South Pasadena • AP Chemistry

Name ________________________________
Period ___ Date ___/___/___

# 20 • Entropy & Free Energy

**STUDY QUESTIONS**

1. Imagine tossing two coins in the air.
   a. Predict the distribution of various combinations of heads and tails.
   b. What is the probability of the result being two heads?
   c. What is the most probable result?

   Now imaging tossing three coins in the air.
   d. What is the probability of a three heads result?
   e. Which system has the highest entropy, the two-coin system or the three-coin system?

2. Which one of the following pairs of samples has the higher entropy?
   a. $Br_2(l)$ or $Br_2(g)$
   b. $C_2H_6(g)$ or $C_3H_8(g)$
   c. $MgO(s)$ or $NaCl(s)$
   d. $KOH(s)$ or $KOH(aq)$

3. Predict the entropy change for the following processes:
   a. $O_2(g) \rightarrow 2O(g)$
   b. $2O_3(g) \rightarrow 3O_2(g)$
   c. $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$
   d. $NaCl(s) \rightarrow Na^+(aq) + Cl^-(aq)$
   e. $C_2H_5OH(l) \rightarrow C_2H_5OH(g)$
   f. $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$

9. Of the following reactions,
   which are spontaneous at any temperature,
   which are never spontaneous regardless of the temperature,
   which are spontaneous only at a high temperature,
   and which are spontaneous only at low temperature?

| | Reaction | ΔH | ΔS |
|---|---|---|---|
| a. | $C_8H_{18}(l) + {}^{25}/_2O_2(g) \rightarrow 8CO_2(g) + 9H_2O(g)$ | – | + |
| b. | $N_2(g) + 2F_2(g) \rightarrow N_2F_4(g)$ | – | – |
| c. | $Cl_2(g) \rightarrow 2Cl(g)$ | + | + |
| d. | $2O_3(g) \rightarrow 3O_2(g)$ | – | + |
| e. | $2C(s) + 2H_2(g) \rightarrow C_2H_4(g)$ | + | – |

# Review

**Name:** **Period:** **Seat#:**

### STATION 1: ENTROPY CHANGE

For each of the following examples, decide whether the entropy is increasing or decreasing. Is ΔS + or –?

ΔS is _____ The electrolytic decomposition of water. $2H_2O(l) \rightarrow 2\ H_2(g) + O_2(g)$

ΔS is _____ The freezing of water. $H_2O(l) \rightarrow H_2O(s)$

ΔS is _____ The reaction of sodium metal with water. $2Na(s) + 2H_2O(l) \rightarrow H_2(g) + 2Na^+(aq) + 2\ OH^-(aq)$

ΔS is _____ The boiling of water. $H_2O(l) \rightarrow H_2O(g)$

ΔS is _____ The reaction of $OF_2$ and water. $OF_2(g) + H_2O(g) \rightarrow O_2(g) + 2HF(g)$

# Entropy and Free Energy

### STATION 2: ΔH, ΔS, ΔG, GIBB'S FREE ENERGY

$$C_2H_2(g) + 2\ H_2(g) \rightarrow C_2H_6(g)$$

| Substance | $S°$ (J/mol·K) | $\Delta H°_f$ (kJ/mol) |
|---|---|---|
| $C_2H_2(g)$ | 200.9 | 226.7 |
| $H_2(g)$ | 130.7 | 0 |
| $C_2H_6(g)$ | 229.6 | -84.7 |

Calculate ΔS, ΔH, and ΔG for this reaction at 298 K.

# Entropy and Free Energy

### STATION 3: EQUILIBRIUM

Consider the boiling of liquid bromine: $Br_{2(l)} \leftrightarrows Br_{2(g)}$

At 25°C, $\Delta H°$ = 30.84 kJ/mol and $\Delta S°$ = 92.9 J/mol·K for this reaction.
Calculate the value of $\Delta G°$.

Assuming that $\Delta H$ and $\Delta S$ do not change at different temperatures, calculate the normal boiling point of liquid bromine.

# Entropy and Free Energy

### STATION 4: PREDICTING SPONTANEITY

Consider the reaction: $MgO(s) + SO_2(g) \rightarrow MgSO_3(s)$

What is the sign of $\Delta H$ for this reaction? ______ Justify your answer.

What is the sign of $\Delta S$ for this reaction? _____ Justify your answer.

This reaction will be:

a) spontaneous at all temperatures
b) spontaneous at high temperatures
c) spontaneous at low temperatures
d) non-spontaneous at all temperatures

# Entropy and Free Energy

**STATION 5: $K_{eq}$ & $\Delta G$**

Consider the reaction: $C_2H_5Cl_{(g)} + Cl_{2(g)} \rightarrow C_2H_4Cl_{2(g)} + HCl_{(g)}$

**Standard Free Energies of Formation at 298 K**

| **Substance** | $\Delta G^\circ_f$ **kJ·mol$^{-1}$** |
|---|---|
| $C_2H_4Cl_{2(g)}$ | -80.3 |
| $C_2H_5Cl_{(g)}$ | -60.5 |
| $HCl_{(g)}$ | -95.3 |
| $Cl_{2(g)}$ | 0 |

Calculate the value of ΔG° for this reaction.

Calculate the value of $K_{eq}$ for the reaction at 298 K. [ΔG° = -RT *ln*K; R = 8.31 J·mol$^{-1}$·K$^{-1}$]

From the AP Exam:

**THERMOCHEMISTRY/KINETICS**

$$\Delta S^\circ = \sum S^\circ \text{ products} - \sum S^\circ \text{ reactants}$$

$$\Delta H^\circ = \sum \Delta H_f^\circ \text{ products} - \sum \Delta H_f^\circ \text{ reactants}$$

$$\Delta G^\circ = \sum \Delta G_f^\circ \text{ products} - \sum \Delta G_f^\circ \text{ reactants}$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$
$$= -RT \ln K = -2.303\,RT \log K$$
$$= -n\mathcal{F}E^\circ$$

$$\Delta G = \Delta G^\circ + RT \ln Q = \Delta G^\circ + 2.303\,RT \log Q$$

$$q = mc\Delta T$$

$$C_p = \frac{\Delta H}{\Delta T}$$

$$\ln[\text{A}]_t - \ln[\text{A}]_0 = -kt$$

$$\frac{1}{[\text{A}]_t} - \frac{1}{[\text{A}]_0} = kt$$

$$\ln k = \frac{-E_a}{R}\left(\frac{1}{T}\right) + \ln A$$

Gas constant, $R = 8.31 \text{ J mol}^{-1}\text{ K}^{-1}$
$= 0.0821 \text{ L atm mol}^{-1}\text{ K}^{-1}$
$= 62.4 \text{ L torr mol}^{-1}\text{ K}^{-1}$
$= 8.31 \text{ volt coulomb mol}^{-1}\text{ K}^{-1}$