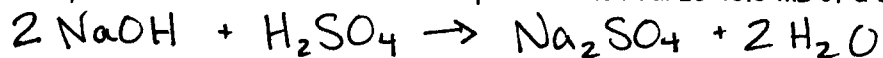


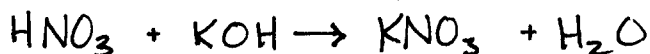
Stoichiometry - Titrations

1. What is the molarity of a sodium hydroxide solution if 25.0 mL is required to neutralize 40.0 mL of a 1.50 M solution of sulfuric acid?



$$C_b = \frac{C_a V_a R_b}{V_b R_a} = \frac{(1.50 \text{ M})(0.0400 \text{ L})(2)}{(0.0250 \text{ L})(1)} = 4.80 \text{ mol/L}$$

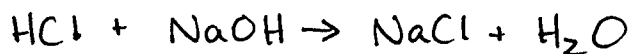
2. Calculate the volume of a 6.00 M solution of nitric acid necessary to neutralize 30.0 mL of a 4.00 M solution of potassium hydroxide.



$$V_a = \frac{C_b V_b R_a}{C_a R_b} = \frac{(4.00 \text{ M})(0.0300 \text{ L})(1)}{(6.00 \text{ M})(1)} = 0.0200 \text{ L} \quad \text{or } 20.0 \text{ mL}$$

3. Calculate the unknown quantity required for complete neutralization of the following:

	Acid		Base	
	<u>Concentration</u>	<u>Volume</u>	<u>Concentration</u>	<u>Volume</u>
a)	0.250 M HCl	30.00 mL	? NaOH	25.00 mL



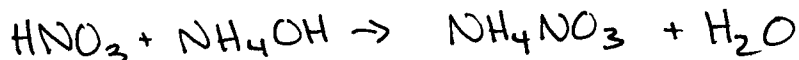
$$C_b = \frac{C_a V_a R_b}{V_b R_a} = \frac{(0.250 \text{ M})(0.03000 \text{ L})(1)}{(0.02500 \text{ L})(1)} = 0.300 \text{ mol/L}$$

b)	0.500 M H ₂ SO ₄	?	0.750 M KOH	20.00 mL
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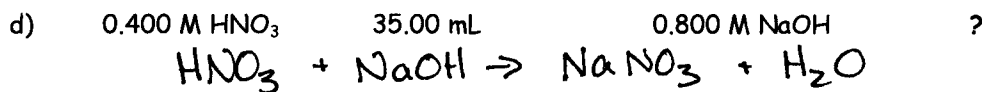


$$V_a = \frac{C_b V_b R_a}{C_a R_b} = \frac{(0.750 \text{ M})(0.02000 \text{ L})(1)}{(0.500 \text{ M})(2)} = 0.0150 \text{ L} \quad \text{or } 15.0 \text{ mL}$$

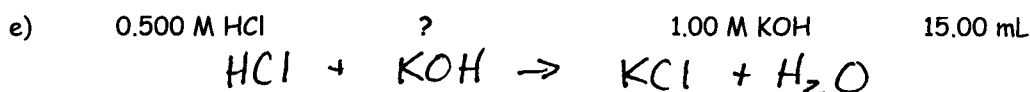
c)	? HNO ₃	15.00 mL	1.50 M NH ₄ OH	25.00 mL
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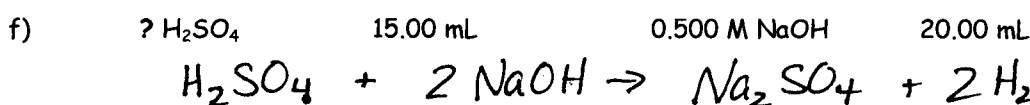
$$C_a = \frac{C_b V_b R_a}{V_a R_b} = \frac{(1.50 \text{ M})(0.02500 \text{ L})(1)}{(0.01500 \text{ L})(1)} = 2.50 \text{ mol/L}$$



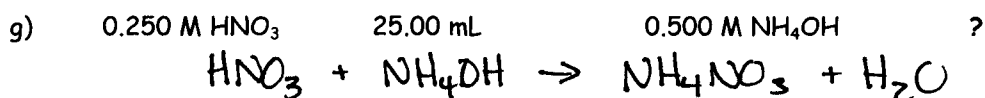
$$V_b = \frac{C_a V_a R_b}{C_b R_a} = \frac{(0.400 \text{ M})(0.03500 \text{ L})(1)}{(0.800 \text{ M})(1)} = 0.0175 \text{ L} \quad \text{or } 17.5 \text{ mL}$$



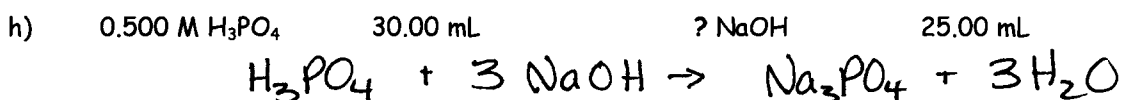
$$V_a = \frac{C_b V_b R_a}{C_a R_b} = \frac{(1.00 \text{ M})(0.01500 \text{ L})(1)}{(0.500 \text{ M})(1)} = 0.0300 \text{ L} \quad \text{or } 30.0 \text{ mL}$$



$$C_a = \frac{C_b V_b R_a}{V_a R_b} = \frac{(0.500 \text{ M})(0.02000 \text{ L})(1)}{(0.01500 \text{ L})(2)} = 0.333 \text{ mol/L}$$

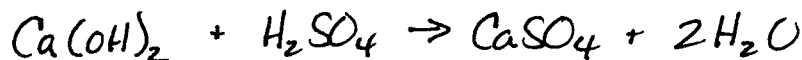


$$V_b = \frac{C_a V_a R_b}{C_b R_a} = \frac{(0.250 \text{ M})(0.02500 \text{ L})(1)}{(0.500 \text{ M})(1)} = 0.0125 \text{ L} \quad \text{or } 12.5 \text{ mL}$$



$$C_b = \frac{C_a V_a R_b}{V_b R_a} = \frac{(0.500 \text{ M})(0.03000 \text{ L})(3)}{(0.02500 \text{ L})(1)} = 1.80 \text{ mol/L}$$

4. How many grams of calcium hydroxide are required to neutralize 50.0 mL of a 1.00 M sulfuric acid solution?



$$n = C \cdot V = (1.00 \text{ M})(0.0500 \text{ L}) = 0.0500 \text{ mol H}_2\text{SO}_4$$

$$(0.0500 \text{ mol H}_2\text{SO}_4) \left(\frac{1 \text{ mol Ca(OH)}_2}{1 \text{ mol H}_2\text{SO}_4} \right) (74.09268 \text{ g/mol}) = 3.70 \text{ g Ca(OH)}_2$$

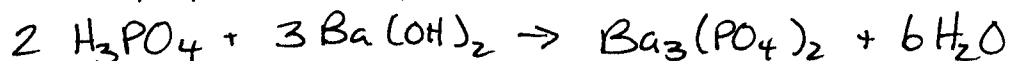
5. Calculate the mass of ammonium hydroxide necessary to neutralize 30.0 mL of a 0.0500 M nitric acid solution.



$$n = C \cdot V = (0.0500 \text{ mol/L})(0.0300 \text{ L}) = 0.00150 \text{ mol HNO}_3$$

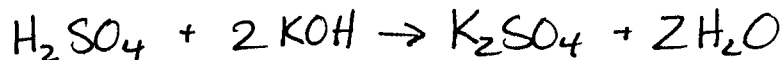
$$(0.00150 \text{ mol HNO}_3) \left(\frac{1 \text{ mol NH}_4\text{OH}}{1 \text{ mol HNO}_3} \right) \left(35.0458 \frac{\text{g}}{\text{mol}} \right) = 0.0526 \text{ g NH}_4\text{OH}$$

6. What volume of 0.250 M phosphoric acid is required to neutralize 30.0 ml of a 1.50 M barium hydroxide solution?



$$V_a = \frac{C_b V_b R_a}{C_a R_b} = \frac{(1.50 \text{ M})(0.0300 \text{ L})(2)}{(0.250 \text{ M})(3)} = 0.120 \text{ L}$$

7. Determine the molarity of a sulfuric acid solution if 30.0 mL is used to neutralize 40.0 mL of a 0.500 M potassium hydroxide solution.



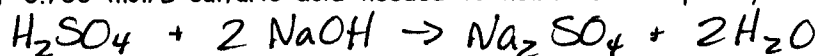
$$C_a = \frac{C_b V_b R_a}{V_a R_b} = \frac{(0.500 \text{ mol/L})(0.0400 \text{ L})(1)}{(0.0300 \text{ L})(2)} = 0.333 \text{ mol/L}$$

8. What is the molarity of a phosphoric acid solution if 25.0 mL of the solution is necessary to neutralize 30.0 mL of a 0.500 M potassium hydroxide solution?



$$C_a = \frac{C_b V_b R_a}{V_a R_b} = \frac{(0.500 \text{ mol/L})(0.0300 \text{ L})(1)}{(0.0250 \text{ L})(3)} = 0.200 \text{ mol/L}$$

9. Calculate the volume of 0.750 mol/L sulfuric acid needed to neutralize completely 20.00 g of sodium hydroxide.



$$\left(\frac{20.00 \text{ g NaOH}}{39.99711 \text{ g/mol}} \right) \left(\frac{1 \text{ mol H}_2\text{SO}_4}{2 \text{ mol NaOH}} \right) = 0.2500 \text{ mol H}_2\text{SO}_4$$

$$V = \frac{n}{C} = \frac{0.2500 \text{ mol}}{0.750 \frac{\text{mol}}{\text{L}}} = 0.333 \text{ L}$$

10. In a laboratory experiment involving the neutralization of vinegar (acetic acid solution) using 0.500 mol/L sodium hydroxide, the following data were collected:

	<u>Volume of Vinegar</u>	<u>Volume of Base</u>
Trial 1	10.00 mL	17.59 mL
Trial 2	15.27 mL	28.39 mL
Trial 3	20.14 mL	36.58 mL

- a) Calculate the molarity of the vinegar in each trial. $\text{HC}_2\text{H}_3\text{O}_2 + \text{NaOH} \rightarrow \text{NaC}_2\text{H}_3\text{O}_2 + \text{H}_2\text{O}$

$$C_a = \frac{C_b V_b R_b}{V_a R_a}$$

$$\text{Trial 1} = \frac{(0.500 \frac{\text{mol}}{\text{L}})(0.01759 \text{ L})(1)}{(0.01000 \text{ L})(1)} = 0.880 \frac{\text{mol}}{\text{L}} \text{ (1)}$$

$$\text{Trial 2} = \frac{(0.500 \frac{\text{mol}}{\text{L}})(0.02839 \text{ L})(1)}{(0.01527 \text{ L})(1)} = 0.930 \frac{\text{mol}}{\text{L}} \text{ (2)}$$

$$\text{Trial 3} = \frac{(0.500 \frac{\text{mol}}{\text{L}})(0.03658 \text{ L})(1)}{(0.02014 \text{ L})(1)} = 0.908 \frac{\text{mol}}{\text{L}} \text{ (3)}$$

- b) Calculate the average molarity of vinegar for the three trials.

$$\text{average} = \frac{0.8795 + 0.9296 + 0.9081}{3} = 0.906 \frac{\text{mol}}{\text{L}}$$

- c) Calculate the mass of acetic acid in each trial.

$$n = C \cdot V$$

$$\text{Trial 1} \quad (0.8795 \frac{\text{mol}}{\text{L}})(0.01000 \text{ L}) = 0.008795 \text{ mol}$$

$$(0.008795 \text{ mol})(60.0504 \text{ g/mol}) = 0.528 \text{ g} \text{ (1)}$$

$$\text{Trial 2} \quad (0.9296 \frac{\text{mol}}{\text{L}})(0.01527 \text{ L}) = 0.01419 \text{ mol}$$

$$(0.01419 \text{ mol})(60.0504 \text{ g/mol}) = 0.852 \text{ g} \text{ (2)}$$

$$\text{Trial 3} \quad (0.9081 \frac{\text{mol}}{\text{L}})(0.02014 \text{ L}) = 0.01829 \text{ mol}$$

$$(0.01829 \text{ mol})(60.0504 \text{ g/mol}) = 1.10 \text{ g} \text{ (3)}$$

- d) Calculate the mass percentage of acetic acid in vinegar for each trial. Assume that the solution has a density of 1.00 g/mL.

$$\text{Trial 1} \quad \frac{0.528 \text{ g}}{10.00 \text{ g}} \times 100 = 5.28 \%$$

$$\text{Trial 2} \quad \frac{0.852 \text{ g}}{15.27 \text{ g}} \times 100 = 5.58 \%$$

$$\text{Trial 3} \quad \frac{1.10 \text{ g}}{20.14 \text{ g}} \times 100 = 5.45 \%$$

- e) Calculate the average percentage of acetic acid in vinegar for the three trials. If the correct percentage is 5.40%, what is the percent error? Which trial gave the best results?

$$\text{Average} = \frac{5.28 + 5.58 + 5.45}{3} = 5.44 \%$$

$$\% \text{ error} = \frac{5.40 - 5.44}{5.40} \times 100$$

Trial 3 gave the best results

11. A titration of 15.0 mL of household ammonia (NH_4OH) required 40.0 mL of a 1.00 mol/L hydrochloric acid solution. Calculate the concentration of the household ammonia. $\text{NH}_4\text{OH} + \text{HCl} \rightarrow \text{NH}_4\text{Cl} + \text{H}_2\text{O}$

$$C_b = \frac{C_a V_a R_b}{V_b R_a} = \frac{(1.00 \text{ mol/L})(0.0400 \text{ L})(1)}{(0.0150 \text{ mol/L})(1)} = 2.67 \text{ mol/L } \text{NH}_4\text{OH}$$

12. Determine the mass of the precipitate of lead(II) sulfate which is produced by the reaction of 30.0 mL of 0.750 M lead(II) nitrate with excess sulfuric acid. $\text{Pb}(\text{NO}_3)_2 + \text{H}_2\text{SO}_4 \rightarrow \text{PbSO}_4 + 2 \text{HNO}_3$

$$n = C \cdot V = (0.750 \text{ mol/L})(0.0300 \text{ L}) = 0.0225 \text{ mol } \text{Pb}(\text{NO}_3)_2$$

$$(0.0225 \text{ mol } \text{Pb}(\text{NO}_3)_2) \left(\frac{1 \text{ mol } \text{PbSO}_4}{1 \text{ mol } \text{Pb}(\text{NO}_3)_2} \right) (303.2636 \text{ g/mol}) = 6.82 \text{ g } \text{PbSO}_4$$

13. Calculate the mass of pure sodium carbonate required to react completely with 20.00 mL of 0.250 mol/L hydrochloric acid. $2 \text{HCl} + \text{Na}_2\text{CO}_3 \rightarrow \text{H}_2\text{CO}_3 + 2 \text{NaCl}$

$$n = C \cdot V = (0.250 \text{ mol/L})(0.02000 \text{ L}) = 0.00500 \text{ mol } \text{HCl}$$

$$(0.00500 \text{ mol } \text{HCl}) \left(\frac{1 \text{ mol } \text{Na}_2\text{CO}_3}{2 \text{ mol } \text{HCl}} \right) (105.98874 \text{ g/mol}) = 0.265 \text{ g } \text{Na}_2\text{CO}_3$$

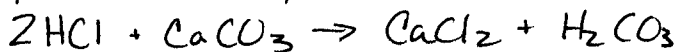
14. What volume of 0.250 M silver nitrate is required to precipitate all the chloride ion as silver chloride in a solution made by dissolving a sample of rock salt which has a mass of 0.300 g and is known to be 99.0% pure sodium chloride? $\text{AgNO}_3 + \text{NaCl} \rightarrow \text{AgCl} + \text{NaNO}_3$

$$(0.300 \text{ g})(0.990) = 0.297 \text{ g}$$

$$\left(\frac{0.297 \text{ g } \text{NaCl}}{58.44277 \text{ g/mol}} \right) \left(\frac{1 \text{ mol } \text{AgNO}_3}{1 \text{ mol } \text{NaCl}} \right) = 0.00508 \text{ mol } \text{AgNO}_3$$

$$V = \frac{n}{C} = \frac{0.00508 \text{ mol}}{0.250 \text{ mol/L}} = 0.0203 \text{ L} \text{ or } 20.3 \text{ mL}$$

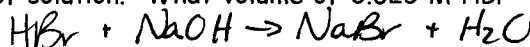
15. If 1.25 g of pure calcium carbonate requires 25.50 mL of a hydrochloric acid solution for complete reaction, calculate the molarity of the acid.



$$\left(\frac{1.25 \text{ g CaCO}_3}{100.0872 \text{ g/mol}} \right) \left(\frac{2 \text{ mol HCl}}{1 \text{ mol CaCO}_3} \right) = 0.0250 \text{ mol HCl}$$

$$C = \frac{n}{V} = \frac{0.0250 \text{ mol}}{0.02550 \text{ L}} = 0.980 \frac{\text{mol}}{\text{L}}$$

16. 17.5 g of NaOH is dissolved in enough water to make 500.0 cm³ of solution. What volume of 0.625 M HBr would be required to neutralize 50.0 cm³ of the NaOH solution?



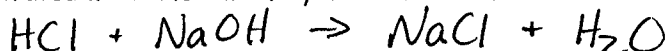
$$\frac{17.5 \text{ g NaOH}}{39.99711 \text{ g/mol}} = 0.438 \text{ mol}$$

$$V_a = \frac{C_b V_b R_a}{C_a R_b} = \frac{(0.875 \text{ M})(0.0500 \text{ L})(1)}{(0.625 \frac{\text{mol}}{\text{L}})(1)}$$

$$C = \frac{n}{V} = \frac{0.438 \text{ mol}}{0.5000 \text{ L}} = 0.875 \frac{\text{mol}}{\text{L}}$$

$$= 0.0700 \text{ L or } 70.0 \text{ mL}$$

17. A solution was prepared by dissolving 25.9 g of sodium hydroxide in enough water to make 500.0 cm³ of solution. 25.0 cm³ of this solution was titrated with 17.6 cm³ of hydrochloric acid. What is the concentration of the hydrochloric acid solution?



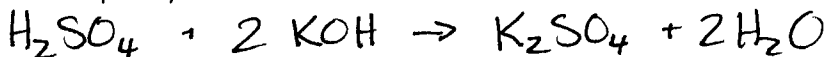
$$\frac{25.9 \text{ g NaOH}}{39.99711 \text{ g/mol}} = 0.648 \text{ mol}$$

$$C_a = \frac{C_b V_b R_a}{V_a R_b} = \frac{(1.30 \frac{\text{mol}}{\text{L}})(0.0250 \text{ L})(1)}{(0.0176 \text{ L})(1)}$$

$$C = \frac{n}{V} = \frac{0.648 \text{ mol}}{0.500 \text{ L}} = 1.30 \frac{\text{mol}}{\text{L}}$$

$$= 1.84 \frac{\text{mol}}{\text{L}}$$

18. A solution was prepared by taking 8.60 cm³ of 18.0 M H₂SO₄ and diluting it to a volume of 750.0 cm³. 28.7 cm³ of this solution was required to completely neutralize 25.0 cm³ of a KOH solution. What is the molarity of the base?



Dilution

$$C_1 V_1 = C_2 V_2$$

$$C_2 = \frac{(18.0 \text{ M})(8.60 \text{ cm}^3)}{750.0 \text{ cm}^3}$$

$$= 0.206 \frac{\text{mol}}{\text{L}}$$

$$C_b = \frac{C_a V_a R_b}{V_b R_a} = \frac{(0.206 \frac{\text{mol}}{\text{L}})(0.0287 \text{ L})(2)}{(0.0250 \text{ L})(1)}$$

$$= 0.474 \frac{\text{mol}}{\text{L}}$$

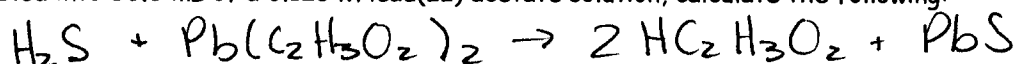
19. What volume of 1.50 M hydrochloric acid solution is required to react completely with a 0.500 g sample of iron(II) sulfide ore if the ore contains 95.0% iron(II) sulfide? $2\text{HCl} + \text{FeS} \rightarrow \text{H}_2\text{S} + \text{FeCl}_2$

$$(0.500 \text{ g})(0.950) = 0.475 \text{ g FeS}$$

$$\left(\frac{0.475 \text{ g FeS}}{87.913 \text{ g/mol}} \right) \left(\frac{2 \text{ mol HCl}}{1 \text{ mol FeS}} \right) = 0.0108 \text{ mol HCl}$$

$$V = \frac{n}{C} = \frac{0.0108 \text{ mol}}{1.50 \frac{\text{mol}}{\text{L}}} = 0.00720 \text{ L} \text{ or } 7.20 \text{ mL}$$

20. Hydrogen sulfide gas will react with a lead solution to give a precipitate of lead(II) sulfide. If hydrogen sulfide is bubbled into 50.0 mL of a 0.125 M lead(II) acetate solution, calculate the following:



- a) the mass of hydrogen sulfide required for complete reaction

$$n = C \cdot V = (0.125 \text{ mol/L})(0.0500 \text{ L}) = 0.00625 \text{ mol Pb}(\text{C}_2\text{H}_3\text{O}_2)_2$$

$$\left(0.00625 \text{ mol Pb}(\text{C}_2\text{H}_3\text{O}_2)_2 \right) \left(\frac{1 \text{ mol H}_2\text{S}}{1 \text{ mol Pb}(\text{C}_2\text{H}_3\text{O}_2)_2} \right) \left(34.0818 \frac{\text{g}}{\text{mol}} \right) = 0.213 \text{ g}$$

- b) the volume of hydrogen sulfide gas at STP required for complete reaction

$$\frac{0.213 \text{ g}}{34.0818 \frac{\text{g}}{\text{mol}}} = 0.00625 \text{ mol H}_2\text{S} \quad (0.00625 \text{ mol})(22.4 \frac{\text{L}}{\text{mol}}) = 0.140 \text{ L H}_2\text{S}$$

- c) the mass of lead(II) sulfide produced

$$\left(0.00625 \text{ mol Pb}(\text{C}_2\text{H}_3\text{O}_2)_2 \right) \left(\frac{1 \text{ mol PbS}}{1 \text{ mol Pb}(\text{C}_2\text{H}_3\text{O}_2)_2} \right) \left(239.266 \frac{\text{g}}{\text{mol}} \right) = 1.50 \text{ g PbS}$$

21. Some sulfuric acid is spilled on a lab bench. It can be neutralized by sprinkling sodium bicarbonate on it and then mopping up the resultant solution. The sodium bicarbonate reacts with the sulfuric acid as follows:

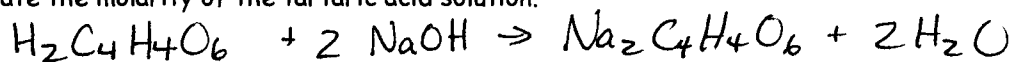


Sodium bicarbonate is added until the fizzing due to the formation of carbon dioxide gas stops. If 35.0 mL of 6.0 mol/L sulfuric acid were spilled, what is the minimum mass of sodium bicarbonate that must be added to the spill to neutralize the acid?

$$n = C \cdot V = \left(6.0 \frac{\text{mol}}{\text{L}} \right) (0.0350 \text{ L}) = 0.21 \text{ mol H}_2\text{SO}_4$$

$$(0.21 \text{ mol H}_2\text{SO}_4) \left(\frac{2 \text{ mol NaHCO}_3}{1 \text{ mol H}_2\text{SO}_4} \right) \left(84.00691 \frac{\text{g}}{\text{mol}} \right) = 35 \text{ g NaHCO}_3$$

22. Tartaric acid, $\text{H}_2\text{C}_4\text{H}_4\text{O}_6$, is often present in wines and precipitates from solution as the wine ages. A solution containing an unknown concentration of the acid is titrated with sodium hydroxide. It requires 22.62 mL of 0.2000 M sodium hydroxide solution to titrate 40.00 mL of the tartaric acid solution. Write a balanced equation and calculate the molarity of the tartaric acid solution.



$$C_a = \frac{C_b V_b R_a}{V_a R_b} = \frac{(0.2000 \frac{\text{mol}}{\text{L}})(0.02262 \text{ L})(1)}{(0.04000 \text{ L})(2)}$$

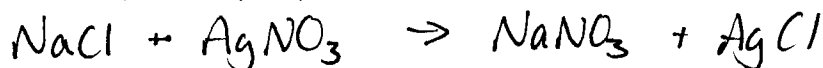
$$= 0.05655 \frac{\text{mol}}{\text{L}} \text{ H}_2\text{C}_4\text{H}_4\text{O}_6$$

23. A sample of solid calcium hydroxide is stirred in water at 30°C for a long time, until the solution contains as much dissolved calcium hydroxide as it can hold. A 100.0 mL sample of this solution is withdrawn and titrated with $5.00 \times 10^{-2} \text{ mol/L}$ hydrobromic acid. It requires 48.8 mL of the acid solution for neutralization. What is the molarity of the calcium hydroxide solution? $2 \text{HBr} + \text{Ca}(\text{OH})_2 \rightarrow \text{CaBr}_2 + 2 \text{H}_2\text{O}$

$$C_b = \frac{C_a V_a R_b}{V_b R_a} = \frac{(5.00 \times 10^{-2} \frac{\text{mol}}{\text{L}})(0.0488 \text{ L})(1)}{(0.1000 \text{ L})(2)}$$

$$= 0.0122 \frac{\text{mol}}{\text{L}} \text{ Ca}(\text{OH})_2$$

24. What mass of sodium chloride is required to precipitate all the silver ions from 20.0 mL of 0.100 M silver nitrate solution?



$$n = C \cdot V = (0.100 \frac{\text{mol}}{\text{L}})(0.0200 \text{ L}) = 0.00200 \text{ mol AgNO}_3$$

$$(0.00200 \text{ mol AgNO}_3) \left(\frac{1 \text{ mol NaCl}}{1 \text{ mol AgNO}_3} \right) \left(58.44277 \frac{\text{g}}{\text{mol}} \right)$$

$$= 0.117 \text{ g NaCl}$$