Chapter 5

Page 265, Practice Problems 5.1.1

1. a) H₂SO₄  acid
b) XeF₆  molecular
c) CH₃COOH  acid
d) NaCH₃COO  salt
e) KOH  base
f) NH₃ molecular (but also a base)

2. a) CH₃COOH  +  LiOH  \rightarrow  LiCH₃COO  +  H₂O  salt
b) 2HI  +  Ca(OH)₂  \rightarrow  2H₂O  +  CaI₂  salt
c) 3Mg(OH)₂  +  2H₃PO₄  \rightarrow  6H₂O  +  Mg₃(PO₄)₂  salt

3.  
<table>
<thead>
<tr>
<th>Parent Acid</th>
<th>Parent Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>KNO₂</td>
<td>HNO₂</td>
</tr>
<tr>
<td>NH₄Cl</td>
<td>HCl</td>
</tr>
<tr>
<td>CuC₂O₄</td>
<td>H₂C₂O₄</td>
</tr>
<tr>
<td>NaCH₃COO</td>
<td>CH₃COOH</td>
</tr>
</tbody>
</table>

Page 268, Practice Problems 5.1.2

1. a) HIO₃  +  NO₂⁻  \leftrightarrow  HNO₂  +  IO₃⁻  acid  base  acid  base
b) HF  +  H₂C₂O₄⁻  \leftrightarrow  H₂C₂O₄⁻  +  F⁻  acid  base  acid  base
c) Al(H₂O)₆³⁺  +  SO₃²⁻  \leftrightarrow  HSO₃⁻  +  Al(H₂O)₅OH²⁺  acid  base  acid  base

2.

<table>
<thead>
<tr>
<th>Conjugate acid</th>
<th>Conjugate base</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O₂</td>
<td>HO₂⁻</td>
</tr>
<tr>
<td>H₂BO₃</td>
<td>H₂BO₃⁻</td>
</tr>
<tr>
<td>HCOOH</td>
<td>HCOO⁻</td>
</tr>
<tr>
<td>H₂C₃H₂O₄²⁻</td>
<td>C₆H₄O₇⁻²</td>
</tr>
</tbody>
</table>

3. a) HNO₂  +  NH₃  \leftrightarrow  NO₂⁻  +  NH₄⁺  acid  base  base  acid  conjugate pairs: HNO₂ / NO₂⁻ and NH₃ / NH₄⁺
b) H₂C₆H₄O₇⁻  +  CN⁻  \leftrightarrow  H₂C₆H₄O₇⁻  +  HCN  acid  base  base  acid  conjugate pairs: H₂C₆H₄O₇⁻ / H₂C₆H₄O₇⁻ and CN⁻ / HCN
c) PO₄³⁻  +  H₂S  \leftrightarrow  HPO₄²⁻  +  HS⁻  base  acid  acid  base  conjugate pairs: HPO₄²⁻ / PO₄³⁻ and H₂S / HS⁻

Page 268, Quick Check

1. HCO₃⁻  +  CN⁻  \leftrightarrow  CO₃²⁻  +  HCN
2. HCO₃⁻  +  H₂O  \leftrightarrow  H₂CO₃  +  OH⁻  base  acid  acid  base
3. b) and e) are amphiprotic

Page 270, 5.1 Review Questions

2. A Hydrogen atom contains 1 proton and 1 electron. When a H⁺ ion is formed, the electron is given away, leaving a single proton.
3. One of the lone pairs of electrons on the oxygen atom of water will attract the H⁺ ion from an acid.

4.

a) NH₃  +  H₃PO₄  \leftrightarrow  NH₄⁺  +  H₂PO₄⁻  base  acid  acid  base
b) H₂PO₄⁻  +  SO₃²⁻  \leftrightarrow  HSO₃⁻  +  HPO₄²⁻  acid  base  acid  base

Conjugate acid  Conjugate base

H₂O₂  HO₂⁻
H₂BO₃  H₂BO₃⁻
HCOOH  HCOO⁻
H₂C₃H₂O₄²⁻  C₆H₄O₇⁻²

C₆H₄O₇⁻²  C₆H₄O₇⁻²
5. 
\[\text{HCOOH} + \text{H}_2\text{O} \leftrightarrow \text{HCOO}^- + \text{H}_3\text{O}^+\]  
Acid  base  base  acid

6. 
\[\text{C}_5\text{H}_5\text{N} + \text{H}_2\text{O} \leftrightarrow \text{C}_5\text{H}_5\text{NH}^+ + \text{OH}^-\]  
Base  acid  acid  base

7. 
\[\text{ClO}^- + \text{NH}_4^+ \leftrightarrow \text{HClO} + \text{NH}_3\]  
Base  acid  acid  base

b) HClO

8. a) Add a H\(^+\) ion. Example: CN\(^-\) becomes HCN  
b) Remove a H\(^+\) ion. Example: HNO\(_2\) becomes NO\(_2\)  
9. a) HO\(_2\)  
b) N\(_3\)H\(_5\)  
c) OC\(_6\)H\(_5\)  
d) C\(_6\)H\(_5\)NH\(_3\)  
10. A substance that is able to act as both an acid or a base depending on the other substance present. Examples: HSO\(_3\), H\(_3\)PO\(_4\), HPO\(_4^{2-}\), H\(_2\)O  
11. a) As an acid: HCO\(_3\) + H\(_2\)O \leftrightarrow CO\(_3^{2-}\) + H\(_2\)O\(^+\); As a base: HCO\(_3^-\) + H\(_2\)O \leftrightarrow H\(_2\)CO\(_3\) + OH\(^-\)  
Use litmus paper to test the solution. If it is acidic, the litmus will turn red. If it is basic, the litmus will turn blue.  
b) As a base. H\(_2\)O and CO\(_2\) can be written as H\(_2\)CO\(_3\).  

Page 275, Quick Check

1. Concentrated acids have a high molarity (ex. 6M acid) whereas a strong acid is one that ionizes completely (ex. HCl). You can have a concentrated weak acid – such as 6 M HF.  
2. HNO\(_3\) is a strong acid so ionizes completely:  
\[\text{HNO}_3(aq) + \text{H}_2\text{O}(l) \rightarrow \text{H}_3\text{O}^+(aq) + \text{NO}_3^-(aq)\]  
1.0 M  1.0 M

CH\(_3\)COOH(aq) + H\(_2\)O(l) \leftrightarrow H\(_3\)O\(^+\) (aq) + CH\(_3\)COO\(^-\) (aq)  
1.0 M  very few  very few

Because both acids are the same concentration, but HNO\(_3\) is strong and CH\(_3\)COOH is weak, the HNO\(_3\) will have more ions in solution.  
3. In 0.1 M NaOH: a bright light  
In 0.1 M NH\(_3\): very dim light or no light visible  
NaOH(aq) \rightarrow Na\(^+(aq) + OH\(^-(aq)\)  
NH\(_3(aq) + H_2O(l) \leftrightarrow NH_4^+(aq) + OH^- (aq)\)  
4. No, Cl\(^-\) will not accept an H\(^+\) ion. HCl is a strong acid and completely ionizes.  

Page 276, Quick Check

1. HF(aq) + H\(_2\)O(l) \leftrightarrow H\(_3\)O\(^+\) (aq) + F\(^-(aq)\)  
\[K_a = \frac{[H_3O^+][F^-]}{[HF]}\]  
2. NaOH is a strong base, which means that it ionizes completely. There is no equilibrium present, so no \(K_b\).  
3. CH\(_3\)CH\(_2\)NH\(_2\) (aq) + H\(_2\)O(l) \leftrightarrow OH\(^-(aq)\) + CH\(_3\)CH\(_2\)NH\(_3^+\)(aq)  
\[K_b = \frac{[OH^-][CH_3CH_2NH_3^+]}{[CH_3CH_2NH_2]^+}\]  
4. Acid: H\(_2\)C\(_2\)O\(_4\) (aq) + H\(_2\)O(l) \leftrightarrow H\(_3\)O\(^+\) (aq) + C\(_2\)O\(_4^{2-}\)(aq)  
\[K_a = \frac{[H_3O^+][C_2O_4^{2-}]}{[H_2C_2O_4]}\]  
Base: H\(_2\)C\(_2\)O\(_4\) (aq) + H\(_2\)O(l) \leftrightarrow OH\(^-(aq)\) + H\(_2\)C\(_2\)O\(_4\) (aq)  
\[K_b = [OH^-][H_2C_2O_4] / [H_2C_2O_4]\]
Page 278, Quick Check
1. a) strong acid
b) strong base
c) weak base
d) weak acid
e) weak base
f) weak acid
2. c) weak base: \( \text{NH}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{NH}_4^+(\text{aq}) + \text{OH}^- (\text{aq}) \)
   \[ K_b = \frac{[\text{NH}_4^+][\text{OH}^-]}{[\text{NH}_3]} \]
d) weak acid: \( \text{C}_6\text{H}_5\text{COOH}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_3\text{O}^+ (\text{aq}) + \text{C}_6\text{H}_5\text{COO}^-(\text{aq}) \)
   \[ K_a = \frac{[\text{H}_3\text{O}^+][\text{C}_6\text{H}_5\text{COO}^-]}{[\text{C}_6\text{H}_5\text{COOH}]} \]
e) weak base: \( \text{CN}^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{HCN}(\text{aq}) + \text{OH}^- (\text{aq}) \)
   \[ K_b = \frac{[\text{HCN}][\text{OH}^-]}{[\text{CN}^-]} \]
f) weak acid: \( \text{HNO}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_3\text{O}^+ (\text{aq}) + \text{NO}_2^- (\text{aq}) \)
   \[ K_a = \frac{[\text{H}_3\text{O}^+][\text{NO}_2^-]}{[\text{HNO}_2]} \]
3. Methanoic acid > carbonic acid > boric acid > phenol
   \[ \text{HCOOH} > \text{H}_2\text{CO}_3 > \text{H}_3\text{BO}_3 > \text{C}_6\text{H}_5\text{OH} \]

Page 281, Quick Check
1. There are more oxygen atoms (which are highly electronegative) attached to the central nitrogen atom - therefore, the O-H bond in Acid 1 is more polarized than in Acid 2 (as 3 oxygen atoms pull electrons away from hydrogen to a greater extent than 2 oxygen atoms do) and hydrogen will be donated more easily in Acid 1. As a result, Acid 1 is stronger than Acid 2.

2. Since the presence of more hydrogen atoms bound to the central atom strengthens the bond between hydrogen and that atom, HBr, HCl, HI > Br > Cl in terms of size. And as the halogen atoms’ size increases, the bond length between the halogen atom and hydrogen increases, so the bond strength decreases, allowing H to be donated more easily and making the acid stronger. Therefore, HI > HBr > HCl in terms of O-H bond and consequently strength.

Page 283, Practice Problems 5.2.1
1a) \( \text{H}_2\text{O}_2 \leftrightarrow \text{H}_2\text{SO}_3 + \text{H}_2\text{O} \); reactants favored
b) \( \text{H}_3\text{C}_6\text{H}_5\text{O}_7 + \text{NH}_3 \rightarrow \text{H}_2\text{C}_6\text{H}_5\text{O}_7^- + \text{NH}_4^+ \); products favored
c) \( \text{HCO}_3^- + \text{H}_3\text{PO}_4^- \rightarrow \text{H}_2\text{CO}_3 + \text{H}_2\text{PO}_4^- \); reactants favored
2. \( \text{H}_3\text{AsO}_4 + \text{SO}_4^{2-} \rightarrow \text{H}_3\text{AsO}_4^- + \text{H}_2\text{SO}_4; \text{H}_2\text{SO}_4 \) is stronger
3. \( \text{SO}_3^{2-} + \text{Cr} (\text{H}_2\text{O})_6^{3+} \rightarrow \text{H}_2\text{SO}_4 + \text{Cr} (\text{H}_2\text{O})_5\text{OH}^{2+} \); products favored so \( K_{eq} > 1 \)

Page 283, 5.2 Review Questions
1. a) strong base
b) weak acid
c) Strong acid
d) weak base
2. \( \text{H}_3\text{BO}_3 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{BO}_3^- + \text{H}_3\text{O}^+ \)
   \[ K_a = \frac{[\text{H}_2\text{BO}_3^-][\text{H}_3\text{O}^+]}{[\text{H}_3\text{BO}_3]} \]
   \( \text{PO}_4^{3-} + \text{H}_2\text{O} \rightarrow \text{HPO}_4^{2-} + \text{OH}^- \)
   \[ K_b = \frac{[\text{HPO}_4^{2-}][\text{OH}^-]}{[\text{PO}_4^{3-}]} \]

Between \( \text{H}_2\text{SO}_4 \) and \( \text{HClO}_4 \), since Cl is more electronegative than \( \text{H}_2\text{SO}_4 \) and pulls electrons away from H more than S does, hydrogen in \( \text{HClO}_4 \) is donated more easily than in \( \text{H}_2\text{SO}_4 \). Therefore, \( \text{HClO}_4 > \text{H}_2\text{SO}_4 \) in terms of acid strength.

For similar reasons, \( \text{H}_2\text{SO}_4 \) is weaker than \( \text{HClO}_4 \) and \( \text{HBrO}_3 \) (since Cl and Br are both electronegative halogens while S is not).

Finally, since Br is less electronegative than Cl, the O-H bond is more polarized in chloric acid than in bromic. This allows hydrogen to be donated more easily. Therefore, \( \text{HBrO}_3 > \text{HClO}_4 > \text{H}_2\text{SO}_4 \). Therefore overall, \( \text{HClO}_4 > \text{H}_2\text{SO}_4 > \text{HBrO}_3 > \text{HClO}_4 > \text{H}_2\text{SO}_4 \).

4. Methanoic acid and benzoic acid have main carbon chain lengths of 1 while ethanoic acid has a carbon chain of length 2. Therefore, ethanoic acid’s O-H bond is the least polarizable. Furthermore, benzoic acid has a huge group of carbon atoms - a benzene ring (phenyl group) - attached to the 1 carbon chain that allows any charge to disperse between the many carbon & hydrogen atoms in the benzene group, so its O-H bond is the less polarizable than that of methanoic acid.

Therefore, methanoic acid > benzoic acid > ethanoic acid in terms of polarity of O-H bond and consequently strength.
3. Both acids have the same concentration. Oxalic acid is a weak acid and hydriodic acid is strong. Conductivity depends on ions in solution. Since hydriodic acid is a strong acid, it will ionize completely. Oxalic acid is weak, so it ionizes to a lesser extent, forming fewer ions in solution.

4. HNO₃ is a strong acid so ionizes completely:

\[
\text{HNO}_3(aq) + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+(aq) + \text{NO}_3^-(aq)
\]

2.0 M 2.0 M total [ion] = 4.0 M

HNO₂ is a weak acid, so does ionize completely.

5. a) 6 M NH₃  
   b) 0.001 M HCl

6. a) water < carbonic acid < citric acid < sulphurous acid < sulphuric acid  
   b) carbonates > ammonia > monohydrogen phosphate > fluoride > nitrite > water

7. HC₆H₅O₇²⁻ + H₂O ⇋ C₆H₅O₇³⁻ + H₃O⁺  
   \( K_a = [\text{C}_6\text{H}_5\text{O}_7^{3-}] / [\text{C}_6\text{H}_5\text{O}_7^{2-}] \)  

   H₂C₆H₅O₇⁻ + H₂O ⇋ HC₆H₅O₇²⁻ + H₃O⁺  
   \( K_a = [\text{C}_6\text{H}_5\text{O}_7^{2-}] / [\text{C}_6\text{H}_5\text{O}_7^{-}] \)  

   Al(H₂O)₆³⁺ + H₂O ⇋ Al(H₂O)₅OH²⁺ + H₃O⁺  
   \( K_a = [\text{Al(H}_2\text{O})_5\text{OH}^{2+}] / [\text{Al(H}_2\text{O})_6^{3+}] \)

   H₂O₂ + H₂O ⇋ HO₂⁻ + H₃O⁺  
   \( K_a = [\text{OH}^{-}] / [\text{H}_2\text{O}_2] \)

8. NH₃ + H₂O ⇋ NH₄⁺ + OH⁻  
   \( K_b = [\text{NH}_4^+] / [\text{NH}_3] [\text{OH}^-] \)

   C₆H₄COO⁻ + H₂O ⇋ C₆H₄COOH + OH⁻  
   \( K_b = [\text{C}_6\text{H}_4\text{COOH}] / [\text{C}_6\text{H}_4\text{COO}^-] \)

   CH₂COO⁻ + H₂O ⇋ CH₃COOH + OH⁻  
   \( K_b = [\text{CH}_3\text{COOH}] / [\text{CH}_2\text{COO}^-] \)

   H₃C₆H₇O₇⁻ + H₂O ⇋ C₆H₅O₇²⁻ + OH⁻  
   \( K_b = [\text{C}_6\text{H}_5\text{O}_7^{-}] / [\text{H}_3\text{C}_6\text{H}_7\text{O}_7] \)

   C₆H₅N + H₂O ⇋ C₆H₅NH⁺ + OH⁻  
   \( K_b = [\text{C}_6\text{H}_5\text{NH}^+] / [\text{C}_6\text{H}_5\text{N}] \)

9. a) Fe(H₂O)₆³⁺(aq) + HO₂⁻(aq) ⇋ H₂O₂ + Fe(H₂O)₅OH²⁺ products  
   b) H₂SO₃(aq) + IO₃⁻(aq) ⇋ HSO₃⁻ + HIO₃ reactants  
   c) CN⁻(aq) + H₂PO₄⁻(aq) ⇋ HCN + HPO₄²⁻ products

10. H₂C₂O₄ + HCO₃⁻ ⇋ H₂CO₃ + HC₂O₄⁻

11. HClO > HBrO > H₂SiO₃

12. All are strong acids so completely ionize in solution to form H₂O⁺:

   HCl + H₂O \rightarrow H₂O⁺ + Cl⁻  
   HBr + H₂O \rightarrow H₂O⁺ + Br⁻  
   HI + H₂O \rightarrow H₂O⁺ + I⁻

Page 290, Quick Check

1. energy + 2H₂O \leftrightarrow H₂O⁺ + OH⁻  
   If temperature increases, equilibrium shifts right and the concentrations of H₂O⁺ and OH⁻ both increase.  
   \( K_w = [\text{H}_2\text{O}^+][\text{OH}^-] \)  
   Therefore, \( K_w \) will increase as well.

2. \([\text{H}_2\text{O}^+] = [\text{OH}^-]\)

3. 5.4 x 10⁻⁸ M = \([\text{H}_2\text{O}^+] = [\text{OH}^-]\)

Page 291, Practice Problems 5.3.1

1. [\text{H}_2\text{O}^+] = 0.15 \text{ M} because HClO₄ is a strong acid; [OH⁻] = 6.67 x 10⁻¹⁴ \text{ M}  
   acidic because [H₂O⁺] > [OH⁻]

2. [OH⁻] = 2 x 10⁻¹⁰ \text{ M}; [H₂O⁺] = 4.5 x 10⁻¹¹ \text{ M}  
   basic because [H₂O⁺] < [OH⁻]

3. [OH⁻] = 0.142 \text{ M}; [H₂O⁺] = 7.04 x 10⁻¹⁴ \text{ M}  
   basic because [H₂O⁺] < [OH⁻]

Page 292, Practice Problems 5.3.2

1. [OH⁻] = 2 x 10⁻¹⁵ \text{ M}
2. 2 g
3. [OH⁻] = 5.32 x 10⁻¹⁴ \text{ M}

Page 294, 5.3 Review Questions

1. NH₃ + NH₃ ⇋ NH₄⁺ + NH₂⁻  
   2. \([\text{H}_3\text{O}^+] / [\text{OH}^-] \)  
   Acidic, basic or neutral?

<table>
<thead>
<tr>
<th>([\text{H}_3\text{O}^+])</th>
<th>[OH⁻]</th>
<th>Acidic, basic or neutral?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.7 x 10⁻¹⁵</td>
<td>6.0 M</td>
<td>basic</td>
</tr>
<tr>
<td>3.2 x 10⁻¹⁴</td>
<td>3.1 x 10⁻¹¹</td>
<td>acidic</td>
</tr>
<tr>
<td>1.1 x 10⁻¹⁴</td>
<td>9.2 x 10⁻¹² M</td>
<td>acidic</td>
</tr>
<tr>
<td>2.5 M</td>
<td>4.0 x 10⁻¹⁵</td>
<td>acidic</td>
</tr>
<tr>
<td>2.1 x 10⁻¹⁰</td>
<td>4.7 x 10⁻⁵ M</td>
<td>basic</td>
</tr>
</tbody>
</table>

3. 57.1 kJ + 2H₂O ⇋ H₂O⁺ + OH⁻  
   As temperature increases, equilibrium shifts right and [H₂O⁺] and [OH⁻] increase, so \( K_w \) increases.

4. [OH⁻] = 5.0 x 10⁻¹⁵ \text{ M}

5. [OH⁻] = 1.6 x 10⁻⁸ \text{ M}  
   acidic because [H₂O⁺] > [OH⁻]
6. Complete the table:

<table>
<thead>
<tr>
<th>Temp</th>
<th>$K_w$</th>
<th>$[H_3O^+]$</th>
<th>$[OH^-]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>50°C</td>
<td>5.5 x 10^{-14}</td>
<td>2.3 x 10^{-5} M</td>
<td>2.3 x 10^{-5} M</td>
</tr>
<tr>
<td>100°C</td>
<td>5.1 x 10^{-13}</td>
<td>7.1 x 10^{-5} M</td>
<td>7.1 x 10^{-5} M</td>
</tr>
</tbody>
</table>

Both are neutral at given temperatures.

7. $K_w = 7.9 \times 10^{-15}$

8. $[OH^-] = 2 \times 0.0211 = 0.0211$ M

9. $[H_3O^+] = 4.7 \times 10^{-12}$ M

10. $[OH^-] = 4.3 \times 10^{-14}$ M

Page 298, Quick Check

1. Solution  | $[H_3O^+]$ | pH  
--- | --- | --- 
Orange Juice | $3.2 \times 10^{-4}$ M | 3.49 
Milk of magnesia | $2.52 \times 10^{-11}$ M | 10.598 
Stomach acid | $0.031$ M | 1.51 

Page 299, Practice Problems 5.4.1

1. $[H_3O^+]$ | No. of sig. digits | pH  
--- | --- | --- 
$5.00 \times 10^{-5}$ M | 3 | 4.301 
$4.6 \times 10^{-5}$ M | 2 | 3.34 
$6.4 \times 10^{-11}$ M | 2 | 10.19 
$8.81 \times 10^{-7}$ M | 3 | 6.055 
$0.00345$ M | 3 | 2.462 

2. Just before the equivalence point was reached: $[H_3O^+] = 4.5 \times 10^{-5}$ M

Just after the equivalence point was reached: $[H_3O^+] = 2.2 \times 10^{-10}$ M

3. Because pH is defined as a negative logarithm, converting a negative pH value to a concentration involves the following: $[H_3O^+] = 16$ M


The pH scale is not necessary to conveniently express concentrations this large.

Page 302, Practice Problems 5.4.2

1. Solution  | $[H_3O^+]$ | $[OH^-]$ | pH  | pOH | Acidic/Basic/Neutral?  
--- | --- | --- | --- | --- | --- 
Orange Juice | $3 \times 10^{-4}$ M | $3 \times 10^{-11}$ M | 3.5 | 10.5 | Acidic 
Tears | $3.98 \times 10^{-8}$ M | $2.51 \times 10^{-7}$ M | 7.40 | 6.60 | Basic 
Blood | $4.0 \times 10^{-6}$ M | $2.5 \times 10^{-7}$ M | 7.40 | 6.60 | Basic 
Milk | $3.16 \times 10^{-7}$ M | $3.16 \times 10^{-8}$ M | 6.500 | 7.500 | Acidic 

2. a) As a solution becomes more acidic, both $[H_3O^+]$ and pOH increase and both $[OH^-]$ and pH decrease.
b) A basic solution has a pOH value which is less than 7, and $[H_3O^+]$ which is greater than $10^{-7}$ M.
c) If the pH of a solution equals 14.0, the $[OH^-]$ equals 1 M. (1 sig. digit)
d) If the pOH of a solution decreases by 5, then the $[H_3O^+]$ has decreased by a factor of $10^5$.

3. We would expect the $K_w$ for water at 10°C to be less than $10^{-14}$ because the autoionization of water is endothermic. Regardless of the temperature, pure water is always neutral and so:

For pure water at any temperature: $[H_3O^+] = [OH^-]$ and $\text{pH} = \text{pOH}$

Therefore, because $\text{pH} + \text{pOH} = \text{pK}_w$, when we calculate the value of $\text{pK}_w$, the pH (and also the pOH) must be half the value of $\text{pK}_w$.

$pK_w = -\log (2.55 \times 10^{15}) = 14.593$  Therefore, $\text{pH} (\text{and pOH}) = 14.5934 = 7.297$
Page 304, Practice Problems 5.4.3
1. 0.86
2. 0.82
3. 2.53
4. 0.0513 g HCl

Page 308, 5.4 Review Questions
1. The pH of a solution is defined as the negative logarithm of the concentration of hydronium ions. Equation: \( \text{pH} = - \log [\text{H}_3\text{O}^+] \)
   The pOH of a solution is defined as the negative logarithm of the concentration of hydroxide ions. Equation: \( \text{pOH} = - \log [\text{OH}^-] \)
   2. Sorenson's logarithmic pH and pOH scales are a convenient and compact way of expressing the typically very small concentrations of hydronium and hydroxide ions respectively and the extent by which they can change in aqueous solutions

<table>
<thead>
<tr>
<th>([\text{H}_3\text{O}^+])</th>
<th>pH</th>
<th>Acidic/Basic/Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.50 x 10^{-6} M</td>
<td>5.456</td>
<td>Acidic</td>
</tr>
<tr>
<td>3.1 x 10^{-12} M</td>
<td>11.51</td>
<td>Basic</td>
</tr>
<tr>
<td>0.00550 M</td>
<td>2.260</td>
<td>Acidic</td>
</tr>
<tr>
<td>1.0 M</td>
<td>0.00</td>
<td>Acidic</td>
</tr>
<tr>
<td>6.8 x 10^{-9} M</td>
<td>8.17</td>
<td>Basic</td>
</tr>
</tbody>
</table>

4. 

<table>
<thead>
<tr>
<th>([\text{OH}^-])</th>
<th>pOH</th>
<th>Acidic/Basic/Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.2 x 10^{-9} M</td>
<td>8.14</td>
<td>Acidic</td>
</tr>
<tr>
<td>2.8 x 10^{-10} M</td>
<td>9.55</td>
<td>Acidic</td>
</tr>
<tr>
<td>4.88 x 10^{-4} M</td>
<td>3.312</td>
<td>Basic</td>
</tr>
<tr>
<td>1.0 x 10^{-14} M</td>
<td>14.00</td>
<td>Acidic</td>
</tr>
<tr>
<td>0.000625 M</td>
<td>3.204</td>
<td>Basic</td>
</tr>
</tbody>
</table>

5. 
   a) As a solution's pOH value and \([\text{H}_3\text{O}^+]\) both decrease, the solution becomes more basic.
   b) As a solution's pH value and \([\text{OH}^-]\) both decrease, the solution becomes more acidic.
   c) The product of the \([\text{H}_3\text{O}^+]\) and \([\text{OH}^-]\) equals \(K_w\).
   d) The sum of pH and pOH equals \(pK_w\).

6. 

<table>
<thead>
<tr>
<th>([\text{H}_3\text{O}^+])</th>
<th>pH</th>
<th>Acidic/Basic/Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0342 M</td>
<td>12.534</td>
<td>Acidic</td>
</tr>
<tr>
<td>2.51 x 10^{-6} M</td>
<td>8.400</td>
<td>Acidic</td>
</tr>
<tr>
<td>7.2 x 10^{-12} M</td>
<td>2.86</td>
<td>Basic</td>
</tr>
<tr>
<td>1.64 x 10^{-11} M</td>
<td>3.215</td>
<td>Basic</td>
</tr>
</tbody>
</table>

7. Pure water is always neutral at any temperature and so pH = pOH.
   Therefore pH = 6.51 (2 sig. digits)

8. pH = 13.78
9. 13.000
10. 0.81 g
11. 

<table>
<thead>
<tr>
<th>([\text{H}_3\text{O}^+])</th>
<th>([\text{OH}^-])</th>
<th>pOH</th>
<th>pH</th>
<th>Acidic/Basic/Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.620 x 10^{-5} M</td>
<td>1.779 x 10^{-10} M</td>
<td>9.7497</td>
<td>4.2503</td>
<td>Acidic</td>
</tr>
<tr>
<td>2.22 x 10^{-11} M</td>
<td>0.000450 M</td>
<td>3.347</td>
<td>10.653</td>
<td>Basic</td>
</tr>
<tr>
<td>3.2 x 10^{-2} M</td>
<td>3.2 x 10^{-13} M</td>
<td>12.50</td>
<td>1.50</td>
<td>Acidic</td>
</tr>
<tr>
<td>3 x 10^{-11} M</td>
<td>3 x 10^{-4} M</td>
<td>3.5</td>
<td>10.5</td>
<td>Basic</td>
</tr>
</tbody>
</table>

12. 0.79
13. 11.8
An alternative approach would be to calculate the total number of moles of hydronium ions from the acid solutions and then subtract that total from the moles of hydroxide ions from the basic solution. The excess moles of hydroxide ions present in the final 100.0 mL are then used to calculate final pH.

Page 314, Quick Check
1. The amount of water that a weak acid will convert to hydronium ions is insignificant compared to the magnitude of water’s concentration (55.6 M). The concentration of water is thus assumed to be constant and so is not included in an ICE table.
2. Because the $K_a$ of a weak acid is normally so much greater than $K_w$, we can assume that the initial $[H_3O^+]$ resulting from the autoionization of water is insignificant compared to the equilibrium $[H_3O^+]$ resulting from the ionization of this weak acid.
3. The value of $K_a$ is small enough compared to the initial concentration of the acid that the percent of the acid which actually ionizes will not significantly change that original concentration. Remember that this assumption is only valid if the percent ionization of the weak acid is $\leq 5\%$.

Page 315, Practice Problems 5.5.1
1. 2.02
2. 2.41 (2 sig. digits)
3. 5.4 %
   The simplifying assumption would not be valid in this case because the percent ionization is greater than 5 %

Page 316, Practice Problems 5.5.2
1. 0.017 M
2. 1.6 M
3. 0.45 M

Page 317, Practice Problems 5.5.3
1. $1.0 \times 10^{-5}$
2. $1.4 \times 10^{-4}$
3. $6.56 \times 10^{-5}$ (The acid is most likely benzoic acid)

Page 319, Quick Check
1. $[OH^-] = 5.8 \times 10^{-6}\text{ M}$ so $pOH = -\log (5.8 \times 10^{-6}) = 5.24$
   $pH = 14.00 - 5.24 = 8.76$ and $[H_3O^+] = 10^{8.76} = 1.7 \times 10^{-9}$ M
3. (a) Methylammonium, CH₃NH₃⁺
   \( K_a = 2.3 \times 10^{-11} \)
   \( pK_a = 10.64 \)
(b) Hydrazinium, N₂H₅⁺
   \( K_a = 5.9 \times 10^{-9} \)
   \( pK_a = 8.23 \)

**Page 322, Practice Problems 5.5.5**
1. 0.87 g \( \text{C}_2\text{H}_5\text{NH}_2 \)
2. 0.49 M
3. 6.0 \times 10^{-3} M

**Page 324, Practice Problems 5.5.6**
1. \( K_b = 0.020 \); Percent ionization = 20.%
   This calculated \( K_b \) value is greater than the \( K_b \) given in the sample problem (4.4 \times 10^{-4}). This indicates that the temperature of the solution is higher than 25° C.
2. \( K_b = 2 \times 10^{-6} \) (1 sig. digits)
   \( pK_b = -\log (1.6 \times 10^{-6}) = 5.79 \)
3. 3.3 \times 10^{-6}

**Page 328, 5.5 Review Questions**
1. \( \text{pH} = -\log (0.01342) = 1.87 \) (2 sig. digits) \[ \text{[H}_3\text{O}^+] = 10^{-1.87} = 0.013 \text{ M} \]
   \( \text{pOH} = 14.00 - 1.87 = 12.13 \)
   \[ \text{[OH}^-] = 10^{-12.13} = 7.4 \times 10^{-13} \text{ M} \]
2. \( \text{pH} = 4.02; \) Percent ionization = 0.095 %
3. \( \text{pH} = 2.873; \) \( K_a = 1.80 \times 10^{-5} \) (The unknown acid is acetic acid.)
4. 8.9 g HF
5. 0.16 M \( \text{H}_3\text{PO}_4 \)
6. 0.11 g \( \text{H}_2\text{C}_2\text{O}_4 \)
7. 2.9 \times 10^{-8}
8. 4.9 \times 10^{-5}
9.

<table>
<thead>
<tr>
<th>Conjugate Acid</th>
<th>Conjugate Base</th>
<th>( K_a ) for acid</th>
<th>( pK_a )</th>
<th>( K_b ) for base</th>
<th>( pK_b )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{HNO}_2 )</td>
<td>( \text{NO}_2^- )</td>
<td>( 4.6 \times 10^{-4} )</td>
<td>3.34</td>
<td>( 2.2 \times 10^{-11} )</td>
<td>10.66</td>
</tr>
<tr>
<td>( \text{H}_2\text{O}_2 )</td>
<td>( \text{HO}_2^- )</td>
<td>( 2.4 \times 10^{-12} )</td>
<td>11.62</td>
<td>( 4.2 \times 10^{-3} )</td>
<td>2.38</td>
</tr>
<tr>
<td>( \text{C}_6\text{H}_5\text{OH} )</td>
<td>( \text{C}_6\text{H}_5\text{O}^- )</td>
<td>( 1.3 \times 10^{-10} )</td>
<td>9.89</td>
<td>( 7.7 \times 10^{-5} )</td>
<td>4.11</td>
</tr>
<tr>
<td>( \text{HSO}_4^- )</td>
<td>( \text{SO}_4^{2-} )</td>
<td>( 1.2 \times 10^{-2} )</td>
<td>1.92</td>
<td>( 8.3 \times 10^{-13} )</td>
<td>12.08</td>
</tr>
</tbody>
</table>

10.

<table>
<thead>
<tr>
<th>Conjugate Acid</th>
<th>Conjugate Base</th>
<th>( K_a ) for acid</th>
<th>( pK_a )</th>
<th>( K_b ) for base</th>
<th>( pK_b )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{H}_2\text{PO}_4^- )</td>
<td>( \text{HPO}_4^{2-} )</td>
<td>( 6.2 \times 10^{-8} )</td>
<td>7.21</td>
<td>( 1.6 \times 10^{-7} )</td>
<td>6.79</td>
</tr>
<tr>
<td>( \text{H}_2\text{C}_6\text{H}_5\text{O}_7^- )</td>
<td>( \text{HC}_6\text{H}_5\text{O}_7^{2-} )</td>
<td>( 1.7 \times 10^{-5} )</td>
<td>4.77</td>
<td>( 5.9 \times 10^{-10} )</td>
<td>9.23</td>
</tr>
<tr>
<td>( \text{H}_2\text{BO}_3^- )</td>
<td>( \text{H}_3\text{BO}_3 )</td>
<td>( 7.3 \times 10^{-10} )</td>
<td>9.14</td>
<td>( 1.4 \times 10^{-5} )</td>
<td>4.86</td>
</tr>
<tr>
<td>( \text{HCO}_3^- )</td>
<td>( \text{CO}_3^{2-} )</td>
<td>( 5.6 \times 10^{-11} )</td>
<td>10.25</td>
<td>( 1.8 \times 10^{-4} )</td>
<td>3.75</td>
</tr>
</tbody>
</table>

11. 11.39
12. 12.23
13. 0.10 M
14. 9.1 L
15. 4.2 \times 10^{-4}