Lecture 16
Thermodynamics II
Worksheet

1) A 85.2 g copper bar was heated to 221.32 ^{o}C and placed in a coffee cup calorimeter containing 425.0 mL of water at 22.55 ^{o}C. The final temperature of the water was recorded to be 26.15 ^{o}C.
    a. How much heat was gained by the water?
    b. How much heat was lost by the copper?
    c. What is the specific heat of copper?
    d. Was energy conserved in the process? Justify your answer.

2) A 100.0 mL sample of 0.76 *M* HCl at 23.0 ^{o}C was mixed with 100.0 mL of 0.76 *M* NaOH at 23.0^{o}C in a coffee cup calorimeter and the following reaction occurred.

$$H^{+}\ (aq) + OH^{-}\ (aq) \rightarrow H_2O\ (l)$$

The temperature of the solution increased and a maximum temperature of 28.2 ^{o}C was recorder. Assume that no heat was lost to the surroundings, the volumes were additive, the specific heat capacity of the solution was 4.184 J/gK, and the density of the solution was 1.00 g/mL.
    a. Calculate the enthalpy change, $\Delta H_{rxn,}$ for the formation of 1.0 mol H_2O in this reaction.
    b. Is the reaction endothermic or exothermic?
    c. Was energy conserved in the process? Justify your answer.

3) A coffee cup calorimeter contains 100.0 mL of 1.50 *M* $Ba(NO_3)_2$ at 25.0^{o}C. A student pours 100.0 mL of 1.50 *M* Na_2SO_4 at 25.0^{o}C into the calorimeter. A precipitate forms and the temperature rises to 29.7^{o}C. Assume that no heat was lost to the surroundings, the volumes were additive, the specific heat capacity of the solution was 4.184 J/gK, and the density of the solution was 1.00 g/mL.
    a. This reaction could be represented as a complete ionic or a net ionic equation. Write the balanced chemical equation that should be used in association with the ΔH_{rxn} value for this reaction. Justify your choice.
    b. Find the amount of heat that was lost or gained by the solution in the calorimeter.
    c. Find the heat of reaction, ΔH_{rxn}.
    d. Is the reaction endothermic or exothermic?

4) An experiment was conducted in order to determine the enthalpy change that occurs when 1.0 mole of ice at 0^{o}C melts and becomes 1.0 mole of water at 0^{o}C. The enthalpy change associated with this process is referred to as the heat of fusion, ΔH_{fus}, of ice. In the experiment, a 9.68 g sample of ice at 0^{o}C was added to a coffee cup calorimeter containing 278.25 mL of distilled water. The temperature of the water was 22.485^{o}C before the ice was added. The lowest temperature that was recorded after the ice had melted was 19.050^{o}C.
    a. Find the amount of heat lost or gained by the water in the calorimeter.

b. In this experiment, the ice melted and then the temperature of the water produced by the ice increased from 0^oC to 19.050^oC. Calculate the amount of heat absorbed by the melted ice ($q_{melted\ ice}$) as its temperature increased from 0.000^oC to 19.050^oC.
c. Calculate the amount of heat that was gained by the ice during the melting process ($q_{melting}$). (Hint: $q_{temp\ gain} + q_{melting} = -q_w$)
d. Calculate the heat of fusion of ice, ΔH_{fus}.
e. Is the reaction endothermic or exothermic?
f. Energy was transferred from one system to another during this experiment. Identify the two interacting systems and outline the direction of energy flow.
g. Was energy conserved in the process? Justify your answer.

5) Determine the value of the enthalpy change, ΔH_{rxn}, for the following reaction using the information below. $2\ Fe_2O_3(s) + 3\ C_{(graphite)} \rightarrow 4\ Fe(s) + 3\ CO_2(g)$

$C_{(graphite)} + O_2(g) \rightarrow CO_2(g)$ $\Delta H = -393.5$ kJ/mol
$8\ Fe(s) + 6\ O_2(g) \rightarrow 4\ Fe_2O_3(s)$ $\Delta H = -3296.8$ kJ/mol

6) Determine the value of the enthalpy change, ΔH_{vap}, for the evaporation of one mole of water using the information below. $H_2O(l) \rightarrow H_2O(g)$

$CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(l)$ $\Delta H = -890.5$ kJ/mol
$CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g)$ $\Delta H = -802.3$ kJ/mol

7) Determine the value of the enthalpy change, ΔH_{rxn}, for the following reaction using the information below.

$$N_2O(g) + NO_2(g) \rightarrow 3\ NO(g)$$

$2\ NO(g) \rightarrow N_2(g) + O_2(g)$ $\Delta H = -181$ kJ/mol
$2\ N_2O(g) \rightarrow 2\ N_2(g) + O_2(g)$ $\Delta H = -163$ kJ/mol
$NO(g) + ½\ O_2(g) \rightarrow NO_2(g)$ $\Delta H = -57$ kJ/mol

8) Determine the value of the enthalpy change, ΔH_{rxn}, for the following reaction using the information below.

$$C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(l)$$

$C_{(graphite)} + O_2(g) \rightarrow CO_2(g)$ $\Delta H = -393.5$ kJ/mol
$H_2O(l) \rightarrow H_2(g) + ½\ O_2(g)$ $\Delta H = 286$ kJ/mol
$C_3H_8(g) \rightarrow 3\ C_{(graphite)} + 4\ H_2(g)$ $\Delta H = 105$ kJ/mol

9) Using standard enthalpy of formation values from the appendix in your textbook, calculate the enthalpy of combustion, ΔH^o_{comb}, of one mole of ethane at 25^oC.

$$C_2H_6(g) + 3.5\ O_2(g) \rightarrow 2\ CO_2(g) + 3\ H_2O(l)$$

10) Using standard enthalpy of formation values from the appendix in your textbook, calculate the enthalpy of reaction, ΔH^o_{rxn}, for the formation of carbon dioxide from graphite and oxygen gas. $C_{(graphite)} + O_2(g) \rightarrow CO_2(g)$

11) The standard heat of formation of $B_2O_3(s)$ is -1263.6 kJ/mol and the standard heat of formation of liquid water is -285.8 kJ/mol. Use the information below to find the standard heat of formation for one mole of B_5H_9.

$2\ B_5H_9(l) + 12\ O_2(g) \rightarrow 5\ B_2O_3(s) + 9\ H_2O(l)$ $\quad \Delta H^o_{rxn} = -9036.6$ kJ

12) Use the following information to find the standard heat of formation for one mole of $NO_2(g)$.

$2\ NO_2(g) + 7\ H_2(g) \rightarrow 2\ NH_3(g) + 4\ H_2O(l)$ $\quad \Delta H^o = -1303.2$ kJ

Standard heat of formation of liquid water $\quad \Delta H_f^o = -285.8$ kJ / mol

Standard heat of formation of gaseous ammonia $\quad \Delta H_f^o = -46$ kJ / mol

13) Using standard enthalpy of formation values from the appendix in your textbook, calculate the enthalpy of combustion, ΔH^o_{comb}, for one mole of methanol at 25°C.

$CH_3OH(g) + 1.5\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(l)$

14) Using standard enthalpy of formation values from the appendix in your textbook, calculate the enthalpy of combustion, ΔH^o_{comb}, for one mole of C_2H_2 at 25°C.

$C_2H_2(g) + 1.5\ O_2(g) \rightarrow 2\ CO_2(g) + H_2O(l)$

15) Humans started using elemental copper about 6000 years ago and started using elemental tin about 3800 years ago. Use the heat of formation values for copper (II) oxide and tin (IV) oxide to help explain why humans were able to use elemental copper before they were able to use elemental tin.

16) Write the balanced chemical equation that outlines the reaction used to determine the enthalpy of formation for one mole of water.

17) Write the balanced chemical equation that outlines the reaction used to determine the enthalpy of formation for one mole of $H_2CO(g)$.

18) How much heat is released when 24.8 g of $CH_4(g)$ is burned in excess oxygen gas to produce carbon dioxide and water?

$CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g)$ $\quad \Delta H_{rxn} = -802.3$ kJ/mol

19) How much heat is released or absorbed when 45.8 g of hydrogen gas reacts with excess nitrogen gas according to the chemical equation below?

$N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g)$ $\quad \Delta H_{rxn} = -92.2$ kJ/mol