YOU MUST:
Put your name and student ID on the bubble sheet correctly.
Put the exam number on the bubble sheet on the upper left side above the word “NAME”. This is exam 2B.
Put all your answers on the bubble sheet.
Please sign the statement on the last page of the exam.

Please make sure your exam has 7 pages (plus this one and the reference page at the back).
Please keep your eyes on your own paper and your answers covered.
Use the exam as scratch paper. We will not grade anything on the exam itself.
Turn in both the exam and bubble sheet when you are done. Good luck!
1. (3 points) For a reversible reaction at the equilibrium
   a) The concentration of reactants equals the concentration of products.
   b) The rates of the forward and reverse reactions are equal to zero.
   c) The forward and reverse reactions still occur.
   d) The value of $Q = K$ only for reactions in the gas phase.
   e) None of the above.

2. (2 points) In the following reaction
   \[ \text{HCO}_3^-(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{CO}_3^{2-}(aq) + \text{H}_3\text{O}^+(aq) \]
   a) HCO$_3^-$ is an acid and H$_2$O is its conjugate base.
   b) H$_2$O is an acid and CO$_3^{2-}$ is its conjugate base.
   c) H$_3$O$^+$ is an acid and HCO$_3^-$ is its conjugate base.
   d) HCO$_3^-$ is an acid and CO$_3^{2-}$ is its conjugate base.
   e) H$_3$O$^+$ is an acid and CO$_3^{2-}$ is its conjugate base.

3. (2 points) Acids that do not ionize extensively in solution are referred to as
   a) non-dissociators.
   b) Brønsted-Lowry acids.
   c) Arrhenius acids.
   d) weak acids.
   e) strong electrolytes.

4. (2 points) An acid with a large $K_a$
   a) is a strong electrolyte.
   b) is an electron pair-donor.
   c) is a proton acceptor.
   d) slightly increases the H$_3$O$^+$ concentration in an aqueous solution.
   e) none of the above.

5. (4 points) What variables give you a linear plot that will tell you the activation energy of a reaction?
   a) rate constant $k$ vs temperature
   b) ln (rate constant $k$) vs 1/temperature
   c) ln (rate constant $k$) vs temperature
   d) rate constant $k$ vs 1/temperature
   e) None of the above

6. (3 points) The conjugate acid of HSO$_4^-$ is ________.
   a) OH$^-$   b) SO$_4^{2-}$   c) H$_2$O   d) H$_2$SO$_4$   e) H$_3$O$^+$

7. (3 points) If we dissolve NH$_4$Cl (NH$_4^+$ $K_a = 5.6 \times 10^{-10}$) in water, the pH of the solution is:
   a) lower than 7  b) equal to 7  c) higher than 7  d) 9.25  e) cannot tell
8. (3 points) If the following reaction $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons \text{NH}_3(\text{g})$ is at equilibrium in a 2 L container, an increase in pressure at constant temperature will
   a) not affect the equilibrium concentrations.
   b) increase the $\text{N}_2$ concentration.
   c) **increase the $\text{NH}_3$ concentration.**
   d) increase the concentration of the three compounds.
   e) none of the above.

9. (2 points) If $Q < K$ for the following reaction $2\text{A} + \text{B} \rightleftharpoons 3\text{C}$, in order to reach the equilibrium
   a) more reactants are produced
   b) the concentration of A increases two fold
   c) the concentration of C decreases by 1/3
   d) **more C is produced**
   e) none of the above

10. (4 points) At 25 °C, what is the $\text{H}_3\text{O}^+$ concentration in 0.044 M NaOH(aq)? ($K_w = 1.0 \times 10^{-14}$)
    a) $2.3 \times 10^{-13}$ M
    b) $4.4 \times 10^{-16}$ M
    c) $4.4 \times 10^{-7}$ M
    d) 1.36 M
    e) 12.6 M

11. (4 points) At 50 °C, the water ionization constant, $K_w$, is $5.5 \times 10^{-14}$. What is the $\text{H}_3\text{O}^+$ concentration in neutral water at this temperature?
    a) $5.5 \times 10^{-28}$ M
    b) **$2.3 \times 10^{-7}$ M**
    c) $4.3 \times 10^{-8}$ M
    d) $8.5 \times 10^{-7}$ M
    e) 5.5 M

12. (4 points) Which salt forms a 0.10 M aqueous solution with the lowest pH?
    a) MgCO$_3$
    b) NaCl
    c) NaF
    d) K$_3$PO$_4$
    e) NH$_4$Cl
13. (4 points) Assuming equal initial concentrations of the given species, which of the following is the weakest acid in an aqueous solution?
   a) benzoic acid, $K_a = 6.3 \times 10^{-5}$
   b) formic acid, $K_a = 1.8 \times 10^{-4}$
   c) hydrogen phosphate ion, $K_a = 3.6 \times 10^{-13}$
   d) hydrogen sulfite ion, $K_a = 6.2 \times 10^{-8}$
   e) nitrous acid, $K_a = 4.5 \times 10^{-4}$

14. (4 points) What is the relationship between $K_p$ and $K_c$ for the reaction below?

$$\text{CS}_2(\text{g}) + 3 \text{Cl}_2(\text{g}) \rightleftharpoons \text{S}_2\text{Cl}_2(\text{g}) + \text{CCl}_4(\text{g})$$

a) $K_c = \frac{K_p}{(RT)^2}$

b) $K_c = \frac{(RT)^2}{K_p}$

c) $K_c = \left(\frac{RT}{K_p}\right)^2$

d) $K_c = (RT)^2 K_p$ correct answer

e) $K_c = \left(\frac{K_p}{RT}\right)^2$

15. (3 points) Which of the following chemical equations corresponds to the acid ionization constant, $K_a$, for formic acid (HCO$_2$H)?
   a) HCO$_2^-$ + H$_3$O$^+$ $\rightleftharpoons$ HCO$_2$H + H$_2$O
   b) HCO$_2$H + H$_3$O$^+$ $\rightleftharpoons$ HCO$_2$H$_2^+$ + H$_2$O
   c) HCO$_2^-$ + H$_2$O $\rightleftharpoons$ HCO$_2$H + OH$^-$
   d) HCO$_2$H + H$_2$O $\rightleftharpoons$ HCO$_2$H + H$_3$O$^+$
   e) HCO$_2$H + OH$^-$ $\rightleftharpoons$ HCO$_2^-$ + H$_2$O

16. (5 points) Given a solution of 0.10 M NH$_3$(aq), what is the effect of adding NH$_4$Cl(s) to this solution?
   1. The pH will decrease.
   2. The concentration of NH$_3$ will increase.
   3. The concentration of H$_3$O$^-$ will increase.
   a) 1, 2, and 3
   b) 1 and 3
   c) 3 only
   d) 2 only
   e) 1 only
17. (3 points) What is the $\text{H}_3\text{O}^+$ concentration of an aqueous solution with a pH of 12.17?  
   a) $1.5 \times 10^{-2}$ M  
   b) $1.9 \times 10^{-9}$ M  
   c) $5.2 \times 10^{-6}$ M  
   d) $6.8 \times 10^{-13}$ M  
   e) 1.1 M

18. (6 points) The pH of aqueous 0.050 M trimethylamine $\{(\text{CH}_3)_3\text{N}\}$ is 11.24. What is the $K_b$ of this base?  
   a) $6.6 \times 10^{-22}$  
   b) $6.3 \times 10^{-5}$  
   c) $5.8 \times 10^{-12}$  
   d) $1.7 \times 10^{-3}$  
   e) 2.76

19. (6 points) What is the $\text{H}_3\text{O}^+$ concentration in 0.45 M HCN(aq)? ($K_a$ of HCN = $4.0 \times 10^{-10}$)  
   a) $4.0 \times 10^{-10}$ M  
   b) $1.8 \times 10^{-10}$ M  
   c) 0.45 M  
   d) $2.0 \times 10^{-5}$ M  
   e) $1.3 \times 10^{-5}$ M
20. (4 points) Propanoic acid (CH₃CH₂CO₂H) has a $pK_a$ value of 4.89. What is the value of $K_b$ for sodium propanoate (Na CH₃CH₂CO₂)?

- a) $7.8 \times 10^{-10}$
- b) $1.3 \times 10^{-5}$
- c) $1.3 \times 10^{-19}$
- d) -9.11
- e) 9.11

21. (4 points) Write a balanced chemical equation which corresponds to the following equilibrium constant expression.

\[ K = [\text{Fe}^{3+}][\text{OH}^-]^3 \]

- a) $\text{FeOH}^2^+(s) \rightleftharpoons \text{Fe}^{3+}(aq) + \text{OH}^-(aq)$
- b) $3 \text{ Fe}^{3+}(aq) + 3 \text{ OH}^-(aq) \rightleftharpoons 3 \text{ Fe(OH)}_3(aq)$
- c) $\text{Fe(OH)}_3(aq) \rightleftharpoons \text{Fe}^{3+}(aq) + 3 \text{ OH}^-(aq)$
- d) $\text{Fe}^{3+}(aq) + 3 \text{ OH}^-(aq) \rightleftharpoons 3 \text{ Fe(OH)}_3(s)$
- e) $\text{Fe(OH)}_3(s) \rightleftharpoons \text{Fe}^{3+}(aq) + 3 \text{ OH}^-(aq)$

22. (3 points) Which of the following statements are CORRECT?

1. For gas phase equilibria, the partial pressures of reactants and products are equal.
2. For a chemical system at equilibrium, the forward and reverse rates of reaction are equal.
3. For an aqueous chemical system at equilibrium, the concentrations of products divided by the concentrations of reactants equals one.

- a) 1, 2, and 3
- b) 1 and 2
- c) 1 only
- d) 2 only
- e) 3 only

23. (4 points) Which of the following solutions is NOT a buffer?

- a) 0.10 M NaF + 0.05 M HF
- b) 0.10 M NaCl + 0.05 M HCl
- c) 0.10 M KCH₃CO₂ + 0.05 M CH₃CO₂H
- d) 0.10 M NH₃ + 0.05 M NH₄Cl
- e) all the above are buffers

24. (6 points) A 4.00 L flask is filled with 0.75 mol SO₃, 2.50 mol SO₂, and 1.30 mol O₂. Predict the effect on the concentrations of SO₃ as equilibrium is achieved by using $Q$, the reaction quotient. Assume the temperature of the mixture is chosen so that $K_c = 12$.

\[ 2 \text{ SO}_3(g) \rightleftharpoons 2 \text{ SO}_2(g) + \text{ O}_2(g) \]

- a) $[\text{SO}_3]$ will decrease because $Q > K$.
- b) $[\text{SO}_3]$ will increase because $Q < K$.
- c) $[\text{SO}_3]$ will increase because $Q > K$.
- d) $[\text{SO}_3]$ will decrease because $Q < K$.
- e) $[\text{SO}_3]$ will remain the same because $Q = K$. 

5
25. (6 points) If the rate constant $k$ for a reaction goes from 10/sec to 30/sec when a reaction goes from 300K to 310K, what is the activation energy of the reaction?
   a) $9.82 \times 10^{-7}$ kJ/mole  
   b) $8.49 \times 10^{4}$ kJ/mole  
   c) 232 kJ/mole  
   **d) 84.9 kJ/mole**  
   e) None of the above

26. (6 points) The equilibrium constant, $K_c$, for the following reaction is $1.0 \times 10^{-5}$ at 1500 K.
   \[ \ce{N_2(g) + O_2(g) <=> 2 NO(g)} \]
   If 0.750 M $\ce{N_2}$ and 0.750 M $\ce{O_2}$ are allowed to equilibrate at 1500 K, what is the final concentration of NO?
   a) $6.7 \times 10^{-4}$ M  
   b) $1.2 \times 10^{-3}$ M  
   c) $5.5 \times 10^{-3}$ M  
   d) $2.7 \times 10^{-3}$ M  
   **e) 2.4 $\times 10^{-3}$ M**
Extra points:

27. (4 points) The thermochemical equation for the formation of ammonia from elemental nitrogen and hydrogen is as follows.

\[ \text{N}_2(g) + 3 \text{H}_2(g) \rightleftharpoons 2 \text{NH}_3(g) \quad \Delta H = -92.2 \text{ kJ} \]

Which of the following will drive the equilibrium system to the right?

a) adding \( \text{NH}_3(g) \)
b) adding \( \text{H}_2(g) \)
c) increasing the volume of the reaction vessel
d) increasing the temperature
e) removing \( \text{N}_2(g) \)

28. (6 points) Given the following acid dissociation constants,

\[ K_a (\text{HF}) = 7.2 \times 10^{-4} \]
\[ K_a (\text{NH}_4^+) = 5.6 \times 10^{-10} \]

determine the equilibrium constant for the reaction below at 25 °C.

\[ \text{HF}(aq) + \text{NH}_3(aq) \rightleftharpoons \text{NH}_4^+(aq) + \text{F}^-(aq) \]

a) \( 4.0 \times 10^{-13} \)  b) \( 1.3 \times 10^{-8} \)  c) \( 7.8 \times 10^{-7} \)  d) \( 1.3 \times 10^6 \)  e) \( 2.5 \times 10^{12} \)

Please sign the following statement at the completion of the exam:

I did not cheat on this exam. _______________________________(name)

_______________________________(signature)
### Periodic Table of the Elements

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| Rb | Sr | Y  | Zr | Nb | Mo | Tc | Ru | Rh | Pd | Ag | Cd | In | Sn | Sb | Te | I  | Xe |
| 85.47 | 87.62 | 88.91 | 91.22 | 92.91 | 95.94 | 99.90 | 101.1 | 102.9 | 106.4 | 107.9 | 112.4 | 114.8 | 118.7 | 121.8 | 127.6 | 126.9 | 131.3 |

| 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Cs | Ba | La | Hf | Ta | W  | Re | Os | Ir | Pt | Au | Hg | Tl | Pb | Bi | Po | At | Rn |
| 132.9 | 137.3 | 138.9 | 178.5 | 181.0 | 183.8 | 186.2 | 190.2 | 192.2 | 195.1 | 197.0 | 200.6 | 204.4 | 207.2 | 209.0 | 209 (210) | (222) |

| 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Fr | Ra | Ac | Unq | Unp | Unh | Unh | Unh | Uno | Uno | Uno | Uno | Uno | Uno | Uno | Uno | Uno | Uno |
| 223 | 226.0 | 227.0 | (261) | (262) | (263) | (262) | (262) | (265) | (265) | (266) |

### Useful Information:

- **P. V = n . R . T**
- **K_w = 1 × 10^{-14}, 25 °C**
- **1 atm = 760 mm Hg**

- **a.x^2+b.x+c = 0**
  \[ x = [-b ± sqrt(b^2-4.a .c)]/(2.a) \]
  - Room Temperature = 25°C = 298K

- **pX = -log X**
  \[ \ln(k_2/k_1) = (-E_a/R)(1/T_2-1/T_1) \]
  - **T (°C) + 273 = T (K)**

- **pH = pK_a + log ([Conjugate Base]/[acid])**
  \[ pK_w = pH + pOH \]
  - **R = 8.31 \times 10^{-3} kJ/(mol K) = 0.0821 (L atm)/(mol K)**

- **pK_w = pK_a + pK_b**