Thermochemistry Practice Problems

Enthalpy of Formation and Hess' Law

1. From the following information calculate the ΔH_f° of nitrogen monoxide, $NO_{(g)}$.
   $4\ NH_{3(g)} + 5\ O_{2(g)} \rightarrow 4\ NO_{(g)} + 6\ H_2O_{(\ell)}$ $\Delta H^\circ = -1170$ kJ
   $4\ NH_{3(g)} + 3\ O_{2(g)} \rightarrow 2\ N_{2(g)} + 6\ H_2O_{(\ell)}$ $\Delta H^\circ = -1530$ kJ

2. Given the ΔH_f° of copper(II) chloride, $CuCl_{2(s)}$ is -220.1 kJ and of copper (I) chloride, $CuCl_{(s)}$ is -137.2 kJ, calculate ΔH° for the following reaction:
   $CuCl_{2(s)} + Cu_{(s)} \rightarrow 2\ CuCl_{(s)}$

3. Using the values for ΔH_f°, calculate ΔH° for each of the following reactions:
   a. $2\ F_{2(g)} + 2\ H_2O_{(\ell)} \rightarrow 4\ HF_{(g)} + O_{2(g)}$
   b. $CS_{2(g)} + 2\ H_2O_{(\ell)} \rightarrow CO_{2(g)} + 2\ H_2S_{(g)}$
   c. $C_2H_{4(g)} + H_{2(g)} \rightarrow C_2H_{6(g)}$
   d. $10\ N_2O_{(g)} + C_3H_{8(g)} \rightarrow 10\ N_{2(g)} + 3\ CO_{2(g)} + 4\ H_2O_{(g)}$

4. Using the values ΔH_f° calculate the amount of heat released if 200 g of brandy containing 40.0 % by weight ethanol, C2H5OH, is poured over a plum pudding and burned. (*Hint*: first write an equation for the combustion of ethanol.)

5. From the following three thermochemical equations:
   a. $Fe_2O_{3(s)} + 3\ CO_{(g)} \rightarrow 2\ Fe_{(s)} + 3\ CO_{2(g)}$ $\Delta H^\circ = -25$ kJ
   b. $3\ Fe_2O_{3(s)} + CO_{(g)} \rightarrow 2\ Fe_3O_{4(s)} + CO_{2(g)}$ $\Delta H^\circ = -47$ kJ
   c. $Fe_3O_{4(s)} + CO_{(g)} \rightarrow 3\ FeO_{(s)} + CO_{2(g)}$ $\Delta H^\circ = +38$ kJ
   calculate the enthalpy change for the reaction $FeO_{(s)} + CO_{(g)} \rightarrow Fe_{(s)} + CO_{2(g)}$

Enthalpy and Phase Change

6. Calculate the amount of heat released when 1.0 kg of water freezes.

7. Calculate the amount of heat necessary to vapourize 350 mL of diethyl ether, $C_4H_{10}O$. The density of diethyl ether is 0.713 g/mL and the ΔH_{vap} for diethyl ether is 384 J/mol.

Calorimetry

8. A 24.6 g sample of nickel is heated to 110.0°C and then placed in a coffee cup calorimeter containing 125 g of water at a temperature of 23.00°C. After the nickel cools, the final temperature of the metal and water is 24.83°C. Assuming that no heat has escaped to the surroundings or has been absorbed by the calorimeter, calculate the specific heat of nickel.

9. When solutions of an acid and a base are mixed, heat is released. Using a coffee cup calorimeter, 100 mL of 0.100 mol/L hydrochloric acid are mixed with 100 mL of 0.100 mol/L sodium hydroxide solution. The initial temperature of the solutions was 22.6°C and the temperature after mixing was 32.4°C. Calculate the molar enthalpy of neutralization for the reaction. Assume that the density and specific heat of each solution is the same as that of water.

10. A 135 g sample of dilute hydrochloric acid is placed in a copper calorimeter with mass of 465 g. The temperature of the acid and calorimeter is 11.7°C. A mass of 5.00 g of aluminum metal is reacted with the acid. After the reaction has ceased, the temperature is 22.3°C. Calculate the molar enthalpy change for the reaction: $Al_{(s)} + 3\ HCl_{(aq)} \rightarrow AlCl_{3(aq)} + 3/2\ H_{2(g)}$

11. A copper flame calorimeter has a mass of 305 g and contains 255 g of water. When 1.01 g of propanol, $CH_3CH_2CH_2OH$ is burned in the calorimeter, the calorimeter and contents increase in temperature by 28.8°C. Calculate the enthalpy of combustion of propanol.

12. Using the reaction for the combustion of ethane: $2\ C_2H_{6(g)} + 7\ O_{2(g)} \rightarrow 4\ CO_{2(g)} + 6\ H_2O_{(\ell)}$
determine the following:
    a. The molar heat of combustion of ethane using bond energies from the Appendix.
    b. The molar heat of combustion of ethane using the standard enthalpy of formation from the Appendix.
    Explain why the answers you get in a. and b. could be expected to be slightly different.

13. The following combustion reaction takes place in the oxyacetylene torch: $C_2H_{2(g)} + 5/2\ O_{2(g)} \rightarrow 2CO_{2(g)} + H_2O_{(g)}$
    a. Calculate the ΔH° for this reaction.
    b. Construct a graph for this reaction showing the relative enthalpy of formation of reactants and products and overall $\Delta H^\circ_{combustion}$

14. Graphically determine ΔH° for the following reaction $2\ FeO_{(s)} + ½\ O_{2(g)} \rightarrow Fe_2O_{3(s)}$ using ΔH_f° found in the Appendix.

15. Given the following information

$2\ ClF_{3(g)} + 2\ NH_{3(g)} \rightarrow N_{2(g)} + 6\ HF_{(g)} + Cl_{2(g)}$	$\Delta H^\circ = -1196$ kJ
$N_2H_{4(\ell)} + O_{2(g)} \rightarrow N_{2(g)} + 2\ H_2O_{(\ell)}$	$\Delta H^\circ = -622$ kJ
$4\ NH_{3(g)} + 3\ O_{2(g)} \rightarrow 2\ N_{2(g)} + 6\ H_2O_{(\ell)}$	$\Delta H^\circ = -1530$ kJ

determine ΔH° for the following reaction:
$3\ N_2H_{4(\ell)} + 4\ ClF_{3(g)} \rightarrow 3\ N_{2(g)} + 12\ HF_{(g)} + 2\ Cl_{2(g)}$

16. Calculate ΔH° for the reaction
$2\ H_3BO_{3(aq)} \rightarrow B_2O_{3(s)} + 3\ H_2O_{(\ell)}$
using the following data:

$H_3BO_{3\ (aq)} \rightarrow HBO_{2(aq)} + H_2O_{(\ell)}$	$\Delta H^\circ = -0.02$ kJ
$2\ B_2O_{3(s)} + H_2O_{(\ell)} \rightarrow H_2B_4O_{7(s)}$	$\Delta H^\circ = -17.5$ kJ
$H_2B_4O_{7(aq)} + H_2O_{(\ell))} \rightarrow 2\ N_{2(g)} + 4\ HBO_{2(aq)}$	$\Delta H^\circ = -11.3$ kJ