calorimeter in the lab.)



a. Used to determine the heat of non-combustion reactions (e.g., placing a hot metal object into cold water.)

b. For two objects, e.g., hot lead (Pb) sphere placed in water:

c. $q_{Pb} = -q_{H2O}$ $q = m\ s\ \Delta T$

d. $m_{Pb}\ s_{Pb}\ \Delta T_{Pb} = -m_{H2O}\ s_{H2O}\ \Delta T_{H2O}$

***Model - 1: Constant-Volume Calorimeter*[2]**

Problem

A 1.274-g sample of naphthalene ($C_{10}H_8$), a pungent substance use in moth repellants, was burned in a constant-volume calorimeter. The temperature of the water rose from 21.49^{O}C to 26.52^{O}C. If the heat capacity of the bomb plus water was 10.17 kJ/^{O}C, calculate the heat of combustion of $C_{10}H_8$ on a per-mole basis (the molar heat of combustion).

Solution

The heat absorbed by the bomb and water equals the heat of combustion of the $C_{10}H_8$.

(a) heat released by the 1.274-g sample:

$$q_{cal} = C_{cal}\,\Delta T$$

$$q_{cal} = (10.17\ \text{kJ}/^{O}\text{C})(26.52 - 21.49)^{O}\text{C}$$

$$q_{cal} = 51.16\ \text{kJ} = -q_{rxn} \Rightarrow q_{rxn} = -51.16\ \text{kJ}$$

(b) molar heat released:

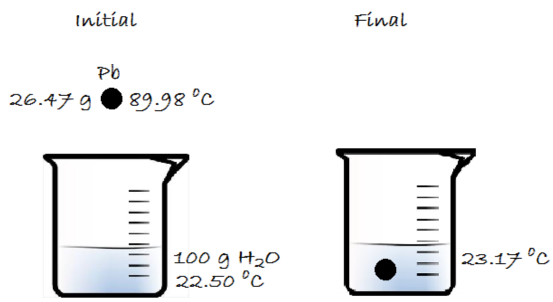
$$\frac{-51.16\ kJ}{1.274\ g\ C_{10}H_8}\,x\,\frac{128.2\ g\ C_{10}H_8}{1\ mol\ C_{10}H_8} = \mathbf{-5.148\ x\ 10^3\ kJ/mole}$$

***Model - 2: Constant-Pressure Calorimeter*[3]**

Problem

A 26.47-g lead (Pb) sample at 89.98^{O}C is placed in a constant-pressure calorimeter of negligible heat capacity containing 100.00 mL of water. The temperature of the water rose from 22.50^{O}C to 23.17^{O}C. What is the specific heat of the lead pellet?

Solution



	Mass (g)	Temperature (°C)		Specific Heat ($\frac{J}{g\cdot °C}$)
		Initial	Final	
Pb	26.47	89.98	23.17	4.184
H_2O	100.0	22.50	23.17	s_{Pb}

$$m_{Pb}\ s_{Pb}\ \Delta T_{Pb} = -m_{H2O}\quad s_{H2O}\quad \Delta T_{H2O}$$

$$s_{Pb} = \frac{-m_{H2O}\quad s_{H2O}\quad \Delta T_{H2O}}{m_{Pb}\qquad\qquad \Delta T_{Pb}}$$

$$s_{Pb} = \frac{-100.0\ g\quad 4.184\ J/g\ ^{o}C\quad 0.67\ ^{o}C}{26.46\ g\qquad\qquad -66.81\ ^{o}C}$$

$$s_{Pb} = 0.159\quad J/g\ ^{o}C$$

[2] Example 6.6, Chang & Overby, 6th edition.
[3] Example 6.7, Chang & Overby, 6th edition.

Problems (specific heat of H_2O = 4.184 J/(g ^oC)

1. What is specific heat? What are the units for it? Is it an intensive or extensive property?
2. Consider the following data:

Metal	Al	Cu
Mass (g)	10	30
Specific Heat (J/(g.^oC))	0.900	0.385
Temperature (^oC)	40	60

   When of these two metals are placed in contact, which of the following will take place?
   (a) Heat will flow from Al to Cu because Al has a larger specific heat.
   (b) Heat will flow from Cu to Al because Cu has a larger specific heat.
   (c) Heat will flow from Cu to Al because Cu has a larger heat capacity.
   (d) Heat will flow from Cu to Al because Cu is at a higher temperature.
3. Consider two metals A and B, each having a mass of 100 g and an initial temperature of 70^oC. The specific heat of A is larger than that of B. Under the same heating conditions, which metal would take longer to reach a temperature of 21^oC?
4. A 352-gram piece of silver at 100^oC is placed in 100-grams of water at 25^oC. The final temperature of the water is 37.60 ^oC. What is the specific heat of silver?
5. A 28.4 g sample of aluminum is heated to 39.4 ^oC, and then is placed in a calorimeter containing 50.0 g of water. The temperature of water increased from 21.00 ^oC to 23.00 ^oC. What is the specific heat of aluminum?
6. A sheet of gold weighing 10.0 g and at a temperature of 18.0^oC is placed flat on a sheet of iron weighing 20.0 g and a temperature of 55.6^oC. What is the final temperature of the combined metals? Assume no heat is lost to the surroundings. (*Hint*: The heat gained by the gold must be equal to the heat lost by the iron. The specific heats of gold and iron are 0.129 J/g·^oC and 0.444 J/g·^oC, respectively.

Extension

7. A quantity of 2.00 x 10^2 mL of 0.862 HCl *M* is mixed with 2.00 x 10^2 mL of 0.431 *M* $Ba(OH)_2$ in a constant-pressure calorimeter of negligible heat capacity. The initial temperature of the HCl and $Ba(OH)_2$ solutions is the same at 20.48^oC. For the process: $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$, the heat of neutralization is –56.2 kJ/mol. What is the final temperature of the mixed solution?
8. A 0.1375-g sample of solid magnesium is burned in a constant-volume bomb calorimeter that has a heat capacity of 3024 J/^oC. The temperature increases by 1.126^oC. Calculate the heat given off by the burning Mg, in kJ/g and kJ/mol.