Answers to Review #4: Thermochemistry

1. Know the meanings of, and be able to apply, the following terms:

enthalpy	thermochemical equation	standard enthalpy (heat) of formation
endothermic reaction	calorimetry	standard state
exothermic reaction	specific heat capacity	Hess's Law

2. A hot piece of metal is placed in 30.0 mL of water in a coffee cup calorimeter. As the metal cools, the water warms from 20.0 °C to 24.0°C. How much heat does the water absorb? (0.502 kJ)

3. What are the standard states of the following elements (give both the chemical formula and state)?

sulfur: **S (s)** carbon: **C (s) as graphite** hydrogen: **H_2 (g)** iodine: **I_2 (s)** neon: **Ne (g)**

phosphorus: **P_4 (s)** lead: **Pb (s)** mercury: **Hg (l)** chlorine: **Cl_2 (g)** bromine: **Br_2 (l)**

4. Write formation equations for the following substances:

a) $Na (s) + \frac{1}{2} N_2 (g) + 3/2\ O_2 (g) \rightarrow NaNO_3 (s)$

b) $N_2 (g) + 4\ H_2 (g) + C (s) + 3/2\ O_2 (g) \rightarrow (NH_4)_2CO_3 (s)$

c) $2\ Hg (l) + S (s) + 3/2\ O_2 (g) \rightarrow Hg_2SO_3 (s)$

d) $C (s) + H_2 (g) + \frac{1}{2} O_2 (g) \rightarrow CH_2O (l)$

5. Use standard enthalpies of formation ($\Delta H°f$) to calculate the heat of reaction (ΔH) for the following:

a) $C_2H_4 (g) + 2\ O_2 (g) \rightarrow 2\ CO_2 (g) + 2\ H_2O (g)$ $\Delta H = -1323$ kJ

b) $N_2H_4 (l) + 2\ H_2O_2 (l) \rightarrow N_2 (g) + 4\ H_2O (g)$ $\Delta H = -642.2$ kJ

c) $NH_3 (g) + HCl (g) \rightarrow NH_4Cl (s)$ $\Delta H = -176.2$ kJ

6. Use Hess's Law to calculate the heat of reaction (ΔH) for the reaction: (-648 kJ)

$$N_2H_4 (l) + 2\ H_2O_2 (l) \rightarrow N_2 (g) + 4\ H_2O (g)$$

Given:

$N_2H_4 (l) + 3\ O_2 (g) \rightarrow 2\ NO_2 (g) + 2\ H_2O (g)$ $\Delta H = -\ 466$ kJ

$H_2O (l) + \frac{1}{2} O_2 (g) \rightarrow H_2O_2 (l)$ $\Delta H = +\ 98$ kJ

$\frac{1}{2} N_2 (g) + O_2 (g) \rightarrow NO_2 (g)$ $\Delta H = +\ 34$ kJ

$H_2O (l) \rightarrow H_2O (g)$ $\Delta H = +\ 41$ kJ

7. A 1.00 gram sample of the rocket fuel hydrazine, N_2H_4, is burned in a calorimeter containing 1200.0 g of water. The temperature of the water rises from 24.62 to 28.16°C. The reaction is:

$$N_2H_4 (l) + 3\ O_2 (g) \rightarrow 2\ NO_2 (g) + 2\ H_2O (g)$$

a) Calculate the amount of heat (Q) absorbed by the water when 1.000 g of hydrazine burns. (17.8 kJ)

b) Calculate the heat of reaction (ΔH) per mole of hydrazine burned. (-570. kJ/mol N_2H_4)

8. For the reaction: $Fe_2O_{3(s)} + 3\ CO_{(g)} \rightarrow 2\ Fe_{(s)} + 3\ CO_{2(g)}$ $\Delta H^\circ = -25.0$ kJ

Calculate the amount of energy required/released when 100.0 grams of pure iron are formed. (-22.4 kJ)

Use stoichiometry. When 2 mol of Fe(s) are produced, -25.0 kJ of heat are released. Convert 100.0 g of pure Fe to moles, then find how much heat this will produce using the mole ratio.

9. Given: $MnO_2\ (s) \rightarrow MnO\ (s) + \frac{1}{2}\ O_2\ (g)$ $\Delta H = +\ 134.8$ kJ

$MnO_2\ (s) + Mn(s) \rightarrow 2\ MnO\ (s)$ $\Delta H = -\ 250.1$ kJ

Calculate the heat of formation of MnO_2 (s). (-519.7 kJl)

The formation reaction for MnO_2 (s) is: $Mn\ (s) + O_2\ (g) \rightarrow MnO_2\ (s)$. This is the target reaction that we want to find ΔH for. Use Hess's Law and the two equations you are given to find ΔH for this target reaction.

10. When one mole of CH_4 (g) burns in a bomb calorimeter containing 21.00 kg of water, the temperature of the water rises by 9.140 °C. (Use c = 4.184 J/g°C so answer will have 4 sig digs)

a) Write the balanced reaction for the complete combustion of methane.

b) Use heats of formation to calculate the ΔH for the combustion per mole of methane (-802.5 kJ/mol)

c) Use the calorimetry data above to calculate the heat of combustion (ΔH) per mole of CH_4 (-803.1 kJ)

11. If a reaction is endothermic, which is higher, the enthalpy of the reactants or of the **<u>products</u>**?
- endothermic reactions absorb energy. The energy is stored as chemical potential energy so the enthalpy of the products is higher.

12. In an experiment, 3.116 g of solid lithium hydroxide is mixed with 200.0 mL of 0.750 M solution of nitric acid in a coffee cup calorimeter. A neutralization (double displacement) reaction occurs and the temperature of the nitric acid goes from 24.5 °C to 31.4 °C.

a) Write the balanced chemical reaction for the reaction that occurs. Include the states of all reactants and products.

$LiOH\ (s) + HNO_3\ (aq) \rightarrow H_2O\ (l) + LiNO_3\ (aq)$

b) Calculate the molar enthalpy of reaction (ΔH) per mole of lithium hydroxide. (–44.4 kJ/mol LiOH)

c) State three assumptions that should not significantly affect the accuracy of the results.
- assume that the density of dilute nitric acid is the same as the density of pure water
- assume that the specific heat capacity of dilute nitric acid is the same as the specific heat capacity of pure water
- assume that the calorimeter is a perfect insulator and no heat is lost to the surroundings
- assume that no energy is transferred to the solution by stirring
- assume that all of the chemical potential energy is converted perfectly to thermal kinetic energy

13. Consider the following equations:

(1) $Fe_2O_{3(s)} + 3\ CO_{(g)} \rightarrow 2\ Fe_{(s)} + 3\ CO_{2(g)}$ $\Delta H^\circ = -25$ kJ

(2) $3\ Fe_2O_{3(s)} + CO_{(g)} \rightarrow 2\ Fe_3O_{4(s)} + CO_{2(g)}$ $\Delta H^\circ = -47$ kJ

(3) $Fe_3O_{4(s)} + CO_{(g)} \rightarrow 3\ FeO_{(s)} + CO_{2(g)}$ $\Delta H^\circ = +38$ kJ

Calculate ΔH for the reaction: $FeO_{(s)} + CO_{(g)} \rightarrow Fe_{(s)} + CO_{2(g)}$ (– 17 kJ)

Hint: Do not use fractional mole ratios. Your final equation will end up with molar coefficients of 6. Simplify the reaction by dividing through by 6 and also divide your ΔH by 6 to give –17 kJ.