Thermochemistry Review

1. Using the data below, calculate the amount of energy required to melt a 16.2 g aluminum pop can. Assume that the aluminum is at an initial temperature of 20°C.
   - Molar heat of fusion of Al(s) = 10.7 kJ/mol
   - Melting point of Al(s) = 660°C
   - Heat capacity of Al(s) = 0.900 J/g°C

2. Given the thermochemical equations:

   $C(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta H = -394$ kJ

   $H_2(g) + \frac{1}{2} O_2(g) \rightarrow H_2O(l)$ $\Delta H = -286$ kJ

   $C(s) + 2 H_2(g) + \frac{1}{2} O_2(g) \rightarrow CH_3OH(l)$ $\Delta H = -239$ kJ

   Calculate the ΔH for the reaction:

   $CH_3OH(l) + {}^3/_2 O_2(g) \rightarrow CO_2(g) + 2 H_2O(l)$

3. Consider the two thermochemical equations:

   $H_2(g) + \frac{1}{2} O_2(g) \rightarrow H_2O(l)$ $\Delta H = -286$ kJ

   $H_2(g) + \frac{1}{2} O_2(g) \rightarrow H_2O(g)$ $\Delta H = -242$ kJ

   a) Provide an explanation based on chemical bonding for the energy change that occurs in the ***first*** reaction.

   b) Based on forces of attraction, explain the difference in ΔH values between these two reactions.

4. Given the following thermochemical equations:

   $PH_3(g) \rightarrow P(g) + 3H(g)$ $\Delta H = 965$ kJ

   $O_2(g) \rightarrow 2 O(g)$ $\Delta H = 490$ kJ

   $2 H(g) + O(g) \rightarrow H_2O(g)$ $\Delta H = -930$ kJ

   $2 P(g) + 5 O(g) \rightarrow P_2O_5(g)$ $\Delta H = -3382$ kJ

   calculate ΔH for the following reaction:

   $2 PH_3(g) + 4 O_2(g) \rightarrow 3 H_2O(g) + P_2O_5(g)$

5. Use these thermochemical equations to calculate the heat of formation of $C_2H_6(g)$

   $2 C(s) + 3 H_2(g) \rightarrow C_2H_6(g)$

   $C(s) + O_2(g) \rightarrow CO_2(g)$ $\Delta H = -394.8$ kJ

   $H_2(g) + \frac{1}{2} O_2(g) \rightarrow H_2O(l)$ $\Delta H = -286.1$ kJ

   $C_2H_6(g) + 3\frac{1}{2} O_2(g) \rightarrow 2 CO_2(g) + 3 H_2O(l)$ $\Delta H = -1559.3$ kJ

6. Using the data below, calculate the total amount of energy required to change 25.0 g of solid mercury at –50.0°C to liquid mercury at 60.0°C.
   - Molar heat of fusion of Hg(s) = 2.27 kJ/mol
   - Melting point of Hg(s) = –38.8°C
   - Specific heat capacity of Hg(s) = 0.141 J/(g°C)
   - Specific heat capacity of Hg(l) = 0.138 J/(g°C)

7. The reaction that occurs when a typical fat, glycerol trioleate, is metabolized in the body is: $C_{57}H_{104}O_6(s) + 80 O_2(g) \rightarrow 57 CO_2(g) + 52 H_2O(l)$

   a) 37.8 kJ is evolved when 1.00 g of this fat (molar mass = 884 g/mol) is metabolized. Determine the amount of energy evolved when one mole of this fat is metabolized.

   b) How many kilojoules of energy must be evolved if you want to get rid of 1.00 kg of this fat by metabolism?

   c) An average-sized student burns 365 kJ/h when running at a rate of 10.0 km/h. How many kilometres does the student need to run at this rate to metabolize 1.00 kg of fat?

   d) Using data from part (a) and that from your tables, calculate the **heat of formation** of fat in kJ/mol.

8. When 50.0 mL of 1.00 mol/L HCl(aq) and 50.0 mL of 1.00 mol/L NaOH(aq) are mixed in a "coffee cup" calorimeter, the temperature of the resulting solution increases from 21.0°C to 27.5°C. Use the specific heat capacity of $H_2O(l)$, given on page 1 of the Chemistry Data Booklet, to calculate the heat of this reaction measured in kilojoules per mole of HCl(aq) $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$

9. We often have to make assumptions when we conduct laboratory experiments. Consider carefully the experiment described in the previous question, and list four unstated assumptions that must be made in order for one to determine the heat of the reaction.

10. A knowledge of bond energies is helpful in understanding why some reactions are exothermic while others are endothermic. Notice that bond energies are all positive because energy is always required to break chemical bonds:

C–H	+413 kJ/mol	C–C	+348 kJ/mol	H–H	+436 kJ/mol
C–O	+358 kJ/mol	O–H	+463 kJ/mol		

    These bond energies were used to calculate the enthalpy of formation of $CH_3OCH_3(g)$ from gaseous atoms.

    $$2 C(g) + 6 H(g) + O(g) \rightarrow \begin{array}{c} H\ \ H \\ |\ \ | \\ H\text{–}C\text{–}O\text{–}C\text{–}H \\ |\ \ | \\ H\ \ H \end{array} (g) \qquad \Delta H^\circ_f = -3194 \text{ kJ}$$

    a) Use bond energies to calculate the enthalpy of formation of $CH_3CH_2OH(g)$ from gaseous atoms. Show your calculations.

    b) Compare the energy given off in these two equations. Explain your answer

    $2 C(g) + 3 H_2(g) + O(g) \rightarrow CH_3CH_2OH(g)$

    $2 C(g) + 6 H(g) + O(g) \rightarrow CH_3CH_2OH(g)$

11. Coffee cup calorimeters usually consist of Styrofoam cups with covers, thermometers, and stirrers. This apparatus absorbs a certain amount of heat during calorimetry experiments. Corrections for the heat absorbed by the coffee cup calorimeter is defined as the number of joules required to increase the temperature of the calorimeter by 1°C, measured in J/°C.

    A calorimeter at 20.0°C contains 25.00 g of water also at 20.0°C. When 75.00 g of water at 40.00°C is added to the water in the calorimeter, the highest observed temperature is 34.4°C. Assuming no heat is lost from the calorimeter to the surroundings, what is the heat capacity of this coffee cup calorimeter?

12. A 2.9 g piece of aluminum, a 6.7 piece of copper, and a 5.0 g piece of iron each absorb the same amount of radiant heat energy from sunlight. Determine which piece of metal will be the warmest. Show your calculations. Use the Chemistry Data Booklet.

13. Coffee cup calorimeters usually consist of Styrofoam cups with covers, thermometers, and stirrers. This apparatus absorbs a certain amount of heat during calorimetry experiments. Corrections for the heat absorbed by the coffee cup calorimeter can be carried out by using the heat capacity of the calorimeter measured in J/°C.

    A 1.00 mol/L solution of NaOH, a 1.00 mol/L solution of HCl, and a coffee cup calorimeter (heat capacity = 109 J/°C) were allowed to stand until the temperature of all three equalled 19.5°C. A 200.0 mL sample of the NaOH was placed in the calorimeter; 200.0 mL of the HCl was added rapidly; and the contents of the calorimeter were mixed. The temperature reached 25.8°C.

    Calculate the heat of neutralization per mole of hydrochloric acid. Assume that the densities of the HCl and NaOH solutions are 1.00 g/mL and that the specific heat capacity of the solution after the reaction is 4.18 J/g°C.

14. A coffee-cup calorimeter normally consists of two nested Styrofoam cups with a lid. A coffee cup calorimeter of this type contains 125.0 g of water at 20.0°C. A 120.0 g sample of copper metal is heated to 98.5°C by putting it into a beaker of hot water. The copper is then put into the calorimeter and the final temperature of the water and copper is 25.8°C.
    a) Calculate the energy change of the copper metal.
    b) Calculate the energy change of the water.
    c) The difference between the two values is due to the energy lost to the Styrofoam cup. The heat capacity of a calorimeter is the amount of energy required to change the temperature of the apparatus by 1°C. Calculate the heat capacity of the calorimeter in J/°C.
    d) In a typical coffee-cup calorimeter experiment we assume that the energy change due to the calorimeter is negligible. In this experiment is this a valid assumption? Explain.

15. In a calorimetry experiment the burning of 5.08 g of hexane, $C_6H_{14}(l)$, released enough heat to raise the temperature of 750. g of water from 10.1°C to 82.7°C.
    a) Calculate the heat of combustion for hexane expressed in kJ/mol of C_6H_{14}.
    b) Write a balanced equation for the combustion reaction. Include the ΔHcomb in the equation.

16. A chemistry laboratory stocks samples of metals. Unfortunately the labels of some of the "t" metals have fallen off their containers. Some of the samples have been identified; however, the tellurium, terbium, titanium, and tungsten samples have not yet been identified. Use the following data to identify one of the metals. When a 60.0 g sample of one of the unlabelled metals at 100.00°C is added to 45.0 g of water at 22.00°C, the final temperature of both the water and the metal is 33.16°C.

17. The two common sugars, glucose ($C_6H_{12}O_6$), and sucrose ($C_{12}H_{22}O_{11}$), are both carbohydrates.
    a) Using the combustion equations below, calculate the molar enthalpy of combustion for the two sugars.
    $C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$
    $C_{12}H_{22}O_{11}(s) + 12O_2(g) \rightarrow 12CO_2(g) + 11H_2O(l)$

    b) The average fuel value for carbohydrates is 17 kJ/g.
        (i) Calculate the enthalpy of combustion per gram for each sugar and explain how your answers compare to the average fuel value for carbohydrates
        (ii) Which of these units, kJ/mol or kJ/g is more likely to be used by chemists? Explain

18. Tetrachloroethylene, C_2Cl_4, is used to treat animals infected with hookworms of all types. It can be produced by the reaction:
    $C_2H_2(g) + 3Cl_2(g) \rightarrow C_2Cl_4(g) + 2HCl(g) \qquad \Delta H = -422.1$ kJ

    a) Using the standard heats of formation, determine the heat of formation of $C_2Cl_4(g)$
    b) Sketch an enthalpy diagram for the formation of $C_2Cl_4(g)$ from the elements.

19. Experienced hikers and campers often make temporary showers using plastic bags. The container is filled from a convenient water source and is left in the sun to absorb heat.
    a) If the container holds 30.0 kg of water initially at 9.5°C when collected from a stream, how much energy is absorbed if the final temperature of the water in the "shower" is 35.0°C?
    b) If a propane stove was used to warm the water instead of sunlight, what mass of propane, $C_3H_8(g)$, must be burned to heat the water from 9.5°C to 35.0°C? (Assume all products of combustion are gases.)
    c) Water is used in several applications where storage of heat energy is a factor. Explain the main thermodynamic advantage of water for this application.