# Volumetric Calculations

1.

15.5 mL of dilute hydrochloric acid reacts completely with 20.8 mL of 0.0100 mol L$^{-1}$ calcium hydroxide. Calculate the concentration of the hydrochloric acid.

(1) $Ca(OH)_{2(aq)} + 2HCl_{(aq)} \rightarrow CaCl_{2(aq)} + 2H_2O_{(l)}$

$n\ Ca(OH)_2 = c \cdot V$

$= .01000 \times 0.208$

$= 0.000208$ mol

(2) Mole ratio $n Ca(OH)_2 : 2n(HCl)$

$n\ HCl = 2 \times Ca(OH)_2$

$= 2 \times .000208 = 0.000416$ mol

(3) $c_{HCl} = \frac{n}{V} = \frac{0.000416}{0.0155}$

$= 0.0268$ mol/L

2.

20.5 mL of 0.200 mol L⁻¹ hydrochloric acid reacts completely with 18.8 mL of sodium hydroxide solution. Calculate the concentration of the sodium hydroxide.

$NaOH_{(aq)} + HCl_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$

$n\,HCl = cV = 0.200 \times 0.0205$

$= 0.00410\,mol$

$n\,NaOH = \frac{1}{1} \times .00410$

$= .00410\,mol$

$c\,NaOH = \frac{.00410}{0.0188}$

$= .218\,mol/L$

3. A 0.100 mol L[-1] $H_2SO_4$ solution is neutralised with 10.0 mL of a solution of 0.300 M KOH.

**a** Write a balanced equation for this reaction.

**b** What volume of sulfuric acid was neutralised?

(a) $H_2SO_{4(aq)} + \sout{HCl}\ 2KOH_{(aq)} \rightarrow K_2SO_{4(aq)} + 2H_2O_{(l)}$

(b) $n\ KOH = CV = .300 \times .0100$

$= 0.00300\ mol$

$n\ H_2SO_4 = 0.00300 \times \frac{1}{2} = 0.00150$

$V\ H_2SO_4 = \frac{0.00150}{0.100} = 0.0150\ L = 15.0\ mL$

4.

15.0 mL of a nitric acid solution is required to react completely with 10.0 mL of a 0.100 mol $L^{-1}$ $Ca(OH)_2$ solution.

a Write a balanced equation for this reaction.

b What is the concentration of the nitric acid solution?

(a) $2HNO_{3(aq)} + Ca(OH)_{2(aq)} \rightarrow Ca(NO_3)_{2(aq)} + 2H_2O_{(l)}$

(b) $n\ Ca(OH)_2 = CV = 0.100 \times 0.010 = 0.00100\ mol$

$n(HNO_3) = 2 \times 0.00100\ mol = .00200\ mol$

$c(HNO_3) = \frac{n}{V} = \frac{0.00200}{0.0150} = 0.133\ mol/L$

5.

18.26 mL of dilute nitric acid reacts completely with 20.00 mL of 0.09927 mol $L^{-1}$ potassium hydroxide solution.

**a** Write a balanced chemical equation for the reaction between nitric acid and potassium hydroxide.

**b** Calculate the amount, in mol, of potassium hydroxide consumed in this reaction.

**c** What amount, in mol, of nitric acid reacted with the potassium hydroxide in this reaction?

**d** Calculate the concentration of the nitric acid.

(a) $HNO_{3(aq)} + KOH_{(aq)} \rightarrow KNO_{3(aq)} + H_2O_{(l)}$

(b) $n\ KOH = CV = 0.09927 \times 0.02000$

$= 0.001985$ mol

(c) $n\ (HNO_3) = n\ (KOH) = 0.001985$ mol

(d) $c\ (HNO_3) = \frac{n}{V} = \frac{0.001985}{0.01826} = 0.1087$ mol/L

6. Potassium hydrogen phthalate ($KH(C_8H_4O_4)$) is used as a primary standard for the analysis of bases. Calculate the concentration of a standard solution prepared in a 50.00 mL volumetric flask by dissolving 2.042 g of potassium hydrogen phthalate in deionised water. The molar mass of $KH(C_8H_4O_4)$ is 204.2 g mol$^{-1}$.

$$n = \frac{m}{M} = \frac{2.042}{204.2} = 0.01000 \text{ mol}$$

$$c = \frac{n}{V} = \frac{0.01000}{0.050000} = .2000 \text{ mol/L}$$

7. Calculate the mass of anhydrous sodium carbonate ($Na_2CO_3$) required to prepare 250.0 mL of a 0.500 mol $L^{-1}$ standard solution.

$c = \frac{n}{V}$

$n = c \cdot V = \cdot 500 \times \cdot 2500 = 0 \cdot 125$ mol

$m = n \times M = 0 \cdot 125 \times 105 \cdot 99 = 13 \cdot 25$ g

$= 13 \cdot 3$ g.

8.

The concentration of a solution of barium hydroxide ($Ba(OH)_2$) was determined by titration with a standard solution of hydrochloric acid.

A 10.00 mL aliquot of $Ba(OH)_2$ solution was titrated with a 0.125 mol $L^{-1}$ solution of HCl. Titres of 17.23 mL, 17.28 mL and 17.21 mL of HCl were required to reach the end point.

What is the concentration of the barium hydroxide solution?

$2HCl_{(aq)} + Ba(OH)_{2(aq)} \rightarrow BaCl_{2(aq)} + 2H_2O_{(l)}$

Avg titre $= \frac{17.21 + 17.23 + 17.28}{3} = 17.24$ mL

$n\,HCl = C \times V = 0.125 \times 0.01724$

$= .002155$ mol

mole ratio - $\frac{n(Ba(OH)_2)}{n(HCl)} = \frac{1}{2}$

$n\,Ba(OH)_2 = \frac{1}{2} \times n\,HCl = \frac{1}{2} \times .002155$

$= .001078$ mol

$c\,Ba(OH)_2 = \frac{n}{V} = \frac{.001078}{.01000} = 1.08 \times 10^{-1}$ mol/L

9.

Potassium hydrogen phthalate, $KH(C_8H_4O_4)$, is a good primary standard for standardising alkali solutions. It contains one acidic hydrogen per formula unit. Potassium hydrogen phthalate (0.917 g) was dissolved in water and titrated with approximately 0.2 mol $L^{-1}$ sodium hydroxide solution: 27.2 mL hydroxide solution was needed to reach the endpoint. Calculate the accurate molarity of the hydroxide solution.

(1) $KH(C_8H_4O_4)_{(aq)} + NaOH_{(aq)} \rightarrow Na^+_{(aq)} + K(C_8H_4O_4)^-_{(aq)} + H_2O_{(l)}$

(2) Calculate n of KHP with NaOH (reacted)

$n\,KHP = \frac{m}{M} = \frac{0.917}{204.22} = 0.00449$ mol

(3) calculate n of NaOH reacted with KHP, using equation (S.R.)

$n\,NaOH = n\,KHP = 0.00449$ mol

(4) calculate M of NaOH.

$C_{NaOH} = \frac{n\,NaOH}{V_{NaOH}} = \frac{.00449}{0.0272} = 0.165$ M or mol/L

**10.**

The acidity of a particular white wine was determined by titrating 25.0mL of the wine with 0.0511 mol L⁻¹ sodium hydroxide solution; 8.70mL was required. Calculate the molarity of hydrogen ions in the wine. Assume that the hydrogen ions come entirely from diprotic tartaric acid, $H_2C_4H_4O_6$, and calculate the concentration of tartaric acid in the wine in grams per 100mL.

(1) Balance equation

$$H_2C_4H_4O_{6(aq)} + 2NaOH_{(aq)} \rightarrow 2Na^+_{(aq)} + C_4H_4O_6^{2-}{}_{(aq)} + 2H_2O_{(l)}$$

(2) Calculate n NaOH reacted with tartaric acid

$$n_{NaOH} = C_{NaOH} \times V_{NaOH} = 0.0511 \times 0.00870$$
$$= 0.000445 \text{ mol}$$

(3) Calculate n $H^+$ reacted with NaOH

$$H^+_{(aq)} + OH^-_{(aq)} \rightarrow H_2O_{(l)} \quad = n_{H^+} = n_{NaOH}$$

Remember tartaric acid is diprotic acid

$$= 0.000445$$

(4) Calculate Molarity of $H^+$ in tartaric acid

$$C_{H^+} = \frac{n_{H^+}}{V_{H_2C_4H_4O_6}} = \frac{0.000445}{0.0250} = 0.0178 \text{ mol/L}$$

(5) Calculate the conc of tartaric acid in g/100 mL, using equation.

$$n_{H_2C_4H_4O_6} = \frac{1}{2} n_{NaOH} = 0.000222 \text{ mol}$$

$$m_{(H_2C_4H_4O_6)} = n_{(H_2C_4H_4O_6)} \times M_{(H_2C_4H_4O_6)}$$

$$= 0.000222 \times 158.088 = 0.0334 g$$

$$[H_2C_4H_4O_6] = \frac{m}{V} = \frac{0.0334}{0.0250} = 1.33 \text{ g/L}$$

or

0.133 g/100mL

a Oxalic acid dihydrate, $(COOH)_2 \cdot 2H_2O$, can be used as a primary standard for standardising alkali solutions. 0.291 g diprotic oxalic acid required 18.2 mL of a potassium hydroxide solution for exact neutralisation. Calculate the molarity of the hydroxide solution.

b 5.267 g anhydrous sodium carbonate was dissolved in water in a volumetric flask and the volume made up to 250 mL. 10 mL of this solution was pipetted into a conical flask and titrated with hydrochloric acid. 21.3 mL was needed to reach the equivalence point. Calculate the molarity of the hydrochloric acid solution. This solution was then used to determine the concentration of an unknown barium hydroxide solution. 25 mL of the barium hydroxide solution required 27.1 mL hydrochloric acid solution for exact neutralisation. Calculate the molarity of the barium hydroxide solution. In addition, calculate its concentration in grams per litre.

(a) ① $(COOH)_{2(aq)} + 2KOH_{(aq)} \rightarrow (COO\cdot)_{2(aq)} + 2H_2O_{(l)}$

② $n_{(COOH)_2+2H_2O} = \frac{m_{(COOH)_2+2H_2O}}{M_{(COOH)_2+2H_2O}} = \frac{0.291}{126.08}$

$= 2.308 \times 10^{-3}$ mol

③ $n_{KOH} = 2 \times n_{(COOH)_2} = 2 \times 2.308 \times 10^{-3}$

$= 4.616 \times 10^{-3}$ mol

④ $c_{KOH} = \frac{n_{KOH}}{V_{KOH}} = \frac{4.616 \times 10^{-3}}{0.0182} = 0.254$ mol/L

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(b) Original $Na_2CO_3$ solution

$n_{Na_2CO_3} = \frac{m_{Na_2CO_3}}{M_{Na_2CO_3}} = \frac{5.267}{105.99} = 0.04969$ mol

$c_{Na_2CO_3} = \frac{0.04969}{0.250} = 0.1988$ mol/L

Titration b/w $Na_2CO_3$ + HCl solution

$Na_2CO_{3(aq)} + 2HCl_{(aq)} \rightarrow NaCl_{(aq)} + CO_{2(aq)} + H_2O_{(l)}$

$n_{Na_2CO_3} = c_{Na_2CO_3} \times V_{Na_2CO_3}$

$= 0.1988 \times 0.010 = 1.988 \times 10^{-3}$ mol

⟹

**Titration Involving Dilution**

Write a balanced chemical equation.

↓

Use the concentration of the standard solution to calculate the amount, in moles, of the primary standard that reacted.

↓

Use the mole ratio in the equation to determine the amount, in moles, of diluted unknown substance that reacted in the titration.

↓

Determine the concentration of the diluted unknown substance.

↓

Multiply the concentration of the diluted solution by the dilution factor to determine the concentration of the undiluted unknown substance.

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$n_{HCl} = 2 \times n_{Na_2CO_3} = 2 \times 1.988 \times 10^{-3} = 3.976 \times 10^{-3}$ mol

$C_{HCl} = \frac{3.976 \times 10^{-3}}{0.0213} = 0.187$ mol/L

Titration b/w $Ba(OH)_2$ + HCl

$2HCl_{(aq)} + Ba(OH)_{2(aq)} \rightarrow BaCl_{2(aq)} + 2H_2O_{(l)}$

$n_{HCl\,(reacted)} = C \times V = 0.187 \times 0.0271 = 5.06 \times 10^{-3}$ mol

$n_{Ba(OH)_2} = \frac{1}{2}\,HCl = \frac{1}{2} \times 5.06 \times 10^{-3} = 2.53 \times 10^{-3}$ mol

$C_{Ba(OH)_2} = \frac{n_{Ba(OH)_2}}{V_{Ba(OH)_2}} = \frac{2.53 \times 10^{-3}}{0.0250} = 0.101$ mol/L

$C_{g/L} = C_{mol/L} \times M_{Ba(OH)_2} = 0.101 \times 171.36 = \boxed{17.3\,g/L}$

1.

A commercial concrete cleaner contains hydrochloric acid. A 25.00 mL volume of cleaner was diluted to 250.0 mL in a volumetric flask.

A 20.00 mL aliquot of 0.4480 mol $L^{-1}$ sodium carbonate solution was placed in a conical flask. Methyl orange indicator was added and the solution was titrated with the diluted cleaner. The indicator changed permanently from yellow to red when 19.84 mL of the cleaner was added.

Calculate the concentration of hydrochloric acid in the concrete cleaner.

$$2HCl_{(aq)} + Na_2CO_{3(aq)} \rightarrow 2NaCl_{(aq)} + H_2O_{(l)} + CO_{2(g)}$$

$n_{(Na_2CO_3)} = CV = 0.4480 \times 0.02000$

$= 0.008960$ mol

mole ratio

$n\,HCl = 2 \times n\,Na_2CO_3$

$= 2 \times 0.008960$

$= 0.01792$ mol

$V_{dil\,HCl} = 0.01984$ L

$c = \frac{n}{V} = \frac{0.01792}{0.01984}$

$= 0.9032$ mol/L

Dilution factor $= \frac{250.0}{25.0} = 10.00$

$C_1V_1 = C_2V$ (can use)

so undiluted c(HCl) = [dil HCl] × 10

$= 0.9032 \times 10$

$= 9.032$ mol/L

**2.**

A commercial concrete cleaner contains hydrochloric acid. A 10.00 mL volume of cleaner was diluted to 250.0 mL in a volumetric flask.

A 20.00 mL aliquot of 0.2406 mol L$^{-1}$ sodium carbonate solution was placed in a conical flask. Methyl orange indicator was added and the solution was titrated with the diluted cleaner. The indicator changed permanently from yellow to pink when 18.68 mL of the cleaner was added.

Calculate the concentration of hydrochloric acid in the concrete cleaner.

① $2HCl_{(aq)} + Na_2CO_{3(aq)} \rightarrow 2NaCl_{(aq)} + H_2O_{(l)} + CO_{2(g)}$

$n\ Na_2CO_3 = cV = 0.2406 \times 0.02000$
$0.004812\ mol$

mole ratio $n\ HCl = 2 \times n\ Na_2CO_3$
$= 2 \times .004812$
$= 0.009624\ mol$

$V_{(dil\ HCl)} = 0.01868\ L$

$c_{(HCl)} = \frac{n}{V} = \frac{0.009629}{0.01868}$

$= 0.5152\ mol/L$

Dilution factor $= \frac{250.0}{10.00} = 25.00$

so undilute(HCl) $= [dil\ HCl] \times 25$
$= .5152 \times 25$
$= 12.88\ mol/L$