Instructions:
1. This exam consists of 25 questions.
2. No scratch paper is allowed. You may do the work in the test margins and on the backs of the test pages.
3. Mark the answers you choose on the test itself for your own information and also on the standard answer sheet you provided. Scoring will be based on the answer sheet.
4. When you finish, turn in both the test form and the answer form. The test form and your personal report will be returned to you at the next class. Write your name on both forms.

Useful Information: 

\[ R = 0.08206 \text{ L atm/mol K} = 8.314 \text{ J/mol K} \]
\[ 1 \text{ atm} = 760 \text{ mm Hg} \]

1. Which of the choices below, when added to 50.0 mL of 0.10 M hydrocyanic acid, HCN, will cause the pH of the solution increase?

- I. 10.0 mL of 0.50 M HCN
- II. 10.0 mL of 0.10 M NaCN
- III. 10.0 mL of 0.10 M HNO\(_3\)
- IV. 10.0 mL of 0.10 M KOH

a) IV only
b) I and III
c) I and II
d) I, II and IV
e) II and IV
2. Which of the following will give a buffer solution when equal volumes of the two solutions are mixed?

   I. 0.10 M HNO₃ and 0.10 M NaNO₃
   II. 0.10 M HCN and 0.10 M NaCN
   III. 0.10 M HCl and 0.10 M NaCN
   IV. 0.05 M NaOH and 0.10 M HCN
   V. 0.20 M NaOH and 0.10 M HCN

   a) I and II
   b) II and IV
   c) II only
   d) II, III, and IV
   e) I, II, III, IV, and V

3. A buffer is prepared by adding 125.0 mL of 0.100 M HCN to 100.0 mL of 0.200 M NaCN. What is the pH of this buffer? (Kₐ for HCN is 4.9 x 10⁻¹⁰.)

   a) 9.31
   b) 9.61
   c) 9.01
   d) 9.11
   e) 9.51

4. 100.0 mL of a buffer which is 0.10 M in HCN and 0.10 M in KCN has 20.0 mL of 0.10 M HCl added to it. What is the pH after the HCl has been added? (Kₐ = 4.9 x 10⁻¹⁰ for HCN)

   a) 9.31
   b) 9.49
   c) 9.01
   d) 9.13
   e) 8.36

5. A 50.0 mL sample of 0.200 M HBr solution is titrated with 0.100 M NaOH. What is the pH of the solution after adding 80.0 mL of base?

   a) 2.69
   b) 5.60
   c) 1.65
   d) 1.81
   e) 1.53

6. Consider the titration of 25.00 mL of 0.150 M acetic acid (HC₂H₃O₂, Kₐ = 1.8 x 10⁻⁵) with 0.100 M NaOH. What is the pH after the addition of 30.00 mL of NaOH?

   a) 5.35
   b) 4.74
   c) 4.14
   d) 4.65
   e) 4.57
7. Consider the titration of 40.00 mL of 0.100 M NH₃ with 0.250 M HCl. What is the pH at the equivalence point? (Kₘ for NH₃ is 1.8 x 10⁻⁵.)

a) 4.63  
b) 5.20  
c) 4.74  
d) 7.00  
e) 4.93

8. What is the Kₛₛ expression for Ca₃(PO₄)₂?

a) Kₛₛ = [Ca²⁺][PO₄³⁻]³/[Ca₃(PO₄)₂]  
b) Kₛₛ = [Ca²⁺][PO₄³⁻]²  
c) Kₛₛ = [Ca₃(PO₄)₂]/[Ca²⁺][PO₄³⁻]  
d) Kₛₛ = (3[Ca²⁺][PO₄³⁻])²  
e) Kₛₛ = [Ca³⁺][PO₄³⁻]²

9. At 25°C, a certain saturated solution of silver phosphate, Ag₃PO₄, has the following concentration of ions:
   [Ag⁺] = 3.0 x 10⁻⁴ M
   [PO₄³⁻] = 6.7 x 10⁻⁵ M
   What is the value of Kₛₛ for silver phosphate at 25°C?

a) 4.9 x 10⁻¹⁷  
b) 6.0 x 10⁻¹⁴  
c) 2.0 x 10⁻⁸  
d) 1.8 x 10⁻¹⁸  
e) 6.0 x 10⁻⁹

10. The solubility of calcium phosphate, Ca₃(PO₄)₂, is 1.6 x 10⁻⁷ moles per liter at 25°C. What is the solubility product constant, Kₛₛ, for calcium phosphate at 25°C?

a) 2.8 x 10⁻¹²  
b) 6.3 x 10⁻⁴  
c) 1.5 x 10⁻¹³  
d) 4.4 x 10⁻¹⁹  
e) 1.1 x 10⁻³²

11. What is the molar solubility of strontium fluoride, SrF₂, in pure water at 25°C? (Kₛₛ for SrF₂ = 7.9 x 10⁻¹⁰ at 25°C.)

a) 7.3 x 10⁻⁴  
b) 9.2 x 10⁻⁴  
c) 2.0 x 10⁻⁵  
d) 2.3 x 10⁻⁴  
e) 5.8 x 10⁻⁴
12. What is the molar solubility of CaF$_2$ in 0.050 M NaF?  
(\(K_{sp}\) for CaF$_2$ is 3.9 \(\times\) 10\(^{-11}\).) 

a) 3.9 \(\times\) 10\(^{-9}\)  
b) 1.6 \(\times\) 10\(^{8}\)  
c) 1.4 \(\times\) 10\(^{-5}\)  
d) 7.8 \(\times\) 10\(^{-10}\)  
e) 2.8 \(\times\) 10\(^{-5}\)

13. \(K_{sp}\) for silver sulfate, Ag$_2$SO$_4$, is 1.2 \(\times\) 10\(^{-5}\). If 100 mL of 0.080 M AgNO$_3$ is added to 100 mL of 0.015 M K$_2$SO$_4$, which statement best describes what happens to the resulting solution? 

a) The solution is supersaturated, and a precipitate will form.  
b) The solution is supersaturated, but a precipitate will not form.  
c) The solution is saturated, and no precipitate will form.  
d) The solution is unsaturated, and no precipitate will form.

14. Which of the ionic solids below will become more soluble as the pH is lowered?  

I. AgBr  
II. PbCl$_2$  
III. Mg(OH)$_2$  
IV. ZnS  

a) III only  
b) I and II  
c) III and IV  
d) I, II, and IV  
e) I, III, and IV

15. Which of the following statements is true?  

a) In any spontaneous process, the entropy of the system always increases.  
b) All spontaneous processes are exothermic.  
c) In order for a process to be spontaneous, the process must be exothermic and the entropy of the system must increase.  
d) In any spontaneous process, the total entropy of the universe always increases.  
e) All of these statements are true.

16. Consider the following processes:  

I. \(\text{N}_2\text{O}_4(g) \rightleftharpoons 2 \text{NO}_2(g)\)  
II. \(\text{C}_6\text{H}_6(g) + 5 \text{O}_2(g) \rightleftharpoons 3 \text{CO}_2(g) + 4 \text{H}_2\text{O}(l)\)  
III. \(\text{H}_2\text{O}(g) \rightleftharpoons \text{H}_2\text{O}(l)\)  

Which of these processes have a positive value for \(\Delta S\)?  

a) I only  
b) I and II  
c) I and III  
d) I, II, and III  
e) II and III
17. Consider the following reaction, which is spontaneous at room temperature:

\[ \text{NH}_3(g) + \text{BF}_3(g) \rightleftharpoons \text{H}_3\text{NBF}_3(s) \]

Which of the following statements must be true of this reaction?

a) \( \Delta H < 0 \)

b) \( \Delta H > 0 \)

c) \( \Delta G > 0 \) at all temperatures

d) \( \Delta G < 0 \) at all temperatures

e) choices (a) and (d) are both correct.

18. Consider the following thermochemical equation:

\[ \text{Cl}_2(g) + \text{C}_2\text{H}_4(g) \rightleftharpoons \text{C}_2\text{H}_4\text{Cl}_2(l) \quad \Delta H^\circ = -217.5 \text{ kJ} \]

Based upon a consideration of the entropy change and the Gibbs free energy change, when is this reaction expected to be spontaneous?

a) spontaneous only at low temperatures

b) spontaneous only at high temperatures

c) spontaneous at all temperatures

d) not spontaneous at any temperature

e) not enough information is given

19. Solid carbon dioxide is commonly known as dry ice. What are the signs of \( \Delta G \), \( \Delta H \), and \( \Delta S \) for the sublimation of dry ice at 25°C?

\[ \Delta G \quad \Delta H \quad \Delta S \]

a) - + -

b) + - -

c) + + +

d) - - +

e) - + +

20. The enthalpy of vaporization of benzene is +30.8 kJ/mol at its boiling point of 80.0°C. What is the \( \Delta S^\circ \) of vaporization of benzene at its boiling point and 1.0 atm pressure?

a) + 11.5 J/mol·K

b) + 0.385 J/mol·K

c) + 385 J/mol·K

d) + 87.3 J/mol·K

e) - 11.5 J/mol·K

21. Use the thermodynamic data below to determine the standard free energy change, \( \Delta G^\circ \), for the following reaction at 25°C.

\[ \text{K(s) + 1/2 Cl}_2(g) \rightarrow \text{KCl(s)} \quad \Delta H^\circ = -435.9 \text{ kJ} \]

The standard molar enthalpies of these substances are as follows:

\[ \begin{align*}
\text{K(s)} & : S^\circ = 64.67 \text{ J/mol·K} \\
\text{Cl}_2(g) & : S^\circ = 222.96 \text{ J/mol·K} \\
\text{KCl(s)} & : S^\circ = 82.7 \text{ J/mol·K}
\end{align*} \]

\[ \begin{align*}
a) & : -473 \text{ kJ} \\
b) & : -408 \text{ kJ} \\
c) & : 27.4 \text{ kJ} \\
d) & : -375 \text{ kJ} \\
e) & : -496 \text{ kJ}
\end{align*} \]
22. What is the standard free energy change, $\Delta G^\circ$, at 25°C for the reaction

$$2\text{NO}(g) + \text{O}_2(g) \rightarrow 2\text{NO}_2(g)$$

given these thermodynamic values:
$\Delta G^\circ_f$ for NO(g) = +86.55 kJ/mol
$\Delta G^\circ_f$ for NO$_2$(g) = +51.31 kJ/mol

a) -35.24 kJ  
b) +35.24 kJ  
c) -70.48 kJ  
d) +70.48 kJ  
e) -140 kJ

23. Consider the following reaction:

$$\text{H}_2(g) + \text{Cl}_2(g) \xrightarrow{\text{catalyst}} 2\text{HCl}(g) \quad \Delta G^\circ = -190.0 \text{ kJ at 25°C}$$

What is the value of $\Delta G$ at 25°C when each gas is at the partial pressure specified below?

- 0.50 atm H$_2$(g)
- 0.50 atm Cl$_2$(g)
- 10.0 atm HCl(g)

a) -159 kJ  
b) -175 kJ  
c) -183 kJ  
d) -205 kJ  
e) -197 kJ

24. The standard enthalpy of formation of ammonia, NH$_3$(g), is given below:

$$\Delta G^\circ_f = -16.66 \text{ kJ/mol at 25°C for NH}_3(g)$$

What is the equilibrium constant at 25°C for the reaction shown?

$$\text{N}_2(g) + 3\text{H}_2(g) \xrightarrow{\text{catalyst}} 2\text{NH}_3(g) \quad K = ????$$

*Hint: Don’t just blindly plug in numbers. Think about this!*

a) $6.9 \times 10^5$  
b) $4.7 \times 10^4$  
c) $8.3 \times 10^2$  
d) 1.0  
e) $1.4 \times 10^{-6}$

25. What is the significance of the third law of thermodynamics? **Choose the one best answer.**

a) The absolute entropy of a substance decreases with increasing temperature.  
b) The entropy of the universe must increase for any spontaneous process.  
c) The absolute value of entropy can be measured for some very pure substances.  
d) The change in entropy of the universe equals the sum of the change in entropy of the system plus the change in entropy of the surroundings.  
e) Energy is conserved.

**Answers**

1. e  6. a  11. e  16. a  21. b  
2. b  7. b  12. b  17. a  22. c  
3. e  8. b  13. c  18. a  23. b  
5. d  10. e  15. d  20. d  25. c