General Chemistry II Jasperse
Entropy, Spontaneity, and Free Energy. Extra Practice Problems

General Types/Groups of problems:

Key Equations Given for Test:

For weak acids alone in water: $[H^+] = \sqrt{K_a x [WA]}$	For weak bases alone in water: $[OH^-] = \sqrt{K_b x [WB]}$
pZ= -logZ General definition for p of anything	pH + pOH = 14
$[H^+][HO^-] = 1.00 \times 10^{-14}$	$K_aK_b = 1.00 \times 10^{-14}$ for conjugate acid/base pair
For Buffer: $pH = pK_a + \log[base]/[acid]$ Henderson-Hasselbalch Equation	$\Delta S^\circ = S^\circ$ (products) – S° (reactants)
$\Delta G^\circ = G^\circ$ (products) – G° (reactants)	$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ (T in Kelvin)

EVALUATING/RANKING STANDARD MOLAR ENTROPY (*S*°) FOR CHEMICALS (non-math)

1. Which of the following is in the correct order of standard state entropy?

I. Liquid water < gaseous water
II. Liquid water < solid water
III. $NH_3 < H_2$

a. I only
b. II only
c. III only
d. I and II only
e. I and III only

2. Which of the following will have the **greatest** standard molar entropy (*S*°)?

a. $NH_3(g)$
b. $He(g)$
c. $C(s$, graphite)
d. $H_2O(l)$
e. $CaCO_3(s)$

3. Indicate which of the following has the **lowest** standard molar entropy (*S*°).

a. $CH_4(g)$
b. $CH_3CH_2OH()$
c. $H_2O(s)$
d. $Na(s)$
e. $He(g)$

4. Indicate which of the following has the **highest** entropy at 298 K.

a. 0.5 g of HCN
b. 1 mol of HCN
c. 2 kg of HCN
d. 2 mol of HCN
e. All of the above have the same entropy at 298 K.

EVALUATING Δ*S* FOR REACTIONS (non-math recognition)

5. Indicate which one of the following reactions result in a **positive** ΔS_{sys}.

   a. $AgNO_3(aq) + NaCl(aq) \leftrightarrows AgCl(s) + NaNO_3(aq)$
   b. $H_2O\,(g) + CO_2\,(g) \leftrightarrows H_2CO_3\,(aq)$
   c. $H_2(g) + I_2(g) \leftrightarrows 2\,HI(g)$
   d. $C_2H_2O_2(g) \leftrightarrows 2\,CO(g) + H_2(g)$
   e. $H_2O(g) \leftrightarrows H_2O(l)$

6. Indicate which one of the following reactions results in a **negative** ΔS_{sys}.

   a. $H_2O(g) \leftrightarrows H_2O(s)$
   b. $CaCO_3(s) \leftrightarrows CaO(s) + CO_2(g)$
   c. $CuSO_4(H_2O)_5\,(s) \leftrightarrows CuSO_4(s) + 5H_2O(g)$
   d. $14O_2(g) + 3NH_4NO_3(s) + C_{10}H_{22}(l) \rightarrow 3N_2(g) + 17H_2O(g) + 10CO_2(g)$
   e. $CO_2(aq) \leftrightarrows CO_2(g)$

7. Which of the processes A–D will lead to a **positive change in the entropy of the system**? If all of these processes lead to a positive change in the entropy of the system, select E.

   a. Sodium chloride crystals form as saltwater evaporates.
   b. Helium gas escapes from the hole in a balloon.
   c. Stalactites form in a cave.
   d. Water freezes in a freezer.
   e. All of these lead to a positive change in entropy of the system, as they are all spontaneous.

8. Which of the following processes will lead to a **decrease in the entropy of the system**?

   a. Salt crystals dissolve in water.
   b. Air escapes from a hole in a balloon.
   c. Iron and oxygen react to form rust.
   d. Ice melts in your hand.
   e. None of these lead to a negative change in the entropy of the system, as they are all spontaneous.

CALCULATING Δ*S* FOR REACTIONS (Math)

9. Determine ΔS for $H_2(g) + I_2(g) \leftrightarrows 2HI(g)$ given the following information.

Substance	***S*° (J/mol · K)**
$H_2(g)$	130.58
$I_2(g)$	116.73
$HI(g)$	206.3

   a. –41.10 J/mol · K
   b. –165.29 J/mol · K
   c. +398.75 J/mol · K
   d. +165.29 J/mol · K
   e. +41.10 J/mol · K

10. Determine ΔS for $N_2O_4(g) \leftrightarrows 2NO_2(g)$ given the following information.

Substance	***S*° (J/mol · K)**
$N_2O_4(g)$	304.3
$NO_2(g)$	240.45

   a. +176.7 J/mol · K
   b. –63.8 J/mol · K
   c. +63.8 J/mol · K
   d. –50.7 J/mol · K
   e. –176.7 J/mol · K

11. What is the entropy change to make 1 mole of SO_3 for the reaction $SO_2(g) + 1/2\ O_2(g) \rightarrow SO_3(g)$

Substance	***S*° (J/mol · K)**
$SO_2(g)$	248.2
$O_2(g)$	205.0
$SO_3(g)$	256.8

a. –196.4 J/K
b. +196.4 J/K
c. –93.9 J/K
d. +93.9 J/K
e. +401.4 J/K

12. NO gas is converted to NO_2 gas according to the following reaction, $NO(g) + 1/2\ O_2(g) \rightarrow NO_2(g)$

What is the standard entropy change when **<u>0.5 mol</u>** of NO gas reacts with **<u>0.5 mol</u>** of O_2 gas?

Substance	***S*° (J/mol · K)**
$NO(g)$	210.7
$O_2(g)$	205.0
$NO_2(g)$	240.0

a. –36.6 J/K
b. –175.7 J/K
c. –83.4 J/K
d. +83.4 J/K
e. +36.6 J/K

13. If 3.500 g of Ni (58.69 g/mol)are reacted with excess oxygen to form nickel oxide (NiO) under standard state conditions, what is the entropy change for the reaction?

$$2Ni(s) + O_2 \leftrightarrows 2NiO(s)$$

Substance	***S*° (J/mol · K)**
Ni	182.1
O_2	205.0
NiO	37.99

a. –49.3 J/K
b. –24.7 J/K
c. –14.7 J/K
d. +49.3 J/K
e. –10.4 J/K

14. What is the entropy change if 4.500 g of $CaCO_3(s)$ is placed in a container and allowed to decompose to $CaO(s)$ and $CO_2(g)$ according to the following reaction?

$$CaCO_3(s) \leftrightarrows CaO(s) + CO_2(g)$$

Substance	***S*° (J/mol · K)**
$CaCO_3(s)$	92.88
$CaO(s)$	39.75
$CO_2(g)$	213.6

a. +7.2 J/K
b. –160.5 J/K
c. +35.7 J/K
d. +160.5 J/K
e. +3.57 J/K

15. What is the standard entropy change when 10.0 g of methane reacts with 10.0 g of oxygen?

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O()$$

Substance	***S*° (J/mol · K)**
$CH_4(g)$	186.2
$O_2(g)$	205.0
$H_2O(l)$	70.0
$CO_2(g)$	213.6

a. –121 J/K
b. –37.9 J/K
c. –242.6 J/K
d. –154.4 J/K
e. –16.8 J/K

CHANGES IN ENTROPY OF UNIVERSE VS SYSTEM. Evaluating Spontaneity Considering both Entropy and Enthalpy

16. In a **spontaneous** process, which of the following **always increases**?

a. the entropy of the system
b. the entropy of the surroundings
c. the entropy of the universe
d. the entropy of the system and the universe
e. the entropy of the system, surroundings and the universe

17. Processes are always spontaneous, regardless of temperature, when _____ (*H* and *S* refer to the system).

a. $\Delta H > 0$ and $\Delta S < 0$
b. $\Delta H < 0$ and $\Delta S < 0$
c. $\Delta H > 0$ and $\Delta S > 0$
d. $\Delta H < 0$ and $\Delta S > 0$
e. None of these is true, as temperature must always be taken into account.

18. The dissolution of ammonium nitrate in water is a **spontaneous endothermic** process. It is spontaneous because the system undergoes _____

a. a decrease in enthalpy.
b. an increase in entropy.
c. an increase in enthalpy.
d. a decrease in entropy.
e. an increase in free energy.

19. Which of the following must be true for a **spontaneous exothermic** process?

a. only that $\Delta S_{sys} < 0$
b. only that $\Delta S_{sys} > 0$
c. both $\Delta S_{sys} < 0$ and the magnitude of ΔS_{sys} < the magnitude of ΔS_{surr}
d. both $\Delta S_{sys} < 0$ and the magnitude of ΔS_{sys} > the magnitude of ΔS_{surr}
e. either $\Delta S_{sys} > 0$, or else $\Delta S_{sys} < 0$ but the magnitude of ΔS_{sys} < the magnitude of ΔS_{surr}

20. Suppose a chemical reaction is found to be **spontaneous**, but with $\Delta \boldsymbol{S}_{\mathbf{sys}} < 0$. Which of the following statements must be **TRUE**?

a. $\Delta S_{surr} < 0$ and its magnitude is < ΔS_{sys}. In other words, the system loses entropy and the surroundings also lose entropy. The loss by the surroundings is less than the loss by the system.
b. $\Delta S_{surr} < 0$ and its magnitude is > ΔS_{sys}. In other words, the system loses entropy and the surroundings also lose entropy. The loss by the surroundings is greater than the loss by the system.
c. $\Delta S_{surr} > 0$ and its magnitude is < ΔS_{sys}. In other words, the system loses entropy but the surroundings gain entropy. The gain by the surroundings is less than the loss by the system.
d. $\Delta S_{surr} > 0$ and its magnitude is > ΔS_{sys}. In other words, the system loses entropy but the surroundings gain entropy, and the gain by the surroundings outweighs the loss by the system.
e. an error has been made, as $S_{sys} > 0$ by necessity for a spontaneous process.

FREE ENERGY AND CALCULATING ΔG FOR REACTIONS (Math)

21. Any reaction will be spontaneous if _____

a. $\Delta G_{sys} > 0$
b. $\Delta G_{sys} < 0$
c. $\Delta S_{sys} > 0$
d. $\Delta S_{sys} < 0$
e. $\Delta H_{sys} < 0$

From $\Delta G_{formationn}$

22. What is the ΔG_{rxn} for the reaction given:

$$CH_4(g) + 2O_2(g) \leftrightarrows CO_2(g) + 2H_2O(g)$$

Substance	**ΔG_{form} (kJ/mol)**
$CH_4(g)$	50.8
$CO_2(g)$	394.4
$H_2O(g)$	–228.57

a. –50.8 kJ/mol
b. –751 kJ/mol
c. –113 kJ/mol
d. –115 kJ/mol
e. –807 kJ/mol

23. Determine ΔG_{rxn} for $C_4H_{10}(l) + 13/2\ O_2(g) \leftrightarrows 4CO_2(g) + 5H_2O(g)$ given the following.

Substance	**ΔG_{form} (J/mol · K)**
$C_4H_{10}(l)$	–15.0
$CO_2(g)$	–394.4
$H_2O(g)$	–228.57

a. –2705 kJ/mol
b. –608.0 kJ/mol
c. –1791 kJ/mol
d. –3457 kJ/mol
e. +608.0 kJ/mol

24. Given the following data, determine the molar free energy of combustion for propane gas, C_3H_8.

$\Delta G\ (C_3H_8, g)$	–23.5 kJ/mol
$\Delta G\ (CO_2, g)$	–394.4 kJ/mol
$\Delta G\ (H_2O, g)$	–105.6 kJ/mol

a. –1629.1 kJ/mol
b. –1582.1 kJ/mol
c. –476.5 kJ/mol
d. +476.5 kJ/mol
e. +1582.1 kJ/mol

From $\Delta H°$ *and* $\Delta S°$

25. Hydrogen reacts with nitrogen to form ammonia (NH_3) according to the reaction

$$3H_2(g) + N_2(g) \leftrightarrows 2NH_3(g)$$

The value of $\Delta H°$ is –92.38 kJ/mol, and that of $\Delta S°$ is –198.2 J/mol · K. Determine $\Delta G°$ at 25°C.

a. $+5.897 \times 10^4$ kJ/mol
b. +297.8 kJ/mol
c. –33.32 kJ/mol
d. –16.66 kJ/mol
e. +49.5 kJ/mol

26. Hydrochloric acid (HCl) reacts with sodium hydroxide (NaOH) to form sodium chloride (NaCl) and water. If $\Delta H° = –56.13$ kJ/mol and $\Delta S° = 79.11$ J/mol · K, what is $\Delta G°$ for this reaction at 20°C?

a. –79.31 kJ/mol
b. –77.73 kJ/mol
c. $–2.324 \times 10^4$ kJ/mol
d. 79.31 kJ/mol
e. –1638 kJ/mol

FREE ENERGY, ENTROPY, ENTHALPY, EQUILIBRIUM, and TEMPERATURE

27. A reaction is at equilibrium at a given temperature and constant pressure when _____

a. $\Delta S_{rxn} = 0$.
b. $\Delta S = 0$.
c. $\Delta G_{rxn} = 0$.
d. $\Delta G = 0$.
e. $\Delta H_{rxn} = 0$.

28. Which of the following statements about equilibrium are true?

I. $\Delta G_{sys} = 0$
II. $\Delta S_{sys} = 0$
III. $\Delta S_{universe} = 0$

a. I only
b. II only
c. III only
d. Both I and II
e. Both I and III

29. A reaction with a low enthalpy of reaction value is not spontaneous at low temperature but becomes spontaneous at high temperature. What are the signs for $\Delta H°$ and $\Delta S°$, respectively?

a. +, –
b. –, –
c. –, +
d. +, +
e. Insufficient data is provided to answer this question.

30. The **enthalpy** of fusion for benzene (C_6H_6, 78.0 g/mol) is 127.40 kJ/kg, and **its melting point** is 5.5°C. What is the **entropy change** when 1 mole of benzene melts at 5.5°C?

a. 9.95 kJ/K
b. 35.7 J/K
c. 1809 J/K
d. 1.81 J/K
e. 127.40 kJ/K

31. The **entropy** of vaporization of water is 109.0 J/mol · K. What is the **enthalpy** of vaporization of water at its normal boiling point of 100°C?

a. +10.90 kJ/mol
b. –40.66 kJ/mol
c. +3.42 kJ/mol
d. +40.66 kJ/mol
e. –10.90 kJ/mol

32. The **enthalpy and entropy** of vaporization of ethanol are 38.6 kJ/mol and 109.8 J/mol · K, respectively. **What is the boiling point** of ethanol, in °C?

a. 352°C
b. 78.5°C
c. 2.84°C
d. 624°C
e. Not enough information is given to answer the question.

33. Dinitrogen tetroxide (N_2O_4) decomposes to nitrogen dioxide (NO_2). If $\Delta H° = 58.02$ kJ/mol and $\Delta S° = 176.1$ J/mol · K, at what temperature are reactants and products in their standard states at equilibrium?

a. +56.5°C
b. +329.5°C
c. –272.7°C
d. +25.0°C
e. +98.3°C

General Chemistry II Jasperse ANSWERS
Entropy, Spontaneity, and Free Energy. Extra Practice Problems

1. A	21. B
2. A	22. C
3. D	23. A
4. C	24. B
5. D	25. C
6. A	26. A
7. B	27. C
8. C	28. E
9. D	29. D
10. A	30. B
11. C	31. D
12. A	32. B
13. C	33. A
14. A	
15. B	
16. C	
17. D	
18. B	
19. E	
20. D	