

## Fall 2007 CH 301 Worksheet 12--Thermodynamics

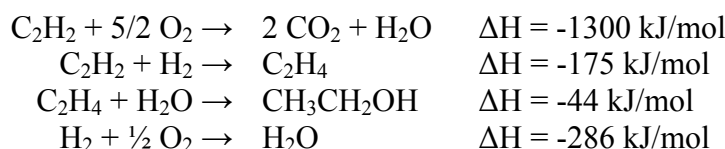
1. A small (74 g) serving of French fries is burned in a bomb calorimeter containing 3 L of water. The temperature of the water increases by 82°C. The calorimeter has a heat capacity of 200 J/°C, the density of water is 1 g/mL, and the heat capacity of water is 4.18 J/g°C. How much heat is evolved per gram of french fries?

$$14.1 \text{ kJ/g}$$

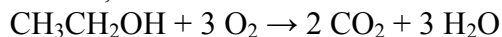
2. The same calorimeter as in number 1 is used to measure the enthalpy of dissolving 2.5 mol of potassium chloride (KCl) in water. If the enthalpy of the process is  $\Delta H = +15 \text{ kJ/mol}$  and the initial temperature of the water is 298 K, what is the final temperature of the water?

$$295.1 \text{ K}$$

3. Given

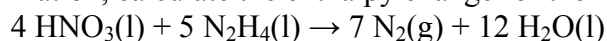


Find  $\Delta H$  for the combustion of ethanol,



$$-1367 \text{ kJ/mol}$$

4. Given the following information, calculate the enthalpy change for the reaction



$$\Delta H_f^\circ (\text{HNO}_3(\text{l})) = -174.10 \text{ kJ/mol}$$

$$\Delta H_f^\circ (\text{N}_2\text{H}_4(\text{l})) = +50.63 \text{ kJ/mol}$$

$$\Delta H_f^\circ (\text{H}_2\text{O}(\text{l})) = -285.83 \text{ kJ/mol}$$

$$-2987 \text{ kJ/mol}$$

5. Calculate the free energy change of the same reaction at 298 K, given

$$S_m^\circ (\text{HNO}_3(\text{l})) = 155.60 \text{ J/K}\cdot\text{mol}$$

$$S_m^\circ (\text{N}_2(\text{g})) = 191.61 \text{ J/K}\cdot\text{mol}$$

$$S_m^\circ (\text{N}_2\text{H}_4(\text{l})) = 121.21 \text{ J/K}\cdot\text{mol}$$

$$S_m^\circ (\text{H}_2\text{O}(\text{l})) = 69.91 \text{ J/K}\cdot\text{mol}$$

$$-3269 \text{ kJ/mol}$$

5. Calculate the enthalpy change for the combustion of ethanol using bond energies.

$$\text{C-H} = 412 \text{ kJ/mol}$$

$$\text{C-O} = 360 \text{ kJ/mol}$$

$$\text{O=O} = 497 \text{ kJ/mol}$$

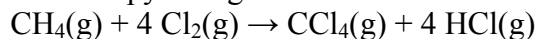
$$\text{C-C} = 348 \text{ kJ/mol}$$

$$\text{C=O} = 743 \text{ kJ/mol}$$

$$\text{O-H} = 463 \text{ kJ/mol}$$

$$-1028 \text{ kJ/mol}$$

6. Using bond energies, calculate the enthalpy change for the reaction



$$\text{C-H} = 412 \text{ kJ/mol}$$

$$\text{Cl-Cl} = 242 \text{ kJ/mol}$$

$$\text{C-Cl} = 338 \text{ kJ/mol}$$

$$\text{Cl-H} = 431 \text{ kJ/mol}$$

$$-460 \text{ kJ/mol}$$

7. Use enthalpies of formation to find the enthalpy change for the same reaction.

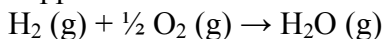
$$\Delta H_f^\circ (\text{CH}_4(\text{g})) = -74.81 \text{ kJ/mol}$$

$$\Delta H_f^\circ (\text{CCl}_4(\text{g})) = -163.78 \text{ kJ/mol}$$

$$\Delta H_f^\circ (\text{HCl}(\text{g})) = -92.31 \text{ kJ/mol}$$

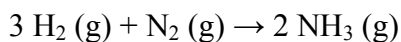
$$-458.21 \text{ kJ/mol}$$

8. Find the approximate work done for the following reaction at 400 K.



$$1.67 \text{ kJ}$$

9. For the reaction



how many moles of hydrogen gas must be reacted for the work to be 8 kJ at 300 K?

*2.4 mol*

10. A reaction occurs in a beaker. You touch the beaker and it feels cold. What is the sign of  $\Delta H$  for the reaction? What can you say about the sign of  $\Delta S$ ?

*$\Delta H > 0, \Delta S < 0$*

11. A reaction happens in a balloon, and in the end, the volume of the balloon has doubled. What is the sign of work for the reaction?

*negative*

12. Give the sign of the entropy change of the system for the following processes:

a. Dr. Laude pours hot water in a tub of liquid  $\text{N}_2$  and makes a thundercloud.

*positive*

b. Water freezes.

*negative*

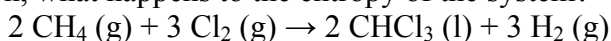
c. Two cars are in a head-on collision.

*positive*

d. Sugar is dissolved in a drink.

*positive*

13. For the following reaction, what happens to the entropy of the system?



*It decreases.*

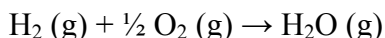
14. The reaction above happens. What can you say about its enthalpy change?

*It is exothermic.*

15. From your knowledge of the temperature dependence of (a) water boiling and (b) water freezing, predict the sign of  $\Delta H$  and  $\Delta S$ .

*(a)  $\Delta H > 0, \Delta S > 0$ ; (b)  $\Delta H < 0, \Delta S < 0$*

16. The reaction



is exothermic. Is its spontaneity temperature-dependent? In what way?

*Yes. It is only spontaneous at low temperatures, where favorable decrease in enthalpy overcomes the unfavorable decrease in entropy.*

17. For each of the following combinations of enthalpy and entropy change, tell whether it occurs *always*, *never*, *at high temperature*, or *at low temperature*.

a.  $\Delta H < 0, \Delta S < 0$  *at low temperature*

b.  $\Delta H < 0, \Delta S > 0$  *always*

c.  $\Delta H > 0, \Delta S < 0$  *never*

d.  $\Delta H > 0, \Delta S > 0$  *at high temperature*

18. Explain why, although water has three vibrational degrees of freedom, carbon dioxide must have four. (Hint: both molecules have 9 total degrees of freedom)

*Carbon dioxide is linear. Thus, rotation around the O-C-O axis doesn't do anything to the molecule – it's not actually a degree of freedom. Thus, CO<sub>2</sub> has one fewer rotation degree of freedom than H<sub>2</sub>O, so it must have one extra vibrational mode to make up for it.*

19. What is the total motional (i.e. due to the motion of the atoms in the molecule) contribution to the energy of methanol, CH<sub>3</sub>OH? Express your answer as a multiple of RT. *9RT counting translational, rotational and vibrational. (6 atoms with 18 degrees of freedom at 3/2 RT per degree = 9RT/mole)*

20. How many translational, rotational, and vibrational degrees of freedom does ammonia have?  
*3 translational, 3 rotational, and 6 vibrational*