Answer the first twenty questions on your Scantron sheet. Be sure to include your name on both the Scantron and this test paper. Include your form letter (A or B) on the Scantron. Multiple choice questions are worth two points each.

1. An increase in temperature causes the rate of a reaction to increase because:
   (16 of 30 correct)
   a. the activation energy is lowered
   b. reactant molecules collide less frequently
   c. reactant molecules collide less frequently and with greater energy per collision
   d. **reactant molecules collide with greater energy per collision**
      (**collide more frequently and with more energy**)
   e. reactant molecules collide more frequently and with less energy per collision

2. In the Arrhenius equation \( k = Ae^{\frac{-E_a}{RT}} \) the activation energy is represented by:
   (28 of 30 correct)
   a. \( k \)
   b. \( A \)
   c. \( E_a \)
   d. \( R \)
   e. \( T \)

3. In the Arrhenius equation (question 3), the units for \( k \) will be:
   (7 of 30 correct)
   a. \( s^{-1} \)
   b. \( Ms^{-1} \)
   c. \( M^{-1}s^{-1} \)
   d. **the same as \( A \)**
   e. the same as \( R \)

4. Consider a hypothetical reaction: \( A(g) \rightleftharpoons 2 B (g) \). Which of the following statements will be true when the system is at equilibrium?
   (14 of 30 correct)
   a. \([A] = [B]\)
   b. \(2[A] = [B]\)
   c. \([A] = 2[B]\)
   d. the rate of formation of \( A \) is twice that of \( B \)
   e. **the rates of the forward and reverse reactions are equal.**
5. The relationship between the equilibrium constant, $K_c$, and the forward rate constant ($k_f$) and the reverse rate constant ($k_r$) is $K_c = \boxed{\frac{k_f}{k_r}}$: 

   (11 of 30 correct)
   
   a. $k_f k_r$
   b. $k_r - k_f$
   c. $k_f + k_r$
   d. $k_f/k_r$
   e. $k_r/k_f$

6. The value of $K_c$ for the reaction below at a particular temperature is 0.25.

   \[
   \text{SO}_2 \text{(g)} + \text{NO}_2 \text{(g)} \rightleftharpoons \text{SO}_3 \text{(g)} + \text{NO} \text{(g)}
   \]

   What is the value of $K_c$ for the reaction:

   \[
   2 \text{SO}_3 \text{(g)} + 2 \text{NO} \text{(g)} \rightleftharpoons 2 \text{SO}_2 \text{(g)} + 2 \text{NO}_2 \text{(g)}
   \]

   (13 of 30 correct)
   
   a. 8.0
   b. 0.125
   c. 0.25
   d. 0.50
   e. \textbf{16.0}

7. Which of the following equilibria will shift to the left in response to a decrease in volume?

   (23 of 30 correct)
   
   a. $\text{H}_2 \text{(g)} + \text{Cl}_2 \text{(g)} \rightleftharpoons 2 \text{HCl} \text{(g)}$
   b. $2 \text{SO}_3 \text{(g)} \rightleftharpoons 2 \text{SO}_2 \text{(g)} + \text{O}_2 \text{(g)}$
   c. $\text{N}_2 \text{(g)} + 3 \text{H}_2 \text{(g)} \rightleftharpoons 2 \text{NH}_3 \text{(g)}$
   d. $4 \text{Fe} \text{(s)} + 3 \text{O}_2 \text{(g)} \rightleftharpoons 2 \text{Fe}_2\text{O}_3 \text{(s)}$
   e. $2 \text{HI} \text{(g)} \rightleftharpoons \text{H}_2 \text{(g)} + \text{I}_2 \text{(g)}$

8. Consider the following reaction at equilibrium:

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

   LeChatelier’s principle predicts that an increase in temperature will result in

   (13 of 30 correct)
   
   a. \textit{a decrease in the number of moles of SO}_3\text{ present}
   b. a decrease in the number of moles of SO$_2$ present
   c. an increase in $K_c$
   d. no changes in the pressures of the components of the equilibrium
   e. a decrease in the number of moles of O$_2$ present
9. According to the Arrhenius concept of acids and bases, 
   (18 of 30 correct)
   a. **an acid generates hydrogen ions and a base generates hydroxide ions in water**
   b. an acid donates hydrogen ions and a base accepts hydrogen ions
   c. an acid generates hydrogen ions and a base accepts hydroxide ions in water
   d. an acid accepts hydrogen ions and a base donates hydrogen ions
   e. an acid accepts an electron pair and a base donates an electron pair

10. According to the Bronsted-Lowry concept of acids and bases, 
    (22 of 30 correct)
    a. an acid generates hydrogen ions and a base generates hydroxide ions in water
    b. **an acid donates hydrogen ions and a base accepts hydrogen ions**
    c. an acid generates hydrogen ions and a base accepts hydroxide ions in water
    d. an acid accepts hydrogen ions and a base donates hydrogen ions
    e. an acid accepts an electron pair and a base donates an electron pair

11. The pH of a particular solution is 5.34. Of the following list, which substance is the 
    only one that could produce this solution? 
    (23 of 30 correct)
    a. BaCl₂
    b. NaNO₃
    c. KF
    d. Ca(C₂H₃O₂)₂
    e. **NH₄Cl**

12. The substance Ca(NO₃)₂ in aqueous solution is: 
    (27 of 30 correct)
    a. **a salt, strong electrolyte, and soluble**
    b. a base, strong electrolyte, and soluble
    c. a salt, strong electrolyte, and insoluble
    d. a salt, weak electrolyte, and soluble
    e. a salt, weak electrolyte, and insoluble

13. The substance AgCl in aqueous solution is: 
    (18 of 30 correct)
    a. a salt, strong electrolyte, and soluble
    b. a base, strong electrolyte, and soluble
    c. **a salt, strong electrolyte, and insoluble**
    d. a salt, weak electrolyte, and soluble
    e. a salt, weak electrolyte, and insoluble

14. The substance MnCl₂ in aqueous solution will produce 
    (20 of 30 correct)
    a. **an acidic solution**
    b. a basic solution
    c. a neutral solution
    d. it is not soluble – will not produce a solution

Page 3 of 9
15. When calculating the pH of a solution of KC$_2$H$_3$O$_2$, the equation that represents the equilibrium of most interest is:

(23 of 30 correct)

a. H$_2$C$_2$H$_3$O$_2$ (aq) + HOH (ℓ) ⇌ C$_2$H$_3$O$_2^-$ (aq) + H$_3$O$^+$ (aq)

b. K$^+$ (aq) + HOH (ℓ) ⇌ KOH (aq) + H$^+$ (aq)

c. C$_2$H$_3$O$_2^-$ (aq) + HOH (ℓ) ⇌ HC$_2$H$_3$O$_2$ (aq) + OH$^-$ (aq)

d. K$^+$ (aq) + C$_2$H$_3$O$_2^-$ (aq) ⇌ KC$_2$H$_3$O$_2$ (aq)

---

16. An aqueous solution of 0.1 M HCN will have a pH that is:

(21 of 30 correct)

a. less than 1.0

b. 1.0

c. **greater than 1.0 but less than 7.0**

d. greater than 7.0 but less than 13.0

---

17. An aqueous solution of 0.1 M NaOH will have pH that is:

(11 of 30 correct – my guess is you mostly put 1.0 but this is pH, not pOH)

a. 1.0

b. **13.0**

c. less than 1.0

d. greater than 1.0 but less than 7.0

e. greater than 7.0 but less than 13.0

---

18. Which of the following is the strongest acid?

(22 of 30 correct)

a. H$_2$Se

b. H$_3$As

c. HBr

d. **HI**

e. HCl

---

19. Consider the following equilibrium:

\[ \text{N}_2\text{O}_4 (g) \rightleftharpoons 2 \text{NO}_2 (g) \]

The equilibrium constant, K$_c$, at a particular temperature is 0.211. A vessel is composed initially of 0.25 M NO$_2$ and 0.12 M N$_2$O$_4$. Which of the following will occur?

(20 of 30 correct)

a. More moles of NO$_2$ will be formed

b. **More moles of N$_2$O$_4$ will be formed. (Notice that 0.25$^2$/0.12 is more than 0.211 – has to shift to the right.)**

c. The number of moles of N$_2$O$_4$ and NO$_2$ will remain the same
20. The base-dissociation constant, $K_b$, for pyridine, $C_5H_5N$, is $1.4 \times 10^{-9}$. The acid-dissociation constant, $K_a$, for the pyridinium ion, $C_5H_5NH^+$, is

(25 of 30 correct)

a. $1.0 \times 10^{-7}$
b. $1.4 \times 10^{-23}$
c. $7.1 \times 10^{-4}$
d. $1.4 \times 10^{-5}$
e. $7.1 \times 10^{-6}$

Problems. Show your work on numerical problems to receive credit. Each problem is worth 10 points.

21. a. Give the formula for the conjugate base of each of the following acids.

HCl $Cl^-$
HC$_2$H$_3$O$_2$ $C_2H_5O_2^-$
HCO$_3^-$ $CO_3^{2-}$
NH$_4^+$ $NH_3$

b. Give the formula for the conjugate acid of each of the following bases.

H$_2$O $H_3O^+$
HCO$_3^-$ $H_2CO_3$
NO$_2^-$ $HNO_2$
F$^-$ $HF$

NH$_3$ $NH_4^+$

22. Consider the following equilibrium:

$$H_2 (g) + I_2 (g) \rightleftharpoons 2 HI (g)$$

A vessel is mixed initially with 0.10 M $H_2$, 0.20 M $I_2$, and no HI. After the system comes to equilibrium, the concentration of HI in the vessel is 0.15 M. What are the values of $K_c$ and $K_p$ for this reaction?

\[
K_c = \frac{[HI]^2}{[H_2][I_2]} = \frac{(0.15)^2}{(0.075)(0.125)} = 7.2
\]

Since $K_p = K_c (RT)^{\Delta n}$ and $\Delta n = 0$, $K_p = K_c (RT)^0 = K_c = 7.2$
23. Find the pH, pOH, \([H_3O^+]\), and \([OH^-]\) for each of the following solutions. \(K_a\) and \(K_b\) values are found at the end of this document.

**0.25 M HClO:**

<table>
<thead>
<tr>
<th>HClO (aq) + HOH (l)</th>
<th>=</th>
<th>H_3O^+ (aq)</th>
<th>+</th>
<th>ClO^- (aq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>0.25 M</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Change</td>
<td>-x</td>
<td>+x</td>
<td>+x</td>
<td></td>
</tr>
<tr>
<td>Equilibrium</td>
<td>0.25 - x</td>
<td>+x</td>
<td>+x</td>
<td></td>
</tr>
</tbody>
</table>

\[ K_a = \frac{[H_3O^+][ClO^-]}{[HClO]} \Rightarrow 3.0 \times 10^{-8} \frac{(x)(x)}{0.25 - x} \]

Assume \(0.25 - x \approx 0.25\)

\[3.0 \times 10^{-8} = \frac{x(x)}{0.25} \Rightarrow (3.0 \times 10^{-8})(0.25) = x^2 \Rightarrow x = 8.66 \times 10^{-5} = [H_3O^+]\]

Check assumption – is \(0.25 - 8.66 \times 10^{-5} \approx 0.25\)? Looks good

So, \([H_3O^+] = 8.66 \times 10^{-5} M;\ pH = -\log(8.66 \times 10^{-5}) = 4.06;\)

\(pOH = 14 - 4.06 = 9.94;\ \[OH^-\] = 10^{-9.94} = 1.15 \times 10^{-10} M\)

**0.125 M Ba(NO_2)_2:**

<table>
<thead>
<tr>
<th>NO_2^- (aq) + HOH (l)</th>
<th>=</th>
<th>OH^- (aq)</th>
<th>+</th>
<th>HNO_2 (aq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>0.250 M</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Change</td>
<td>-x</td>
<td>+x</td>
<td>+x</td>
<td></td>
</tr>
<tr>
<td>Equilibrium</td>
<td>0.250 - x</td>
<td>+x</td>
<td>+x</td>
<td></td>
</tr>
</tbody>
</table>

\[ K_b = \frac{[OH^-][HClO]}{[ClO^-]} \Rightarrow 1.0 \times 10^{-14} \frac{(x)(x)}{4.5 \times 10^{-4}} = 2.22 \times 10^{-11} \]

Assume \(0.250 - x \approx 0.250\)

\[2.22 \times 10^{-11} = \frac{x(x)}{0.250} \Rightarrow (2.22 \times 10^{-11})(0.250) = x^2 \Rightarrow x = 2.36 \times 10^{-6} = [OH^-]\]

Check assumption – is \(0.250 - 2.36 \times 10^{-6} \approx 0.250\)? Looks good

So, \([OH^-] = 2.36 \times 10^{-6} M;\ pOH = -\log(2.36 \times 10^{-6}) = 5.627;\)

\(pH = 14 - 5.627 = 8.373;\ \[H_3O^+] = 10^{-8.373} = 4.24 \times 10^{-9} M\)
### 0.095 M HONH$_2$:

<table>
<thead>
<tr>
<th></th>
<th>HONH$_2$ (aq)</th>
<th>+</th>
<th>HOH (l)</th>
<th>=</th>
<th>OH$^-$ (aq)</th>
<th>+</th>
<th>HONH$_3^+$ (aq)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial</strong></td>
<td>0.095 M</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td><strong>Change</strong></td>
<td>-x</td>
<td></td>
<td></td>
<td>+x</td>
<td>+x</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Equilibrium</strong></td>
<td>0.095 – x</td>
<td></td>
<td>+x</td>
<td>+x</td>
<td>+x</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
K_b = \frac{[OH^-][HONH_3^+]}{[HONH_2]} \Rightarrow 1.1 \times 10^{-8} = \frac{(x)(x)}{0.095 - x}
\]

Assume $0.095 - x \approx 0.095$

\[
1.1 \times 10^{-8} = \frac{(x)(x)}{0.095} \Rightarrow (1.1 \times 10^{-8})(0.095) = x^2 \Rightarrow x = 3.23 \times 10^{-5} = [OH^-]
\]

*Check assumption – is $0.095 - 3.23 \times 10^{-5} \approx 0.095$? Looks good*

So, $[OH^-] = 3.23 \times 10^{-5} M$; $pOH = -\log(3.23 \times 10^{-5}) = 4.49$;

\[
pH = 14 - 4.49 = 9.51; \quad [H_3O^+] = 10^{-9.51} = 3.09 \times 10^{-10} M
\]
24. a. A solution is made by dissolving HC$_2$H$_3$O$_2$ in a quantity of water. The pH of the resulting solution is 3.00. What is the concentration of the HC$_2$H$_3$O$_2$?

(\textit{It would have helped if I actually gave you }K_a\textit{ for this one. The omission was not pointed out until the end of the test period. I will just “X” through this one but keep the points in the total test points.})

\[ \text{HC}_2\text{H}_3\text{O}_2 (\text{aq}) + \text{HOH (l)} \rightleftharpoons \text{H}_3\text{O}^+ (\text{aq}) + \text{C}_2\text{H}_3\text{O}_2^- (\text{aq}) \]

Since pH = 3.00, \([\text{H}_3\text{O}^+] = 1 \times 10^{-3} \text{ M}. \) Since the production of each H$_3$O$^+$ also produces One C$_2$H$_3$O$_2^-$, their concentrations are equal.

\[
K_a = \frac{[\text{H}_3\text{O}^+][\text{C}_2\text{H}_3\text{O}_2^-]}{[\text{HC}_2\text{H}_3\text{O}_2]} = 1.8 \times 10^{-5} = \frac{(1 \times 10^{-3})(1 \times 10^{-3})}{[\text{HC}_2\text{H}_3\text{O}_2]} \Rightarrow \\
[\text{HC}_2\text{H}_3\text{O}_2] = \frac{(1 \times 10^{-3})(1 \times 10^{-3})}{1.8 \times 10^{-5}} \Rightarrow [\text{HC}_2\text{H}_3\text{O}_2] = 5.56 \times 10^{-2}
\]

\text{This assumes the dissociation is small compared to the initial concentration – i.e.} \quad .0556 -.001 \approx 0.556 \text{ which doesn’t seem to be a bad assumption.}

b. Phenylacetic acid (HC$_8$H$_7$O$_2$) is one of the substances that accumulates in the blood of people with phenylketonuria, an inherited disorder. A 0.085 M solution of HC$_8$H$_7$O$_2$ is found to have a pH of 2.68. Calculate the $K_a$ for this acid.

\[ \text{HC}_8\text{H}_7\text{O}_2 (\text{aq}) + \text{HOH (l)} \rightleftharpoons \text{H}_3\text{O}^+ (\text{aq}) + \text{C}_8\text{H}_7\text{O}_2^- (\text{aq}) \]

\text{According to the dissociation above, the }[\text{H}_3\text{O}^+] \text{ is equal to the }[\text{HC}_8\text{H}_7\text{O}_2] \text{ since their primary source is the dissociation (the small amount of hydronium from water is insignificant compared to the amount generated through the dissociation.)}

\text{So, }[\text{H}_3\text{O}^+] = [\text{C}_8\text{H}_7\text{O}_2^-] = 10^{-2.68} = 2.09 \times 10^{-3} \text{ M}

\[
K_a = \frac{[\text{H}_3\text{O}^+][\text{C}_8\text{H}_7\text{O}_2^-]}{[\text{HC}_8\text{H}_7\text{O}_2]} \Rightarrow K_a = \frac{(2.09 \times 10^{-3})(2.09 \times 10^{-3})}{(0.085 - 2.09 \times 10^{-3})} = 5.27 \times 10^{-5}
\]
Information Sheet

\[ k = Ae^{-\frac{E_a}{RT}} \]

\( K_a \) for HClO = 3.0 x 10^{-8}

\( K_a \) for HNO₂ = 4.5 x 10^{-4}

\( K_b \) for HONH₂ = 1.1 x 10^{-8}