

Chapter Four

- 4.1 (a) Solvent – the medium into which something (a solute) is dissolved to make a solution
(b) Solute – Something dissolved in a solvent to make a solution
(c) Concentration – the ratio of the quantity of solute to the quantity of solution or quantity of solvent
- 4.2 (a) Concentrated – a solution that has a large ratio of the amounts of solute to solvent
(b) Dilute – a solution in which the ratio of the quantities of solute to solvent is small
(c) Saturated – a solution that holds as much solute as it can at a given temperature
(d) Unsaturated – Any solution with a concentration less than that of a saturated solution of the same solute and solvent
(e) Supersaturated – a solution whose concentration of solute exceeds the equilibrium concentration
(f) Solubility – the ratio of the quantity of solute to the quantity of solvent in a saturated solution
- 4.5 Precipitate – a solid that separates from a solution usually as the result of a chemical reaction
- For a precipitate to form spontaneously in a solution, the equilibrium must be disrupted. A supersaturated solution may form a precipitate spontaneously, or if the temperature changes in the direction that will cause a precipitate to form.
- 4.6 Electrolyte – a substance that dissolves in water to give an electrically conducting solution.
Nonelectrolyte – a substance that dissolves in water to give a solution that does not conduct electricity.
- 4.7 An electrolyte is able to conduct electricity since it has a charge and can allow ions to move, a nonelectrolyte does not have a charge, so it cannot allow ions to move. An ion is hydrated when it is surrounded by water molecules.
- 4.8 Dissociation – the dissolving of an ionic compound in water such that the individual ions that compose the ionic compound become separated from one another (via hydration), and move about freely in solution, acting more or less independently of one another.
- 4.9 (a) $\text{CaCl}_2(aq) \rightarrow \text{Ca}^{2+}(aq) + 2\text{Cl}^{-}(aq)$
(b) $(\text{NH}_4)_2\text{SO}_4(aq) \rightarrow 2\text{NH}_4^{+}(aq) + \text{SO}_4^{2-}(aq)$
(c) $\text{NaC}_2\text{H}_3\text{O}_2(aq) \rightarrow \text{Na}^{+}(aq) + \text{C}_2\text{H}_3\text{O}_2^{-}(aq)$
- 4.11 The spectator ions are Na^{+} and Cl^{-} . The net ionic equation is:
$$\text{Co}^{2+} + 2\text{OH}^{-} \rightarrow \text{Co}(\text{OH})_2(s)$$
- 4.16 (a) NaOH dissociation
(b) HNO_3 ionization
(c) NH_3 ionization
(d) H_2SO_4 ionization
- 4.18 Dynamic equilibrium is a condition in which two opposing processes are occurring at equal rates. Acetic acid is not a strong acid, so that it forms an equilibrium between the molecular form, $\text{HC}_2\text{H}_3\text{O}_2$, and the ionized form, H^{+} and $\text{C}_2\text{H}_3\text{O}_2^{-}$.
- 4.20 (a) HCN: weak
(b) HNO_3 : strong

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- (c) H_2SO_3 : weak
 (d) HCl : strong
 (f) HCHO_2 : weak
 (e) HNO_2 : weak
- 4.21 (a) $\text{C}_5\text{H}_5\text{N}$: weak
 (b) $\text{Ba}(\text{OH})_2$: strong
 (c) KOH : strong
 (d) $\text{C}_6\text{H}_5\text{NH}_2$: weak
 (e) Cs_2O : strong
 (f) N_2O_5 : acidic solution
- 4.34 A metathesis reaction is also called a double replacement reaction. A precipitate is an insoluble ionic solid that forms when two ionic solutions are mixed.
- 4.43 $M \times L = \left(\frac{\text{mol}}{\text{L}}\right) \times L = \text{mol}$
- 4.44 The number of moles of HNO_3 in the solution has not changed because none of the original sample was removed. Instead, the concentration has decreased since more water was added.
- 4.47 (a) Buret – a long glass tube fitted with a stopcock, graduated in mL, and used for the controlled, measured addition of a volume of a solution to a receiving flask.
 (b) Titration – a procedure for obtaining quantitative information about a reactant by a controlled addition of one substance to another until a signal (usually a color change of an indicator) shows that equivalent quantities have reacted.
 (c) Titrant – the solution delivered from a buret during a titration.
 (d) End point – that point during a titration when the indicator changes color, the titration is stopped, and the total added volume of the titrant is recorded.
- 4.50 (a) ionic: $\text{Cu}^{2+}(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) + \text{Ba}^{2+}(\text{aq}) + 2\text{Cl}^{-}(\text{aq}) \rightarrow \text{BaSO}_4(\text{s}) + \text{Cu}^{2+}(\text{aq}) + 2\text{Cl}^{-}(\text{aq})$
 net: $\text{Ba}^{2+}(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) \rightarrow \text{BaSO}_4(\text{s})$
 (b) $\text{Fe}^{3+}(\text{aq}) + 3\text{NO}_3^{-}(\text{aq}) + 3\text{Li}^{+}(\text{aq}) + 3\text{OH}^{-}(\text{aq}) \rightarrow \text{Fe}(\text{OH})_3(\text{s}) + 3\text{Li}^{+}(\text{aq}) + 3\text{NO}_3^{-}(\text{aq})$
 net: $\text{Fe}^{3+}(\text{aq}) + 3\text{OH}^{-}(\text{aq}) \rightarrow \text{Fe}(\text{OH})_3(\text{s})$
 (c) $6\text{Na}^{+}(\text{aq}) + 2\text{PO}_4^{3-}(\text{aq}) + 3\text{Ca}^{2+}(\text{aq}) + 6\text{Cl}^{-}(\text{aq}) \rightarrow \text{Ca}_3(\text{PO}_4)_2(\text{s}) + 6\text{Na}^{+}(\text{aq}) + 6\text{Cl}^{-}(\text{aq})$
 net: $3\text{Ca}^{2+}(\text{aq}) + 2\text{PO}_4^{3-}(\text{aq}) \rightarrow \text{Ca}_3(\text{PO}_4)_2(\text{s})$
 (d) $2\text{Na}^{+}(\text{aq}) + \text{S}^{2-}(\text{aq}) + 2\text{Ag}^{+}(\text{aq}) + 2\text{C}_2\text{H}_3\text{O}_2^{-}(\text{aq}) \rightarrow 2\text{Na}^{+}(\text{aq}) + 2\text{C}_2\text{H}_3\text{O}_2^{-}(\text{aq}) + \text{Ag}_2\text{S}(\text{s})$
 net: $2\text{Ag}^{+}(\text{aq}) + \text{S}^{2-}(\text{aq}) \rightarrow \text{Ag}_2\text{S}(\text{s})$
- 4.54 $\text{C}_5\text{H}_5\text{N}(\text{aq}) + \text{H}_2\text{O} \rightleftharpoons \text{C}_5\text{H}_5\text{NH}^{+}(\text{aq}) + \text{OH}^{-}(\text{aq})$
- 4.56 $\text{HC}_5\text{H}_9\text{O}_2(\text{aq}) + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^{+}(\text{aq}) + \text{C}_5\text{H}_9\text{O}_2^{-}(\text{aq})$
- 4.60 (a) $\text{Fe}^{3+}(\text{aq}) + 3\text{NO}_3^{-}(\text{aq}) + 3\text{K}^{+}(\text{aq}) + 3\text{OH}^{-}(\text{aq}) \rightarrow \text{Fe}(\text{OH})_3(\text{s}) + 3\text{K}^{+}(\text{aq}) + 3\text{NO}_3^{-}(\text{aq})$
 net: $\text{Fe}^{3+}(\text{aq}) + 3\text{OH}^{-}(\text{aq}) \rightarrow \text{Fe}(\text{OH})_3(\text{s})$
 (b) $6\text{Na}^{+}(\text{aq}) + 2\text{PO}_4^{3-}(\text{aq}) + 3\text{Sr}^{2+}(\text{aq}) + 6\text{Cl}^{-}(\text{aq}) \rightarrow \text{Sr}_3(\text{PO}_4)_2(\text{s}) + 6\text{Na}^{+}(\text{aq}) + 6\text{Cl}^{-}(\text{aq})$
 net: $3\text{Sr}^{2+}(\text{aq}) + 2\text{PO}_4^{3-}(\text{aq}) \rightarrow \text{Sr}_3(\text{PO}_4)_2(\text{s})$
- 4.62 molecular: $\text{Fe}_2(\text{SO}_4)_3(\text{aq}) + 3\text{BaCl}_2(\text{aq}) \rightarrow 3\text{BaSO}_4(\text{s}) + 2\text{FeCl}_3(\text{aq})$
 ionic: $2\text{Fe}^{3+}(\text{aq}) + 3\text{SO}_4^{2-}(\text{aq}) + 3\text{Ba}^{2+}(\text{aq}) + 6\text{Cl}^{-}(\text{aq}) \rightarrow 3\text{BaSO}_4(\text{s}) + 2\text{Fe}^{3+}(\text{aq}) + 6\text{Cl}^{-}(\text{aq})$
 net: $3\text{Ba}^{2+}(\text{aq}) + 3\text{SO}_4^{2-}(\text{aq}) \rightarrow 3\text{BaSO}_4(\text{s})$

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- 4.64 The soluble ones are (a), (b), (d), and (f).
- 4.66 (a) molecular: $2\text{HC}_2\text{H}_3\text{O}_2(aq) + \text{Mg}(\text{OH})_2(s) \rightarrow \text{Mg}(\text{C}_2\text{H}_3\text{O}_2)_2(aq) + 2\text{H}_2\text{O}$
 ionic: $2\text{HC}_2\text{H}_3\text{O}_2(aq) + \text{Mg}(\text{OH})_2(s) \rightarrow \text{Mg}^{2+}(aq) + 2\text{C}_2\text{H}_3\text{O}_2^-(aq) + 2\text{H}_2\text{O}$
 net: $2\text{HC}_2\text{H}_3\text{O}_2(aq) + \text{Mg}(\text{OH})_2(s) \rightarrow \text{Mg}^{2+}(aq) + 2\text{C}_2\text{H}_3\text{O}_2^-(aq) + 2\text{H}_2\text{O}$
- (b) molecular: $\text{HClO}_4(aq) + \text{NH}_3(aq) \rightarrow \text{NH}_4\text{ClO}_4(aq)$
 ionic: $\text{H}^+(aq) + \text{ClO}_4^-(aq) + \text{NH}_3(aq) \rightarrow \text{NH}_4^+(aq) + \text{ClO}_4^-(aq)$
 net: $\text{H}^+(aq) + \text{NH}_3(aq) \rightarrow \text{NH}_4^+(aq)$
- (c) molecular: $\text{H}_2\text{CO}_3(aq) + 2\text{NH}_3(aq) \rightarrow (\text{NH}_4)_2\text{CO}_3(aq)$
 ionic: $\text{H}_2\text{CO}_3(aq) + 2\text{NH}_3(aq) \rightarrow 2\text{NH}_4^+(aq) + \text{CO}_3^{2-}(aq)$
 net: $\text{H}_2\text{CO}_3(aq) + 2\text{NH}_3(aq) \rightarrow 2\text{NH}_4^+(aq) + \text{CO}_3^{2-}(aq)$
- 4.76 (a) molecular: $(\text{NH}_4)_2\text{S}(aq) + 2\text{NaOH}(aq) \rightarrow 2\text{NH}_3(g) + 2\text{H}_2\text{O} + \text{Na}_2\text{S}(aq)$
 ionic: $2\text{NH}_4^+(aq) + \text{S}^{2-}(aq) + 2\text{Na}^+(aq) + 2\text{OH}^-(aq) \rightarrow 2\text{NH}_3(g) + 2\text{H}_2\text{O} + 2\text{Na}^+(aq) + \text{S}^{2-}(aq)$
 net: $\text{NH}_4^+(aq) + \text{OH}^-(aq) \rightarrow \text{NH}_3(g) + \text{H}_2\text{O}$
- (b) molecular: $\text{Cr}_2(\text{SO}_4)_3(aq) + 3\text{K}_2\text{CO}_3(aq) \rightarrow \text{Cr}_2(\text{CO}_3)_3(s) + 3\text{K}_2\text{SO}_4(aq)$
 ionic: $2\text{Cr}^{3+}(aq) + 3\text{SO}_4^{2-}(aq) + 6\text{K}^+(aq) + 3\text{CO}_3^{2-}(aq) \rightarrow \text{Cr}_2(\text{CO}_3)_3(s) + 6\text{K}^+(aq) + 3\text{SO}_4^{2-}(aq)$
 net: $2\text{Cr}^{3+}(aq) + 3\text{CO}_3^{2-}(aq) \rightarrow \text{Cr}_2(\text{CO}_3)_3(s)$
- (c) molecular: $3\text{AgNO}_3(aq) + \text{Cr}(\text{C}_2\text{H}_3\text{O}_2)_3(aq) \rightarrow 3\text{AgC}_2\text{H}_3\text{O}_2(aq) + \text{Cr}(\text{NO}_3)_3(aq)$
 ionic: $3\text{Ag}^+(aq) + 3\text{NO}_3^-(aq) + \text{Cr}^{3+}(aq) + 3\text{C}_2\text{H}_3\text{O}_2^-(aq) \rightarrow 3\text{Ag}^+(aq) + 3\text{C}_2\text{H}_3\text{O}_2^-(aq) + \text{Cr}^{3+}(aq) + 3\text{NO}_3^-(aq)$
 net: NR
- (d) molecular: $\text{Sr}(\text{OH})_2(aq) + \text{MgCl}_2(aq) \rightarrow \text{SrCl}_2(aq) + \text{Mg}(\text{OH})_2(s)$
 ionic: $\text{Sr}^{2+}(aq) + 2\text{OH}^-(aq) + \text{Mg}^{2+}(aq) + 2\text{Cl}^-(aq) \rightarrow \text{Mg}(\text{OH})_2(s) + \text{Sr}^{2+}(aq) + 2\text{Cl}^-(aq)$
 net: $\text{Mg}^{2+}(aq) + 2\text{OH}^-(aq) \rightarrow \text{Mg}(\text{OH})_2(s)$
- 4.78 We need to choose a set of reactants that are both soluble and that react to yield only one solid product. Choose (b). It can form CuCO_3 , depending on the concentration of $(\text{NH}_4)_2\text{CO}_3$. The solution needs to be kept acidic enough to prevent the formation of $\text{Cu}(\text{OH})_2$. Choices (a), (c), and (e) all have insoluble reactants, and for (d), the K_2CO_3 is basic enough to form $\text{Cu}(\text{OH})_2$.
- 4.80 (a) $\text{H}_2\text{SO}_4 \rightarrow 2\text{H}^+ + \text{SO}_4^{2-}$
 $\text{mol H}_2\text{SO}_4 = (3.60 \text{ g H}_2\text{SO}_4) \left(\frac{1 \text{ mol H}_2\text{SO}_4}{98.08 \text{ g H}_2\text{SO}_4} \right) = 0.0367 \text{ mol H}_2\text{SO}_4$
 $M \text{ H}_2\text{SO}_4 \text{ solution} = \left(\frac{0.0367 \text{ mol H}_2\text{SO}_4}{450 \text{ mL H}_2\text{SO}_4} \right) \left(\frac{1000 \text{ mL H}_2\text{SO}_4}{1 \text{ L H}_2\text{SO}_4} \right) = 0.0816 M \text{ H}_2\text{SO}_4$
- (b) $\text{Fe}(\text{NO}_3)_2 \rightarrow \text{Fe}^{2+} + 2\text{NO}_3^-$
 $M \text{ Fe}(\text{NO}_3)_2 \text{ solution} = \left(\frac{2.0 \times 10^{-3} \text{ mol Fe}(\text{NO}_3)_2}{12.0 \text{ mL Fe}(\text{NO}_3)_2} \right) \left(\frac{1000 \text{ mL Fe}(\text{NO}_3)_2}{1 \text{ L Fe}(\text{NO}_3)_2} \right) = 0.17 M \text{ Fe}(\text{NO}_3)_2$
- 4.82 $\text{mL HNO}_3 = (1.67 \text{ g HNO}_3) \left(\frac{1 \text{ mol HNO}_3}{63.02 \text{ g HNO}_3} \right) \left(\frac{1 \text{ L HNO}_3}{0.615 \text{ mol HNO}_3} \right) \left(\frac{1000 \text{ mL HNO}_3}{1 \text{ L HNO}_3} \right) = 43.1 \text{ mL HNO}_3$

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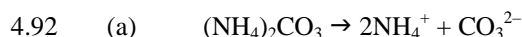
$$4.86 \quad \text{mol of HNO}_3 = 150 \text{ mL HNO}_3 \left(\frac{1 \text{ L soln}}{1000 \text{ mL soln}} \right) \left(\frac{0.45 \text{ mol HNO}_3}{1 \text{ L soln}} \right) = 0.067 \text{ mol HNO}_3$$

$$M \text{ of final solution} = \left(\frac{0.067 \text{ mol HNO}_3}{450 \text{ mL HNO}_3} \right) \left(\frac{1000 \text{ mL HNO}_3}{1 \text{ L HNO}_3} \right) = 0.15 \text{ M HNO}_3$$

$$4.90 \quad M_1V_1 = M_2V_2 \quad V_2 = \left(\frac{M_1V_1}{M_2} \right)$$

$$V_2 = \frac{(1.50 \text{ M HCl})(120 \text{ mL})}{1.00 \text{ M HCl}} = 180 \text{ mL HCl}$$

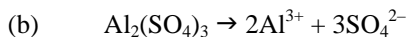
The 120.0 mL of HCl must be diluted to 180 mL. The volume of water to be added is: 180 mL of V_2 – 120 mL of V_1 = 60. mL water



$$\text{mol } (\text{NH}_4)_2\text{CO}_3 = 0.40 \text{ mol/L} \times 0.0185 \text{ L} = 0.0074 \text{ mol } (\text{NH}_4)_2\text{CO}_3$$

$$0.0074 \text{ mol } (\text{NH}_4)_2\text{CO}_3 \times 2 \text{ mol NH}_4^+/\text{mol } (\text{NH}_4)_2\text{CO}_3 = 0.015 \text{ mol NH}_4^+$$

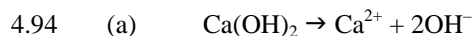
$$0.0074 \text{ mol } (\text{NH}_4)_2\text{CO}_3 \times 1 \text{ mol CO}_3^{2-}/\text{mol } (\text{NH}_4)_2\text{CO}_3 = 0.0074 \text{ mol CO}_3^{2-}$$



$$\text{mol Al}_2(\text{SO}_4)_3 = 0.35 \text{ mol/L} \times 0.0300 \text{ L} = 0.011 \text{ mol Al}_2(\text{SO}_4)_3$$

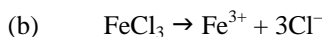
$$0.0105 \text{ mol Al}_2(\text{SO}_4)_3 \times 2 \text{ mol Al}^{3+}/\text{mol Al}_2(\text{SO}_4)_3 = 0.021 \text{ mol Al}^{3+}$$

$$0.0105 \text{ mol Al}_2(\text{SO}_4)_3 \times 3 \text{ mol SO}_4^{2-}/\text{mol Al}_2(\text{SO}_4)_3 = 0.033 \text{ mol SO}_4^{2-}$$



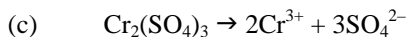
$$M \text{ Ca}^{2+} = \left(\frac{0.060 \text{ mol Ca}(\text{OH})_2}{1 \text{ L Ca}(\text{OH})_2 \text{ soln}} \right) \left(\frac{1 \text{ mol Ca}^{2+}}{1 \text{ mol Ca}(\text{OH})_2} \right) = 0.060 \text{ M Ca}^{2+}$$

$$M \text{ OH}^- = \left(\frac{0.060 \text{ mol Ca}(\text{OH})_2}{1 \text{ L Ca}(\text{OH})_2 \text{ soln}} \right) \left(\frac{2 \text{ mol OH}^-}{1 \text{ mol Ca}(\text{OH})_2} \right) = 0.12 \text{ M OH}^-$$



$$M \text{ Fe}^{3+} = \left(\frac{0.15 \text{ mol FeCl}_3}{1 \text{ L FeCl}_3 \text{ soln}} \right) \left(\frac{1 \text{ mol Fe}^{3+}}{1 \text{ mol FeCl}_3} \right) = 0.15 \text{ M Fe}^{3+}$$

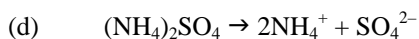
$$M \text{ Cl}^- = \left(\frac{0.15 \text{ mol FeCl}_3}{1 \text{ L FeCl}_3 \text{ soln}} \right) \left(\frac{3 \text{ mol Cl}^-}{1 \text{ mol FeCl}_3} \right) = 0.45 \text{ M Cl}^-$$



$$M \text{ Cr}^{3+} = \left(\frac{0.22 \text{ mol Cr}_2(\text{SO}_4)_3}{1 \text{ L Cr}_2(\text{SO}_4)_3 \text{ soln}} \right) \left(\frac{2 \text{ mol Cr}^{3+}}{1 \text{ mol Cr}_2(\text{SO}_4)_3} \right) = 0.44 \text{ M Cr}^{3+}$$

$$M \text{ SO}_4^{2-} = \left(\frac{0.22 \text{ mol Cr}_2(\text{SO}_4)_3}{1 \text{ L Cr}_2(\text{SO}_4)_3 \text{ soln}} \right) \left(\frac{3 \text{ mol SO}_4^{2-}}{1 \text{ mol Cr}_2(\text{SO}_4)_3} \right) = 0.66 \text{ M SO}_4^{2-}$$

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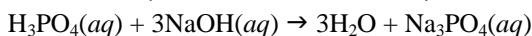
$$M \text{NH}_4^+ = \left(\frac{0.60 \text{ mol } (\text{NH}_4)_2\text{SO}_4}{1 \text{ L } (\text{NH}_4)_2\text{SO}_4 \text{ soln}} \right) \left(\frac{2 \text{ mol NH}_4^+}{1 \text{ mol } (\text{NH}_4)_2\text{SO}_4} \right) = 1.2 \text{ M NH}_4^+$$

$$M \text{SO}_4^{2-} = \left(\frac{0.60 \text{ mol } (\text{NH}_4)_2\text{SO}_4}{1 \text{ L } (\text{NH}_4)_2\text{SO}_4 \text{ soln}} \right) \left(\frac{1 \text{ mol SO}_4^{2-}}{1 \text{ mol } (\text{NH}_4)_2\text{SO}_4} \right) = 0.60 \text{ M SO}_4^{2-}$$

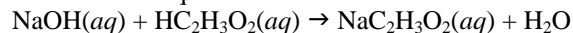
4.98 $\text{mL NaOH soln} = 25.0 \text{ mL soln} \left(\frac{0.250 \text{ mol H}_2\text{C}_4\text{H}_4\text{O}_6}{1000 \text{ mL soln}} \right) \left(\frac{2 \text{ mol NaOH}}{1 \text{ mol H}_2\text{C}_4\text{H}_4\text{O}_6} \right) \left(\frac{1000 \text{ mL soln}}{0.100 \text{ mol NaOH}} \right)$
 $= 125 \text{ mL NaOH soln}$

4.100 $\text{mol H}_3\text{PO}_4 = (26.04 \text{ mL NaOH}) \left(\frac{1 \text{ L NaOH soln}}{1000 \text{ mL NaOH soln}} \right) \left(\frac{0.1024 \text{ mol NaOH}}{1 \text{ L NaOH}} \right) \left(\frac{1 \text{ mol H}_3\text{PO}_4}{3 \text{ mol NaOH}} \right)$
 $= 8.888 \times 10^{-4} \text{ mol H}_3\text{PO}_4$

$$M \text{H}_3\text{PO}_4 = \left(\frac{8.888 \times 10^{-4} \text{ mol H}_3\text{PO}_4}{12.88 \text{ mL H}_3\text{PO}_4} \right) \left(\frac{1000 \text{ mL H}_3\text{PO}_4}{1 \text{ L H}_3\text{PO}_4} \right) = 6.901 \times 10^{-2} \text{ M H}_3\text{PO}_4$$



4.112 (a) The balanced equation for the titration is:



$$\text{mol HC}_2\text{H}_3\text{O}_2 = (20.65 \text{ mL NaOH}) \left(\frac{0.504 \text{ mol NaOH}}{1000 \text{ mL NaOH}} \right) \left(\frac{1 \text{ mol HC}_2\text{H}_3\text{O}_2}{1 \text{ mol NaOH}} \right)$$

$$= 1.04 \times 10^{-2} \text{ mol HC}_2\text{H}_3\text{O}_2$$

$$1.04 \times 10^{-2} \text{ mol} / 0.0125 \text{ L} = 0.833 \text{ M HC}_2\text{H}_3\text{O}_2$$