Spring 2009

2. The reaction of an elemental halogen with an alkane is a very common reaction. The reaction between chlorine and butane is provided below. (NOTE: Questions a – d and f pertain to this reaction.)

$$C_4H_{10}(g) + 2Cl_2(g) \rightarrow C_4H_8Cl_2(l) + 2HCl(g)$$

a) Calculate ΔH°_{rxn} for the reaction above. (8 points)

b) Predict the sign of ΔS°_{rxn} for the reaction above. Provide an explanation to support the sign of ΔS°_{rxn}. (5 points)

c) Which factor, the change in enthalpy, ΔH°, or the change in entropy, ΔS°, provides the principal driving force for the reaction at 298 K? Explain. (6 points)

d) For the reaction, how is the value of the standard free energy, ΔG°, and the spontaneity of the reaction affected by an increase in temperature? You may wish to use a mathematical relationship to help in your explanation. (6 points)

(15) 1. Given the reaction

$$CO_{2(g)} + 2NH_{3(g)} \rightarrow 2\ CO(NH_2)_{2(s)} + H_2O_{(l)} \quad \Delta H^\circ = -134\ kJ\ mol^{-1}$$

a) For the reaction, indicate whether the standard entropy change, ΔS°, is positive, negative or zero. Support your response with a brief explanation. (5)

b) Which factor, the change in enthalpy, ΔH°, or the change in entropy, ΔS°, provides the principal driving force for the reaction at 298 K. Explain. (5)

c) For the reaction, how is the value of the standard free energy change, ΔG° affected by an increase in temperature? Explain. (5)

(30) 3. Carbon monoxide can be converted to carbon dioxide according to the following equation;

$$2CO(g) + O_2(g) \rightarrow 2CO_2(g)$$

a) Calculate $\Delta H°$ for the reaction above at 25 °C. (6 points)

b) Calculate ΔS° for the reaction at 25 °C. (6 points)

c) Calculate ΔG° for the reaction at 25 °C. (6 points)

d) Which factor, the change in enthalpy, ΔH°, or the change in entropy, ΔS°, provides the principal driving force for the reaction at 298 K? Explain. (6 points)

e) For the reaction, how is the value of the standard free energy, ΔG°, affected by an increase in temperature? Explain using a mathematical explanation. (6 points)

(10) 6. Short answer

a)

i) Write the formation reaction for $H_2O(l)$ and for $H_2O(g)$ (4 points)

ii) Predict the sign of ΔS for each formation reaction? (2 points)

iii) Is the magnitude of ΔS the same or different (is one value more positive or more negative compared to the other) for the two formation reactions? Explain. (4 points)

(16) 1.

$$Cl_{2(g)} + 3\ F_{2(g)} \rightarrow 2\ ClF_{3(g)}$$

ClF_3 can be prepared by the reaction represented by the equation above. For ClF_3 the standard enthalpy of formation, ΔH_f°, is -163.2 kJ mol^{-1} and the standard free energy of formation, ΔG_f°, is -123.0 kJ mol^{-1}.

(a) Calculate the standard entropy change, ΔS°, for the reaction at 298K.

(b) Does the sign of ΔS° that you calculated in part a) make sense in terms of the balanced chemical equation? Explain.

(c) If ClF_3 were produced as a liquid rather than as a gas, how would the sign and the magnitude of ΔS for the reaction be affected? Explain.

(d) At 298K the absolute entropies of $Cl_{2(g)}$ and $ClF_{3(g)}$ are 222.96 J mol^{-1} K^{-1} and 281.50 J mol^{-1} K^{-1}, respectively.

(i) Account for the larger entropy of $ClF_{3(g)}$ relative to that of $Cl_{2(g)}$.

(ii) Calculate the value of the absolute entropy of $F_{2(g)}$ at 298K.

8. When solid sodium carbonate reacts with aqueous acetic acid bubbles are formed and the container becomes cool to the touch. Which of the following statements best describes what has happened in this system?

(A) ΔG, ΔH and ΔS are all positive;
(B) ΔG and ΔH are negative, but ΔS is positive;

(C) ΔG, ΔH and ΔS are all negative;
(D) ΔS and ΔH are both positive and ΔG is negative;
(E) ΔS and ΔG are both negative and ΔH is positive;

4. Which of the following is an endothermic reaction?

(A) $6CO_2(g) + 6H_2O(g) \rightarrow 2C_3H_6(g) + 9O_2(g)$

(B) $4Al(s) + 3O_2(g) \rightarrow 2Al_2O_3(s)$

(C) $C(s) + \frac{1}{2}O_2(g) \rightarrow CO(g)$

(D) $H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l)$

(E) $H_2O(g) \rightarrow H_2O(l)$

7. Solid mercury(II) oxide must be heated to decompose to elemental mercury and oxygen. Which of the following statements best describes what has happened in this system?

(A) ΔG, ΔH and ΔS are all positive;
(B) ΔG and ΔH are negative, but ΔS is positive;

(C) ΔG, ΔH and ΔS are all negative;
(D) ΔS and ΔH are both positive and ΔG is negative;
(E) ΔS and ΔG are both negative and ΔH is positive;

18. Which of the following reactions is a formation reaction?

(A) $H_2(g) + Cl_2(g) \rightarrow 2\ HCl(g)$
(B) $2\ NH_4Cl(s) \rightarrow N_2(g) + 4\ H_2(g) + Cl_2(g)$
(C) $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$
(D) $Cl_2(g) + 1/2\ O_2(g) \rightarrow Cl_2O(g)$
(E) $Cl_2(g) \rightarrow 2\ Cl(g)$

5. Hydrogen gas reacts with oxygen gas to form liquid water. The container becomes hot to the touch. Which of the following statements best describes what has happened in this system?

   (A) ΔG, ΔH and ΔS are all positive;
   (B) ΔG and ΔH are negative, but ΔS is positive;

   (C) ΔG, ΔH and ΔS are all negative;
   (D) ΔS and ΔH are both positive and ΔG is negative;
   (E) ΔS and ΔG are both negative and ΔH is positive;

6. ΔG°_{rxn} for the combustion of 1 mol of ethane is

   (A) -32.4 kJ mol^{-1}
   (B) -598 kJ mol^{-1}
   (C) -733 kJ mol^{-1}
   (D) -1466 kJ mol^{-1}
   (E) -2932 kJ mol^{-1}

Thermodynamic Values (25 ˚C)

Substance and State	ΔH^o_f $\left(\frac{kJ}{mol}\right)$	ΔG^o_f $\left(\frac{kJ}{mol}\right)$	S^o $\left(\frac{J}{K \cdot mol}\right)$
Carbon			
C(*s*) (graphite)	0	0	6
C(*s*) (diamond)	2	3	2
CO(*g*)	-110.5		198
CO_2(*g*)	-393.5		214
CH_4(*g*)	?	-51	186
CH_3OH(*g*)	-201	-163	240
CH_3OH(*l*)	-239	-166	127
CH_3Cl(*g*)	-80.8	-57.4	234
$CHCl_3$(*g*)	-100.8		
$CHCl_3$(*l*)	-131.8		
H_2CO(*g*)	-116	-110	219
HCOOH(*g*)	-363	-351	249
HCN(*g*)	135.1	125	202
C_2H_2(*g*)	227	209	201
C_2H_4(*g*)	52	68	219
CH_3CHO(*g*)	-166	-129	250
C_2H_5OH(*l*)	-278	-175	161
C_2H_6(*g*)	-84.7	-32.9	229.5
C_3H_6(*g*)	20.9	62.7	266.9
C_3H_8(*g*)	-104	-24	270
C_4H_{10}(*g*)	-125	-16.7	310
$C_4H_8Cl_2$(*l*)	-229		
Bromine			
Br_2(*l*)	0	0	152.
BrCl*(g)*	14.64	-0.96	240
Chlorine			
Cl_2(*g*)	0	0	223
Cl_2(*aq*)	-23	7	121
Cl^-(*aq*)	-167	-131	57
HCl(*g*)	-92	-95	187
Fluorine			
F_2(*g*)	0	0	
F^-(*aq*)	-333	-279	-14
HF(*g*)	-271	-273	174
Hydrogen			
H_2(*g*)	0	0	131
H(*g*)217	203	115	
H^+(*aq*)	0	0	0
OH^-(*aq*)	-230	-157	-11
H_2O(*l*)			
H_2O(*g*)	-242	-229	189
Magnesium			
Mg(s)	0	0	33
Mg(aq)	-492	-456	-118
MgO(s)	-601	-569	26.9

Substance and State	ΔH^o_f $\left(\frac{kJ}{mol}\right)$	ΔG^o_f $\left(\frac{kJ}{mol}\right)$	S^o $\left(\frac{J}{K \cdot mol}\right)$
Oxygen			
O_2(*g*)	0	0	205
O(*g*)249	232	161	
O_3(*g*)	143	163	239
Nitrogen			
N_2(*g*)	0	0	192
NCl_3(*g*)	230	271	-137
NF_3(*g*)	-125	-83.6	-139
NH_3(*g*)	?	-17	193
NH_3(*aq*)	?	-27	111
NH_2CONH_2(aq)	?	?	174
NO(*g*)	90	87	211
NO_2(*g*)	32	52	240
N_2O(*g*)	82	104	220
N_2O_4(*g*)	10	98	304
N_2O_5(*g*)	-42	134	178
HNO_3(*aq*)	-207	-111	146
HNO_3(*l*)	-174	-81	156
NH_4Cl(s)	-314	-201	95
NH_4ClO_4(*s*)	-295	-89	186
Silver			
Ag*(s)*	0	0	42.6
Ag^+*(aq)*	105.6	77.1	72.7
$Ag(S_2O_3)^{3-}$*(aq)*	-1285.7	--	--
AgBr(s)	-100.4	-96.9	107.1
AgCl(s)	-127.1	-109.8	96.2
Sulfur			
S(rhombic)	0	0	31.8
SO_2(g)	-296.8	-300.2	248.8
SO_3(g)	-395.7	-371.1	256.3
H_2S(g)	-20.17	-33.0	205.6
Phosphorus			
P_4(*s*)	0	0	41.1
PCl_5(*g*)	-375	-305	365
Aluminum			
$AlCl_3$(*s*)	-526	-505	184
Barium			
$BaCl_2$(*aq*)	-872	-823	123
$Ba(OH)_2 \cdot 8H_2O$(*s*)	-3342	-2793	427
Iodine			
I_2(*s*)	0	0	116.7
HI(*g*)	25.94	1.30	206.3