Problems

Acid- Base Titrations

1. Convert the following to equivalents.
   a. 0.12 mol H₂SO₄
      for H₂SO₄ with 2 acidic protons (H⁺), 1 mol = 2 eq
      0.12 mol x (2 eq/1 mol) = 0.24 eq
   b. 0.34 mol NaHCO₃
      for NaHCO₃ which can accept one proton, 1 mol = 1 eq
      0.34 mol = 0.34 eq
   c. 0.56 mol Cr(OH)₃
      for Cr(OH)₃ which can react with 3 protons, 1 mol = 3 eq
      0.56 mol = 1.7 eq

2. Convert the following to moles.
   a. 0.98 eq H₂S
      for H₂S which has 2 acidic H⁺, 1 mol = 2 eq
      0.98 eq x (1 mol/2 eq) = 0.48 mol
   b. 0.763 eq CH₃COOH
      acetic acid has one acidic proton (on the end) so 1 mol = 1 eq
      0.763 eq = 0.763 mol
   c. 0.5647 eq Ba(OH)₂
      barium hydroxide reacts with 2 protons, 1 mol = 2 eq
      0.5647 eq = 0.2824 mol

3. Convert the following to normality.
   a. 0.54 M NH₃
      1 mol = 1 eq
      0.54 mol/L x (1 eq/1 mol) = 0.54 eq/L
      0.54 M = 0.54 N
   b. 0.43 M H₂C₂O₄
      1 mol = 2 eq
      0.43 M = 0.86 N
   c. 0.32 M H₃AsO₄
      1 mol = 3 eq
      0.32 M = 0.96 N
4. Convert the following to molarity.
   a. 0.211 N CH₃NH₂
      \[1 \text{ mol} = 1 \text{ eq}\]
      \[0.211 \text{ eq/L} \times (1 \text{ mol/1 eq}) = 0.211 \text{ mol/L}\]
      \[0.211 N = 0.211 M\]
   b. 0.1951 N Ca(OH)₂
      \[1 \text{ mol} = 2 \text{ eq}\]
      \[0.1951 N = 0.09755 M\]
   c. 0.334 N C₆H₅COOH
      \[1 \text{ mol} = 1 \text{ eq}\]
      \[0.344 N = 0.344 M\]

5. What is the equivalent weight of each of the following substances?
   a. NH₃
      \[\text{Molar mass} = 14.01 + 3(1.01) = 17.04 \text{ g/mol}\]
      \[\text{For ammonia, 1 mol} = 1 \text{ eq}\]
      \[17.04 \text{ g/mol} \times (1 \text{ mol/1 eq}) = 17.04 \text{ g/eq}\]
   b. Ca(OH)₂
      \[\text{Molar mass} = 40.08 + 2(16.00 + 1.01) = 74.10 \text{ g/mol}\]
      \[\text{For calcium hydroxide, 1 mol} = 2 \text{ eq}\]
      \[74.10 \text{ g/mol} \times (1 \text{ mol/2 eq}) = 37.05 \text{ g/eq}\]
   c. H₃AsO₄
      \[\text{Molar mass} = 3(1.01) + 74.92 + 4(16.00) = 141.95 \text{ g/mol}\]
      \[\text{For arsenic acid, 1 mol} = 3 \text{ eq}\]
      \[141.95 \text{ g/mol} \times (1 \text{ mol/3 eq}) = 47.32 \text{ g/eq}\]
   d. H₂S
      \[\text{Molar mass} = 2(1.01) + 32.07 = 34.09 \text{ g/mol}\]
      \[\text{For hydrosulfuric acid, 1 mol} = 2 \text{ eq}\]
      \[34.09 \text{ g/mol} \times (1 \text{ mol/2 eq}) = 17.04 \text{ g/eq}\]

6. How many milliliters of 0.341 N H₂SO₄ are required to react with 30.0 mL of 0.333 N Cr(OH)₃?
   \[N_aV_a = N_bV_b\]
   \[(0.341 \text{ N})V = (0.333 \text{ N})(30.0 \text{ mL})\]
   \[V = 29.3 \text{ mL}\]

7. What is the normality of a solution of unknown base if 23.45 mL of 0.1236 N HCl are required to neutralize 33.5 mL of it?
   \[N_aV_a = N_bV_b\]
   \[(0.1236 \text{ N})(23.45 \text{ mL}) = N(33.50 \text{ mL})\]
   \[[\text{base}] = 0.08652 \text{ N}\]
8. To standardize a solution of HCl, 0.1423 g of Na₂CO₃ (eq wt = 53.00) was dissolved in 50 mL of water and titrated with 27.82 mL of HCl. What is the normality of the HCl(aq)?

\[
N = \text{eq/L} \quad 27.82 \text{ mL} \times (1 \text{ L}/1000 \text{ mL}) = 0.02782 \text{ L HCl} \\
0.1423 \text{ g Na}_2\text{CO}_3 \times (1 \text{ eq/53.00 g}) \times (1 \text{ eq acid/1 eq base}) = 0.002684 \text{ eq} \\
[\text{HCl}] = 0.002684 \text{ eq}/0.02782 \text{ L} = 0.09651 \text{ N}
\]

9. To standardize a solution of NaOH, 0.5531 g of KHP (eq wt = 204.23) was dissolved in 50 mL of water. This solution required 31.11 mL of NaOH(aq) for neutralization. What is the normality of the NaOH(aq)?

\[
[\text{NaOH}] = \text{eq/L} \quad 31.11 \text{ mL} \times (1 \text{ L}/1000 \text{ mL}) = 0.03111 \text{ L NaOH} \\
0.5531 \text{ g KHP} \times (1 \text{ eq/204.23 g}) \times (1 \text{ eq base/1 eq acid}) = 0.002708 \text{ eq} \\
[\text{NaOH}] = 0.002708 \text{ eq}/0.03111 \text{ L} = 0.08705 \text{ N NaOH}
\]

10. A 0.9932 g sample of limestone was titrated with 15.67 mL of 0.113 N HCl, what is the percent of calcium carbonate in the sample?

\[
\% \text{CaCO}_3 = (\text{g CaCO}_3/\text{g limestone}) \times 100 \\
\text{g limestone} = 0.9932 \text{ g} \\
\text{Eq wt CaCO}_3 = 100.09 \text{ g/mol} \times (1 \text{ mol/2 eq}) = 50.04 \text{ g/eq} \\
15.67 \text{ mL HCl} \times (1 \text{ L}/1000 \text{ mL}) \times (0.113 \text{ eq/1 L}) \times (1 \text{ eq CaCO}_3/1 \text{ eq HCl}) \times (2 \text{ mol/1 eq}) \times (100.09 \text{ g/1 mol}) = 0.0886 \text{ g} \\
\text{Or} 15.67 \text{ mL HCl} \times (1 \text{ L}/1000 \text{ mL}) \times (0.113 \text{ eq/1 L}) \times (1 \text{ eq CaCO}_3/1 \text{ eq HCl}) \times (50.04 \text{ g/1 eq}) = 0.0886 \text{ g} \\
\% \text{CaCO}_3 = 0.0886 \text{ g/0.9932 g} \times 100 = 8.92\%
\]

11. 27.44 mL of 0.222 N Ba(OH)₂ was required to neutralize all the benzoic acid (C₆H₅COOH) in a 1.224 g sample of organic material. What was the percent benzoic acid in the sample?

\[
\text{BA = benzoic acid} \\
\% \text{BA} = (\text{g BA/g sample}) \times 100 \\
\text{g sample} = 1.224 \text{ g} \\
\text{Eq wt BA} = 122.13 \text{ g/mol} \times (1 \text{ mol/1 eq}) = 122.13 \text{ g/eq} \\
27.44 \text{ mL Ba(OH)}_2 \times (1 \text{ L}/1000 \text{ mL}) \times (0.222 \text{ eq/1 L}) \times (1 \text{ eq BA/1 eq Ba(OH)}_2) \times (122.13 \text{ g/1 eq}) = 0.744 \text{ g BA} \\
\% \text{BA} = (0.744 \text{ g/1.224g}) \times 100 = 60.8\%
\]
12. The citric acid in a 0.541 g vitamin tablet was dissolved in 20.00 mL of 1.021 N NaOH. The excess base was titrated with 9.21 mL of 0.223 N HCl. How many mg of citric acid (eq wt = 64.0) was in the vitamin tablet?

\[
CA = \text{citric acid}
\]

\[
\text{Original amount of base} = (0.02000 \text{ L})(1.021 \text{ eq/L}) = 0.02042 \text{ eq base}
\]

\[
\text{Excess base} = 9.21 \text{ mL HCl} \times (1 \text{ L}/1000 \text{ mL}) \times (0.223 \text{ eq/1L}) \times (1 \text{ eq base/1 eq acid}) = 0.00205 \text{ eq}
\]

\[
0.01837 \text{ eq} \times (64.0 \text{ g/eq}) \times (1000 \text{ mg/1 g}) = 1175 \text{ mg} = 1.18 \times 10^3 \text{ mg}
\]

13. A 1.113 g sample of antacid was dissolved in 50.00 mL of 0.555 N HCl. The excess HCl was titrated with 10.2 mL of 0.033 N NaOH. What is the power of the antacid in meq/g?

\[
\text{Original equivalents of acid} = (0.05000 \text{ L})(0.555 \text{ eq/L}) = 0.0278 \text{ eq}
\]

\[
\text{Excess acid} = 10.2 \text{ mL NaOH} \times (1 \text{ L}/1000 \text{ mL}) \times (0.033 \text{ eq/L}) \times (1 \text{ eq acid/1 eq base}) = 0.00034 \text{ eq}
\]

\[
\text{Acid consumed} = 0.0278 \text{ eq} – 0.000336 \text{ eq} = 0.0274 \text{ eq} \times (1000 \text{ meq/1 eq}) = 27.4 \text{ meq}
\]

\[
\text{Power} = 27.4 \text{ meq}/1.113 \text{ g} = 24.6 \text{ meq/g}
\]

14. A 0.1298 g sample of pure acid was titrated with 42.11 mL of 0.1234 N NaOH. What is the equivalent weight of the acid?

\[
\text{Equivalent weight} = \frac{\text{grams}}{\text{equivalent}}
\]

\[
\text{grams acid} = 0.1298
\]

\[
42.11 \text{ mL NaOH} \times (1 \text{ L}/1000 \text{ mL}) \times (0.1234 \text{ eq/L}) \times (1 \text{ eq acid/1 eq base}) = 0.005196 \text{ eq}
\]

\[
\text{Eq wt} = 0.1298 \text{ g}/0.005196 \text{ eq} = 24.98 \text{ g/eq}
\]

15. A 0.3349 g sample of pure base was titrated with 33.33 mL of 0.1673 N H₂SO₄. What is the equivalent weight of the base?

\[
\text{Equivalent weight} = \frac{\text{grams}}{\text{equivalent}}
\]

\[
\text{grams base} = 0.3349
\]

\[
33.33 \text{ mL} \times (1 \text{ L}/1000 \text{ mL}) \times (0.1673 \text{ eq/L}) \times (1 \text{ eq base/1 eq acid}) = 0.005576 \text{ eq}
\]

\[
\text{Eq wt} = 0.3349 \text{ g}/0.005576 \text{ eq} = 60.06 \text{ g/eq}
\]
Redox Titrations

Refer to the following half-reactions, as needed, to answer the questions below about redox reactions.

\[ 5 \text{e}^- + \text{MnO}_4^- + 8 \text{H}^+ \rightarrow \text{Mn}^{2+} + 4 \text{H}_2\text{O} \]
\[ 3 \text{e}^- + \text{MnO}_4^- + 2 \text{H}_2\text{O} \rightarrow \text{MnO}_2 + 4 \text{OH}^- \]
\[ 12 \text{H}^+ + 8 \text{e}^- + 3 \text{IO}_3^- \rightarrow \text{I}_3^- + 6 \text{H}_2\text{O} \]
\[ \text{I}_3^- + 2 \text{e}^- \rightarrow 3 \text{I}^- \]
\[ \text{F}_2 + 2 \text{e}^- \rightarrow 2 \text{F}^- \]
\[ \text{NO}_3^- + 4 \text{H}^+ + 3 \text{e}^- \rightarrow \text{NO} + 2 \text{H}_2\text{O} \]
\[ \text{Zn}^{2+} + 2 \text{e}^- \rightarrow \text{Zn} \]
\[ \text{Fe}^{3+} + \text{e}^- \rightarrow \text{Fe}^{2+} \]

1. Convert the following to equivalents.
   a. 0.222 mol \text{IO}_3^-
      using stoichiometric coefficients in half-rxn above, 3 mol \text{IO}_3^- = 8 eq electrons
      
      \[ 0.222 \text{ mol} \times \left( \frac{8 \text{ eq}}{3 \text{ mol}} \right) = 0.592 \text{ eq} \]
   b. 0.045 mol \text{Fe}^{3+}
      using stoichiometric coefficients in half-rxn above, 1 mol = 1 eq
      
      \[ 0.045 \text{ mol} \times \left( \frac{1 \text{ eq}}{1 \text{ mol}} \right) = 0.045 \text{ eq} \]
   c. 0.31 mol \text{I}^-
      using stoichiometric coefficients in half-rxn above, 3 mol = 2 eq
      
      \[ 0.31 \text{ mol} \times \left( \frac{2 \text{ eq}}{3 \text{ mol}} \right) = 0.21 \text{ eq} \]

2. Convert the following to moles.
   a. 0.55 eq \text{MnO}_4^-(acidic conditions)
      using stoichiometric coefficients in half-rxn above, 1 mol = 5 eq
      
      \[ 0.55 \text{ eq} \times \left( \frac{1 \text{ mol}}{5 \text{ eq}} \right) = 0.11 \text{ mol} \]
   b. 0.0781 eq \text{Zn}
      using stoichiometric coefficients in half-rxn above, 1 mol = 2 eq
      
      \[ 0.0781 \text{ eq} \times \left( \frac{1 \text{ mol}}{2 \text{ eq}} \right) = 0.0390 \text{ mol} \]
   c. 0.211 eq \text{IO}_3^-
      using stoichiometric coefficients in half-rxn above, 3 mol = 8 eq
      
      \[ 0.211 \text{ eq} \times \left( \frac{3 \text{ mol}}{8 \text{ eq}} \right) = 0.0791 \text{ mol} \]

3. Convert the following to normality.
   a. 0.101 M \text{Fe}^{2+}
      using stoichiometric coefficients in half-rxn above, 1 mol = 1 eq
      
      \[ 0.101 \text{ mol/L} \times \left( \frac{1 \text{ eq}}{1 \text{ mol}} \right) = 0.101 \text{ N} \]
   b. 0.0056 M \text{MnO}_4^-(basic conditions)
      using stoichiometric coefficients in half-rxn above, 1 mol = 3 eq
      
      \[ 0.0056 \text{ mol/L} \times \left( \frac{3 \text{ eq}}{1 \text{ mol}} \right) = 0.017 \text{ N} \]
   c. 0.207 M \text{I}_3^-
      using stoichiometric coefficients in half-rxn above, 1 mol = 2 eq
      
      \[ 0.207 \text{ mol/L} \times \left( \frac{2 \text{ eq}}{1 \text{ mol}} \right) = 0.414 \text{ N} \]
4. Convert the following to molarity.
   a. 0.440 N Mn²⁺
      using stoichiometric coefficients in half-rxn above, 1 mol = 5 eq
      \[0.440 \text{ eq/L} \times \left(\frac{1 \text{ mol}}{5 \text{ eq}}\right) = 0.0880 \text{ M}\]
   b. 1.03 N IO₃⁻
      using stoichiometric coefficients in half-rxn above, 3 mol = 8 eq
      \[1.03 \text{ eq/L} \times \left(\frac{3 \text{ mol}}{8 \text{ eq}}\right) = 0.386 \text{ M}\]
   c. 0.224 N NO₃⁻
      using stoichiometric coefficients in half-rxn above, 1 mol = 3 eq
      \[0.244 \text{ eq/L} \times \left(\frac{1 \text{ mol}}{3 \text{ eq}}\right) = 0.0813 \text{ M}\]

5. How many milliliters of 0.134 N permanganate ion is needed to titrate 25.00 mL of 0.223 N iron(II) ion?

   \[NV = NV \]
   \[(0.134 \text{ N})(25.00 \text{ mL})\]
   \[V = 41.6 \text{ mL}\]

6. What is the normality of an iodate solution if 35.44 mL of 0.0111 N thiosulfate is required to titrate 30.00 mL of the iodate solution?

   \[NV = NV \]
   \[(0.0111 \text{ N})(35.44 \text{ mL}) = N(30.00 \text{ mL})\]
   \[[\text{iodate}] = 0.0131 \text{ N}\]

7. How many grams of zinc metal are needed to reduce 25.00 mL of 0.123 N nitric acid?

   \[25.00 \text{ mL} \times \left(\frac{1 \text{ L}}{1000 \text{ mL}}\right) \times (0.123 \text{ eq/L}) \times (1 \text{ eq Zn/1 eq HNO}_3) \times (1 \text{ mol Zn/2 eq}) \times \]
   \[\left(\frac{65.39 \text{ g}}{1 \text{ mol}}\right) = 0.101 \text{ g}\]

8. What is the percent of iron in a 1.2299 g sample that requires 14.35 mL of 0.075 N acidic permanganate to titrate it from iron (II) to iron(III)?

   \[\% \text{ Fe} = \left(\frac{g \text{ Fe/g sample}}{g \text{ sample}}\right) \times 100 \]
   \[14.35 \text{ mL} \times \left(\frac{1 \text{ L}}{1000 \text{ mL}}\right) \times (0.075 \text{ eq MnO}_4^-/L) \times (1 \text{ eq Fe/1 eq MnO}_4^-) \times (1 \text{ eq/1 mol}) \times \]
   \[\left(\frac{55.845 \text{ g}}{1 \text{ mol}}\right) = 0.060 \text{ g Fe}\]
   \[\% \text{ Fe} = \left(\frac{0.060 \text{ g}}{1.2299 \text{ g}}\right) \times 100 = 4.8\%\]
9. What is the normality of a basic solution of permanganate ion if 15.00 mL of the solution requires 16.43 mL of 0.143 N oxalate ion for a complete reaction?

\[
N = \text{eq}/L \\
= \frac{15.00 \text{ mL} \times (1 \text{ L}/1000 \text{ mL})}{0.01500 \text{ L}} = 16.43 \text{ mL} \times (1 \text{ L}/1000 \text{ mL}) \times (0.143 \text{ eq/L}) \times \left( \frac{1 \text{ eq MnO}_4^-}{1 \text{ eq C}_2\text{O}_4^{2-}} \right) \times \frac{0.00235 \text{ eq}}{0.01500 \text{ L}} = 0.157 \text{ N}
\]

10. What is the normality of a solution of copper(II) ion that requires 21.33 mL of 0.236 N silver nitrate to titrate 25.00 mL of the copper solution?

\[
N = \text{eq}/L \\
= \frac{25.00 \text{ mL} \times (1 \text{ L}/1000 \text{ mL})}{0.02500 \text{ L}} = 21.33 \text{ mL} \times (1 \text{ L}/1000 \text{ mL}) \times (0.236 \text{ eq/L}) \times \left( \frac{1 \text{ eq Cu}}{1 \text{ eq Ag}} \right) \times \frac{0.00503 \text{ eq}}{0.02500 \text{ L}} = 0.201 \text{ N}
\]