18.2: Dispersal of Energy - Entropy

Entropy and Second Law of Thermodynamics

18.2.1. Predict the entropy change in the reaction,

$$2H_2(g) + O_2(g) \longrightarrow 2H_2O(l)$$

a. increase
b. decrease
c. same
d. not enough information

18.2.2. Predict the entropy change in the reaction,

$$Ag^+(aq) + Cl^-(aq) \longrightarrow AgCl(s)$$

a. increase
b. decrease
c. same
d. not enough information

18.2.3. Which one of the following decreases of the entropy of the system?

a. dissolving NaCl in water
b. sublimation of benzene
c. dissolving oxygen in water
d. boiling of alcohol

18.2.4. Which one has the highest absolute entropy at 25^0C?

a. H_2O(l)
b. He(g)
c. C(s)
d. NH_3(g)

18.2.5. Calculate the change of entropy for the reaction at 25^0C, where S^0 for Al(s), O_2(g) and Al_2O_3(s) are 28.32, 205.0 and 51.0 J/K*mol respectively.

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

18.6: Gibbs Free Energy

Gibbs Free Energy

18.6.1. Calculate the change of the Gibbs free energy for the reaction at 25°C, where standard free energy of formation of C_2H_4(g), H_2O(g), C_2H_5OH(l) are 68, -229, -175kJ/mol respectively.

$$C_2H_4(g) + H_2O(g) \longrightarrow C_2H_5OH(l)$$

18.6.2. What is the change of entropy if S^0 of C_2H_4(g), H_2O(g), C_2H_5OH(l) are219, 189, and 161 J/K*mol.

18.6.3. What is the change of enthalpy at 25°C for the same reaction?

18.6.4. For a reaction to be spontaneous at all temperatures, what should be the signs of ΔH° and ΔS°?

a. +,+
b. +,-
c. -,+
d. -,-

18.6.5. A reaction that is not spontaneous at low temperatures becomes spontaneous at high temperatures. Predict the sign of ΔH and ΔS.

a. +,+
b. +,-
c. -,+
d. ,-,

18.6.6. When ammonium sulfate dissolves in water, the temperature of the solution decreased. Predict the sign of ΔH and ΔS?

a. +,-
b. +,+
c. -,+
d. -,-

Gibbs Free Energy and K

18.6.7. The equilibrium constant for a reaction is 0.48 at 25°C. What is the value of ΔG° at this temperature? R=8.314J/K*mol

18.6.8. Using the reaction and the giving the following data, determine the value for ΔS°.

$$Ag^+(aq) + Cl^-(aq) \longrightarrow AgCl(s)$$

	$\Delta H_f°$ (kJ/mol)	S° (J/mol*K)
Ag^+ (aq)	105.9	73.93
Cl^- (aq)	-167.2	56.5
AgCl (s)	127.0	96.11

18.6.9. Use the information from 18.6.8, determine the value for ΔH°.

18.6.10. Use the information from 18.6.8, determine the value for ΔG°.

18.6.11. Use the information from 18.6.8, determine the value for K.

18.6.12. Using the information below, calculate the value of K at 25°C for the reaction of C(s) and O_2(g) to form CO.

$$C(s) + O_2(g) \longrightarrow CO_2(g) \quad \Delta G^\circ = -394.4\ kJ/mol$$

$$CO(g) + \frac{1}{2}O_2(g) \longrightarrow CO_2(g) \Delta G^\circ = -257.2 kJ/mol$$

Free Energy and Temperature

18.6.13. What is the melting point of gold, Au, at 100kPa if ΔH°_{fusion}=12.36kJ/mol, and ΔS°_{fusion} = 0.0092kJ/mol?

18.6.14. What is the state of gold if the temperature is 1200°C?

a. solid
b. liquid
c. gas
d. a mixture of solid and liquid

18.6.15. What is the state of gold if the temperature is 900°C?

a. solid
b. liquid
c. gas
d. a mixture of liquid and gas

18.6.16. What is the ΔS°_{fusion} of water if ΔH°_{fusion}=6.01kJ/mol?

18.6.17. What is the ΔS°_{vap} of water if ΔH°_{vap}=40.7kJ/mol?

Enthalpy, Entropy, and Gibbs Free Energy

18.6.18. Use the Selected Thermodynamic Values appendix in the back of your book to answer the questions below. Your answer may differ slightly due to different tables in different texts.

$$MgCl_2(s) + H_2O(l) \longrightarrow MgO(s) + 2HCl(g)$$

a. Find the ΔH_{rxn} for the reaction above.

b. Find the ΔS_{rxn} for the reaction above.

c. Find the ΔG_{rxn} for the reaction above.

18.6.19. Use the Selected Thermodynamic Values appendix in the back of your book to answer the questions below. Your answer may differ slightly due to different tables in different texts.

$$2NOCl\ (g) \longrightarrow 2NO(g) + Cl_2(g)$$

a. Find the ΔH_{rxn} for the reaction above.

b. Find the ΔS_{rxn} for the reaction above.

c. Find the ΔG_{rxn} for the reaction above.

18.6.20. Use the Selected Thermodynamic Values appendix in the back of your book to answer the questions below. Your answer may differ slightly due to different tables in different texts.

$$2NO(g) + Cl_2(g) \longrightarrow 2NOCl(g)$$

a. Find the ΔH_{rxn} for the reaction above.

b. Find the ΔS_{rxn} for the reaction above.

c. Find the ΔG_{rxn} for the reaction above.

Finding K

18.6.21. Find the K for the reaction at the following temperatures.

$$MgCl_2(s) + H_2O(l) \longrightarrow MgO(s) + 2HCl(g)$$

a. Temperature at 25°C?

b. Temperature at 20°C?

c. Temperature at 100°C?

18.6.22. Find the K for the reaction at the following temperatures.

$$2NOCl\ (g) \longrightarrow 2NO(g) + Cl_2(g)$$

a. Temperature at 25°C?

b. Temperature at 15°C?

c. Temperature at 150°C?

18.6.23. Find the K for the reaction at the following temperatures.

$$2NO(g) + Cl_2(g) \longrightarrow 2NOCl(g)$$

a. Temperature at 25°C?

b. Temperature at 10°C?

c. Temperature at 200°C?

Reactant and Product Loading

Use the following reaction for questions 18.6.24-18.6.27

$$MgCl_2(s) + H_2O(l) \longrightarrow MgO(s) + 2HCl(g) \quad \Delta G^\circ = 69.27\ kJ/mol$$

18.6.24. Does the reaction favor products or reactants?

a. reactant
b. product
c. both
d. none of the above

18.6.25. What is the expression for Q?

18.6.26. At what minimal pressures would the reaction proceed to the left?

18.6.27. What is the ΔG° for $P_{HCl} = 5.2*10^{-4}$?

18.6.28. What is the ΔG and does the reaction proceed towards products or reactants?

2NO(g) +	Cl_2(g)	⟶	2NOCl (g)
$4.9*10^{-6}$M	$3.1*10^{-3}$M		$2.4*10^{-1}$M

18.6.29. What is the ΔG and does the reaction proceed towards products or reactants?

2NOCl (g)	⟶	2NO(g) +	Cl_2(g)
$3.1*10^{-1}$M		$2.4*10^{-6}$M	$4.9*10^{-3}$M

General Questions

18.1. Which of the following must have a negative value for an exothermic process?

a. enthalpy change
b. entropy change
c. free energy change
d. electrode cell potential
e. equilibrium constant

18.2. Which of the following is true when one mole of naphthalene sublimes to gas?

1. The entropy increases
2. The entropy decreases
3. The enthalpy increases
4. The enthalpy decreases

a. 1 only
b. 2 only
c. 1 and 3 only
d. 2 and 3 only
e. 1 and 4 only

18.3. The total entropy of a system and its surroundings always increases for a spontaneous process. This is a statement of

a. the law of constant composition
b. the first law of thermodynamics
c. the second law of thermodynamics
d. the third law of thermodynamics
e. the law of conservation of matter

18.4. Which of the following is a spontaneous process?

1. ice melting at 25C
2. heat flowing from a hot to a cold object
3. an iron tool rusting

a. 1 only
b. 2 only
c. 3 only
d. 1 and 2 only
e. 1, 2, and 3

18: Entropy and Free Energy

18.5. The heat of vaporization of ammonia is 23.4 kJ/mol. Its boiling point is -33°C. What is the change in entropy for the vaporization of ammonia in J/(mol*K)?

18.6. At the boiling point of benzene, C_6H_6, ΔH_{vap} = 30.78 kJ/mol, ΔS_{vap} = 87.15 J/(mol*K). Determine the normal boiling temperature in degrees Celsius for C_6H_6.

18.7. Arrange the following in order of <u>increasing</u> entropy:

$CH_4(g)$, C(s), Li(s), Na(s)

a. Li, C, CH_4, Na
b. C, Li, Na, CH_4
c. Na, Li, C, CH_4
d. CH_4, Li, Na, C
e. Na, Li, CH_4, C

18.8. Arrange the following in order of <u>increasing</u> entropy, S°:

Hg(l), Hg(s), C_6H_6(l), CH_3OH(l)

a. Hg(s), CH_3OH(l), C_6H_6(l), Hg(l)
b. CH_3OH(l), Hg(s), Hg(l), C_6H_6(l)
c. Hg(l), Hg(s), C_6H_6(l), CH_3OH(l)
d. Hg(s), Hg(l), C_6H_6(l), CH_3OH(l)
e. Hg(s), Hg(l), CH_3OH(l), C_6H_6(l)

18.9. Which of the following processes would be expected to have a positive ΔS value?

a. $2H_2(g) + O_2(g) \longrightarrow 2H_2O(g)$
b. $I_2(g) \longrightarrow I_2(s)$
c. $2ClBr(g) \longrightarrow Cl_2(g) + Br_2(g)$
d. $NH_4HS(s) \longrightarrow NH_3(g) + H_2S(g)$
e. $2NO(g) + O_2(g) \longrightarrow 2NO_2(g)$

18.10. Which of the following compounds has the highest entropy in J/(mol*K) at 298K?

a. CH_3OH(l)
b. CO(g)
c. SiO_2(s)
d. H_2O(l)
e. $CaCO_3$(s)

18.11. Arrange the following reactions in order of increasing $\Delta S°_{rxn}$ values:

1. $H_2(g) + Cl_2(g) \longrightarrow 2HCl(g)$
2. $3H_2(g) + N_2(g) \longrightarrow 2NH_3(g)$
3. $(NH_4)_2Cr_2O_7(s) \longrightarrow Cr_2O_3(s) + 4H_2O(l) + N_2(g)$

a. 1 < 3 < 2
b. 1 < 2 < 3
c. 2 < 1 < 3
d. 2 < 3 < 1
e. 3 < 1 < 2

18: Entropy and Free Energy

18.12. Which of the following processes would be expected to have a ΔS value very close to zero?

a. $H_2O(s) \longrightarrow H_2O(l)$
b. $2H_2(g) + O_2(g) \longrightarrow 2H_2O(g)$
c. $H_2O(s) \longrightarrow H_2O(g)$
d. $N_2(g) + O_2(g) \longrightarrow 2NO(g)$
e. $OF_2(g) + H_2O(g) \longrightarrow O_2(g) + 2HF(g)$

18.13. Calculate ΔS° for the decomposition of ozone from oxygen.

$$2O_3(g) \longrightarrow 3O_2(g)$$

$$S° = 205\,J/(mol * K)\ for\ O_2(g), and\ 239\,J/(mol * K)\ \ for\ O_3(g)\ at\ 25°C$$

18.14. If a reaction is endothermic and nonspontaneous at 25°C, then it

a. can never be spontaneous
b. can become spontaneous by adding a catalyst
c. may be spontaneous at higher temperatures
d. may be spontaneous at lower temperatures
e. is exothermic and spontaneous at high temperatures

18.15. Given the following

$$Fe_2O_3(s) + 3CO(g) \longrightarrow 2Fe(s) + 3CO_2(g) \quad \Delta G° = -29.4\,kJ$$

$$3Fe_2O_3(s) + CO(g) \longrightarrow 2Fe_3O_4(s) + CO_2(g) \quad \Delta G° = -61.6\,kJ$$

calculate ΔG° for

$$Fe_3O_4(s) + CO(g) \longrightarrow Fe(s) + Fe_2O_3(g) + CO_2(g)$$

18.16. If a reaction is exothermic and nonspontaneous at 25°C and 1 atm of pressure, it may be

a. spontaneous at higher temperatures
b. spontaneous at lower temperatures
c. endothermic at lowest temperatures
d. endothermic at higher temperatures
e. nonspontaneous at all temperatures

18.17. For the following process:

$$Br_2(l) \longrightarrow 2Br(g)$$

a. ΔH is + and ΔS is + for the reaction
b. ΔH is - and ΔS is - for the reaction
c. ΔH is + and ΔS is - for the reaction
d. ΔH is - and ΔS is + for the reaction
e. ΔG is + for all temperatures

18.18. The normal boiling point of ammonia is 33°C. For the process

$$NH_3(g) \longrightarrow NH_3(l)$$

at -40°C, the signs of ΔH, ΔS, and ΔG would be

	ΔG	ΔH	ΔS
a.	–	–	–
b.	–	+	+
c.	+	+	+
d.	0	+	–
e.	+	–	–

18.19. The reaction $Br_2(g) \longrightarrow 2Br(l)$ is spontaneous at 1,600 °C. We can conclude that

a. ΔH is + and ΔS is + for the reaction
b. ΔH is - and ΔS is - for the reaction
c. ΔH is + and ΔS is - for the reaction
d. ΔH is - and ΔS is + for the reaction
e. ΔG is + for all temperatures

18.20. For the reaction $3C(s) + 4H_2(g) \rightleftharpoons C_3H_8(g)$,

$$\Delta S° = -269\ J/(mol * K)$$

$$\Delta H° = -103.8\ kJ/mol$$

Calculate the equilibrium constant at 25°C for the reaction above.