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?

$$2\,NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2\,H_2O$$

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

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.

$$HNO_3 + KOH \rightarrow KNO_3 + H_2O$$

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

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

	Acid		Base	
	Concentration	Volume	Concentration	Volume
a)	0.250 M HCl	30.00 mL	? NaOH	25.00 mL

$$HCl + NaOH \rightarrow NaCl + H_2O$$

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

b) 0.500 M H_2SO_4 ? 0.750 M KOH 20.00 mL

$$H_2SO_4 + 2\,KOH \rightarrow K_2SO_4 + 2\,H_2O$$

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

c) ? HNO_3 15.00 mL 1.50 M NH_4OH 25.00 mL

$$HNO_3 + NH_4OH \rightarrow NH_4NO_3 + H_2O$$

$$C_a = \frac{C_b V_b R_a}{V_a R_b} = \frac{(1.50\ M)(0.02500\ L)(1)}{(0.01500\ L)(1)} = 2.50\ mol/L$$

d) 0.400 M HNO_3 35.00 mL 0.800 M NaOH ?

$$HNO_3 + NaOH \rightarrow NaNO_3 + H_2O$$

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

e) 0.500 M HCl ? 1.00 M KOH 15.00 mL

$$HCl + KOH \rightarrow KCl + H_2O$$

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

f) ? H_2SO_4 15.00 mL 0.500 M NaOH 20.00 mL

$$H_2SO_4 + 2\ NaOH \rightarrow Na_2SO_4 + 2\ H_2O$$

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

g) 0.250 M HNO_3 25.00 mL 0.500 M NH_4OH ?

$$HNO_3 + NH_4OH \rightarrow NH_4NO_3 + H_2O$$

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

h) 0.500 M H_3PO_4 30.00 mL ? NaOH 25.00 mL

$$H_3PO_4 + 3\ NaOH \rightarrow Na_3PO_4 + 3\ H_2O$$

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

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

$$Ca(OH)_2 + H_2SO_4 \rightarrow CaSO_4 + 2\ H_2O$$

$$n = C \cdot V = (1.00\ M)(0.0500\ L) = 0.0500\ mol\ H_2SO_4$$

$$(0.0500\ mol\ H_2SO_4)\left(\frac{1\ mol\ Ca(OH)_2}{1\ mol\ H_2SO_4}\right)\left(74.09268\ g/mol\right) = 3.70\ g\ Ca(OH)_2$$

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

$$NH_4OH + HNO_3 \rightarrow NH_4NO_3 + H_2O$$

$$n = C \cdot V = (0.0500\ mol/L)(0.0300\ L) = 0.00150\ mol\ HNO_3$$

$$(0.00150\ mol\ HNO_3)\left(\frac{1\ mol\ NH_4OH}{1\ mol\ HNO_3}\right)(35.0458\ g/mol) = 0.0526\ g\ NH_4OH$$

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

$$2\ H_3PO_4 + 3\ Ba(OH)_2 \rightarrow Ba_3(PO_4)_2 + 6\ H_2O$$

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

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.

$$H_2SO_4 + 2\ KOH \rightarrow K_2SO_4 + 2\ H_2O$$

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

$$= 0.333\ mol/L$$

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?

$$H_3PO_4 + 3\ KOH \rightarrow K_3PO_4 + 3\ H_2O$$

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

$$= 0.200\ mol/L$$

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

$$H_2SO_4 + 2\ NaOH \rightarrow Na_2SO_4 + 2\ H_2O$$

$$\left(\frac{20.00\ g\ NaOH}{39.9971\ g/mol}\right)\left(\frac{1\ mol\ H_2SO_4}{2\ mol\ NaOH}\right) = 0.2500\ mol\ H_2SO_4$$

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

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:

	Volume of Vinegar	Volume of Base
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. $HC_2H_3O_2 + NaOH \rightarrow NaC_2H_3O_2 + H_2O$

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

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

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

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

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

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

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

$n = C \cdot V$

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

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

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

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

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

$(0.01829\ mol)(60.0504\ g/mol) = 1.10\ g$ (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.

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

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

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

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?

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

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

$= -0.679\%\ \text{error}$

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. $NH_4OH + HCl \rightarrow NH_4Cl + H_2O$

$$C_b = \frac{C_a V_a K_b}{V_b K_a} = \frac{(1.00\ mol/L)(0.0400\ L)(1)}{(0.0150\ mol/L)(1)} = 2.67\ mol/L\ NH_4OH$$

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. $Pb(NO_3)_2 + H_2SO_4 \rightarrow PbSO_4 + 2\ HNO_3$

$$n = C \cdot V = (0.750\ mol/L)(0.03000\ L) = 0.0225\ mol\ Pb(NO_3)_2$$

$$(0.0225\ mol\ Pb(NO_3)_2)\left(\frac{1\ mol\ PbSO_4}{1\ mol\ Pb(NO_3)_2}\right)(303.2636\ g/mol)$$

$$= 6.82\ g\ PbSO_4$$

13. Calculate the mass of pure sodium carbonate required to react completely with 20.00 mL of 0.250 mol/L hydrochloric acid. $2\ HCl + Na_2CO_3 \rightarrow H_2CO_3 + 2\ NaCl$

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

$$(0.00500\ mol\ HCl)\left(\frac{1\ mol\ Na_2CO_3}{2\ mol\ HCl}\right)\left(105.98874\ \frac{g}{mol}\right) = 0.265\ g\ Na_2CO_3$$

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? $AgNO_3 + NaCl \rightarrow AgCl + NaNO_3$

$$(0.300\ g)(0.990) = 0.297\ g$$

$$\left(\frac{0.297\ g\ NaCl}{58.4277\ g/mol}\right)\left(\frac{1\ mol\ AgNO_3}{1\ mol\ NaCl}\right) = 0.00508\ mol\ AgNO_3$$

$$V = \frac{n}{C} = \frac{0.00508\ mol}{0.250\ \frac{mol}{L}} = 0.0203\ L$$

or 20.3 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. $2HCl + CaCO_3 \rightarrow CaCl_2 + H_2CO_3$

$$\left(\frac{1.25\ g\ CaCO_3}{100.0872\ g/mol}\right)\left(\frac{2\ mol\ HCl}{1\ mol\ CaCO_3}\right) = 0.0250\ mol\ HCl$$

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

16. 17.5 g of NaOH is dissolved in enough water to make 500.0 cm^3 of solution. What volume of 0.625 M HBr would be required to neutralize 50.0 cm^3 of the NaOH solution? $HBr + NaOH \rightarrow NaBr + H_2O$

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

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

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

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

17. A solution was prepared by dissolving 25.9 g of sodium hydroxide in enough water to make 500.0 cm^3 of solution. 25.0 cm^3 of this solution was titrated with 17.6 cm^3 of hydrochloric acid. What is the concentration of the hydrochloric acid solution? $HCl + NaOH \rightarrow NaCl + H_2O$

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

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

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

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

18. A solution was prepared by taking 8.60 cm^3 of 18.0 M H_2SO_4 and diluting it to a volume of 750.0 cm^3. 28.7 cm^3 of this solution was required to completely neutralize 25.0 cm^3 of a KOH solution. What is the molarity of the base? $H_2SO_4 + 2\ KOH \rightarrow K_2SO_4 + 2H_2O$

Dilution

$C_1V_1 = C_2V_2$

$$C_2 = \frac{(18.0\ M)(8.60\ cm^3)}{750.0\ cm^3} = 0.206\ \frac{mol}{L}$$

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

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

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? $2HCl + FeS \rightarrow H_2S + FeCl_2$

$(0.500\,g)(0.950) = 0.475\,g\ FeS$

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

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

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:

$H_2S + Pb(C_2H_3O_2)_2 \rightarrow 2HC_2H_3O_2 + PbS$

a) the mass of hydrogen sulfide required for complete reaction

$n = C \cdot V = (0.125\,mol/L)(0.0500\,L) = 0.00625\ mol\ Pb(C_2H_3O_2)_2$

$\left(0.00625\ mol\ Pb(C_2H_3O_2)_2\right)\left(\frac{1\ mol\ H_2S}{1\ mol\ Pb(C_2H_3O_2)_2}\right)\left(34.08188\,\frac{g}{mol}\right) = 0.213\,g$

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

$\frac{0.213\,g}{34.08188\,\frac{g}{mol}} = 0.00625\ mol\ H_2S$ $\quad (0.00625\,mol)(22.4\,L/mol) = 0.140\,L\ H_2S$

c) the mass of lead(II) sulfide produced

$\left(0.00625\ mol\ Pb(C_2H_3O_2)_2\right)\left(\frac{1\ mol\ PbS}{1\ mol\ Pb(C_2H_3O_2)}\right)\left(239.266\,\frac{g}{mol}\right) = 1.50\,g\ PbS$

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:

$2NaHCO_3(s) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l) + 2CO_2(g)$

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?

$n = C \cdot V = \left(6.0\,\frac{mol}{L}\right)(0.0350\,L) = 0.21\ mol\ H_2SO_4$

$\left(0.21\ mol\ H_2SO_4\right)\left(\frac{2\ mol\ NaHCO_3}{1\ mol\ H_2SO_4}\right)\left(84.00691\,\frac{g}{mol}\right) = 35\,g\ NaHCO_3$

22. Tartaric acid, $H_2C_4H_4O_6$, 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.

$$H_2C_4H_4O_6 + 2\ NaOH \rightarrow Na_2C_4H_4O_6 + 2H_2O$$

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

$$= 0.05655\ \frac{mol}{L}\ H_2C_4H_4O_6$$

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 5.00×10^{-2} mol/L hydrobromic acid. It requires 48.8 mL of the acid solution for neutralization. What is the molarity of the calcium hydroxide solution?

$$2\ HBr + Ca(OH)_2 \rightarrow CaBr_2 + 2H_2O$$

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

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

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?

$$NaCl + AgNO_3 \rightarrow NaNO_3 + AgCl$$

$$n = C \cdot V = (0.100\ \frac{mol}{L})(0.0200\ L) = 0.00200\ mol\ AgNO_3$$

$$(0.00200\ mol\ AgNO_3)\left(\frac{1\ mol\ NaCl}{1\ mol\ AgNO_3}\right)\left(58.44277\ \frac{g}{mol}\right)$$

$$= 0.117\ g\ NaCl$$