18. Consider the following acid-base reaction

$$HS^-(aq) + HSO_4^-(aq) \rightleftharpoons SO_4^{2-}(aq) + H_2S(g)$$

Which of the following cells correctly identifies the acid/base conjugate pairs in this equilibrium?

	Base	**Conjugate acid**	**Acid**	**Conjugate base**
a)	SO_4^{2-}	H_2S	HSO_4^-	HS^-
b)	HS^-	H_2S	HSO_4^-	SO_4^{2-}
c)	HS^-	SO_4^{2-}	HSO_4^-	H_2S
d)	H_2S	SO_4^{2-}	HS^-	HSO_4^-

19. Which one of the following solutions would have a pH of 10?

(a) 1×10^{-10} mol L^{-1} sodium hydroxide

(b) 5×10^{-5} mol L^{-1} barium hydroxide

(c) 1×10^{-4} mol L^{-1} calcium hydroxide

(d) 1×10^{-10} mol L^{-1} nitric acid

20. Which one of the following lists the oxides in order of increasing acidity?

(a) MgO, CaO, SrO, BaO

(b) SO_2, Al_2O_3, MgO, Na_2O

(c) Na_2O, MgO, Al_2O_3, SO_2

(d) CuO, Fe_2O_3, CaO

Acid Base Calculations

1. 20.0 mL of a 0.015 mol L^{-1} solution of $Ca(OH)_2$ is mixed with 80.0 mL of a 0.010 mol L^{-1} solution of HNO_3. What would the final pH be?

2. If 25.0 mL of 0.200 M sodium hydroxide solution is added to 30.0 mL of 0.175 M nitric acid, what is the pH of the mixture?

3. 200 mL of 0.0500 mol L^{-1} barium hydroxide solution is mixed with 400 mL of a 0.200 M nitric acid. The mixture is then diluted with water so that the final volume is 6.00 L. What is the pH of the final solution?

4. (a) What mass of HCl must be dissolved in 300 mL of solution to give a solution of pH = 2?

   (b) What will be the pH of the solution containing 0.0730 g of HCl made up to 2.00 L of solution?

5. (a) What mass of sodium hydroxide must be dissolved in 600 mL of solution to give a pH of 13?

   (b) If 0.600 g of sodium hydroxide is dissolved in 1500 mL of solution, what will be the pH of the final solution?

6. What volume of water must be added to 20.0 mL of a 0.100 M hydrochloric acid to give a solution of pH 3?

7. What volume of HCl gas at STP must be added to 1.00 L of water to produce a solution which has a pH of 4?

8. Explain, using equations, why aqueous solutions of sodium carbonate, sodium sulfide and sodium ethanoate all have pH values greater than 7.

9. A 10.0 mL sample of 0.00500 M $Ca(OH)_2$ is diluted with water to 1.0 L.

   (a) What is the pH of the undiluted solution?

   (b) What change occurs in the pH of the solution due to the dilution?

   (c) What mass of $Ca(OH)_2$ is present in the diluted solution?

(d) What volume of CO_2 at 25°C and 110 kPa pressure must be bubbled through the dilute solution in order to convert the OH^- ions into CO_3^{2-} ions?

10. Exactly 23.6 mL of a 0.131 M HCl solution was required to completely react with 25.0 mL of NaOH solution. What was the concentration of the NaOH solution?

11. An approximately 0.1 M HCl solution was standardised (its exact concentration found) by titrating it into a solution containing 0.1223 g of 99.95% pure Na_2CO_3.

The equation for the reaction is:

$$Na_2CO_3(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2O(l) + CO_2(g).$$

The equivalence point was reached when 22.65 mL of the HCl solution had been used.

What was the exact concentration of the acid?

12. Calculate the concentration of ethanoic acid in a titration with sodium hydroxide after 30.0 mL of 0.100 M NaOH solution has been added to 50.0 mL of 0.100 M ethanoic acid solution.

13. In the titration of 50.0 mL of a 0.020 M solution of $NaHCO_3$ with a 0.020 M HCl solution, what is the concentration of the excess species after 25.0 mL of the acid solution has been added?

14. A hydrated form of sodium carbonate, called washing soda, has the formula $Na_2CO_3 . \times H_2O$.

A crushed 0.561 g sample of washing soda required 30.50 mL of a 0.131 mol L^{-1} HNO_3 solution for complete neutralisation.

Calculate the value of x, the number of molecules of water of crystallisation in the molecule.

15. Four 20.0 mL samples of different HBr solutions were titrated with 0.100 M NaOH solution. The volumes of base required to reach the equivalence point in each were

(a) 27.5 mL (b) 21.8 mL (c) 48.9 mL (d) 25.5 mL

Calculate the concentrations of the four HBr solutions.

16. A 20.0 mL sample of a 0.200 M HCl solution is titrated with 0.200 M NaOH solution. Calculate the pH of the solution after the following volumes of base have been added.

(a) 5.00 mL (b) 15.0 mL (c) 19.9 mL

17. Three medicine tablets, which were claimed by the pharmaceutical company to contain 300 mg of aspirin each [$C_6H_4(OCOCH_3)COOH$], were heated in 50.00 mL of a 0.5090 M NaOH. The tablets reacted according to the following equation:

$$C_6H_4(OCOCH_3)COOH + 2NaOH(aq) \rightarrow C_6H_4(OH)COONa(aq) + CH_3COONa(aq) + H_2O(l)$$

After cooling, the solution was transferred to a 100 mL standard flask and the volume was made up to exactly the 100.0 mL mark. Aliquots of 20.0 mL of this solution were then titrated against 0.1232 M HCl. The mean titre was 25.10 mL. (Note: this is a back-titration!)

(a) What was the average mass of aspirin in each tablets?

(b) From your answer to a) comment on the pharmaceutical company's claim.

18. To analyse some household ammonia, the following procedure was followed:

A 15.14 g sample of cloudy ammonia mixture was weighed and transferred into a 250.0 mL flask. Then 100.0 mL of 0.6342 M HCl was added to the flask and the mixture was thoroughly agitated. The volume was then made up to 250.0 mL using distilled water. 20.0 mL aliquots of this final mixture were titrated against 0.1098 M NaOH. The mean titre was 18.75 mL.

(a) State the sequence of this procedure in the correct order.

(b) Write equations for each of the reaction steps.

(c) Calculate the % mass of ammonia in the original commercial cloudy ammonia.

(d) If the student's final calculated % was less than that claimed by the company, does it conclusively mean that the company made a false statement?

19. 20.0 mL of dilute sulfuric acid were placed in a flask and 3.00 g of barium hydroxide added. The solution was stirred until reaction was complete.

(a) Write a balanced equation for the reaction.

(b) The excess $Ba(OH)_2$ was back titrated with 0.100 mol L^{-1} HCl and 34.5 mL of the acid were required for neutralisation. Write a balanced equation for this reaction.

(c) Choose a suitable indicator for this reaction from the following:

Name of Indicator	pH Range	Color (low pH – high pH)
Methyl orange	3.1 – 4.4	Red – yellow
Bromothymol blue	6.0 – 7.6	Yellow – blue
Phenolphthalein	8.3 – 10.0	Colorless – red
Litmus	5.0 – 8.0	Red – blue

(d) Calculate the concentration of the original sulfuric acid solution.

20. In an experiment to determine the concentration of an HCl solution, 20.0 mL of 0.100 M Na_2CO_3 solution are placed in a conical flask and titrated to a methyl orange end point. The actual concentration of the HCl solution is 0.140 M, but several mistakes were observed during the experimental procedure. Four of these are listed below. For each mistake, state the correct procedure and, if the calculated concentration of the HCl would be more, less or unaffected by these mistakes.

(a) Before filling up the burette, it was rinsed with distilled water.

(b) The conical flask is rinsed with distilled water before adding the Na_2CO_3 solution.

(c) The pipette used to deliver the Na_2CO_3 is rinsed with water.

(d) Phenolphthalein is used as the indicator, instead of methyl orange (phenolphthalein changes colour at pH 9 and methyl orange changes colour at pH 5).

21. Outline a step-by-step procedure for the following:

(a) Prepare 250.0 mL of approximately 0.1 M Na_2CO_3 solution.

(b) Dilute 25.0 mL of 5.0 M sulfuric acid to a concentration of 0.50 M.

(c) Make up 100 mL of approximately 0.1 M solution of HCl from a stock 10 M solution.

22. Select the right indicator from the list in Q. 19 for the following titrations:

(a) Ammonia solution with hydrochloric acid.

(b) Ethanoic acid with sodium hydroxide.

(c) Barium hydroxide with nitric acid.

(d) Ethanoic acid with potassium hydroxide.

23. Rain water is slightly acidic due to the dissolution of CO_2 from the atmosphere.

(a) Write an equation for this reaction.

(b) Explain how you can determine the pH of rainwater in the laboratory.

24. A solid organic, diprotic acid is hydrated in its crystalline form.

When a 0.808 g sample of the acid was heated at 110°C to constant mass, the mass of anhydrous solid remaining was 0.576 g.

(i) What is the percentage by mass of water of crystallisation in the hydrated organic acid and what percentage is actual acid?

Another 2.050 g sample of the hydrated acid was dissolved in water and made up to 250.0 mL in a volumetric flask. A 20.00 mL aliquot of this solution was titrated against a 0.110 mol L^{-1} sodium hydroxide solution and an end-point was reached at a volume of 23.70 mL.

(ii) Calculate the number of moles of acid (minus the water of crystallisation) in the 2.050 g sample and hence the molar mass of the acid.

(iii) Empirical analysis of the anhydrous acid gave an empirical formula of CHO_2. What is the molecular formula of the anhydrous acid?

(iv) From part (i) determine the molecular formula of the hydrated acid.

25. Solution X is a mixture of hydrochloric and sulfuric acids of unknown concentration. 20.0 mL of X required 10.7 mL of a 0.698 mol L^{-1} sodium hydroxide for complete neutralisation. An excess of barium chloride solution was then added to a separate 25.0 mL sample of X, and this resulted in a precipitate of 0.541 g of barium sulfate.

    Calculate the concentration of hydrochloric acid in solution X in moles per litre.

26. A bottle of Swab-It sewer cleaner has sodium hydroxide as its active ingredient. Some Swab-It is accidentally tipped into a farmer's water tank which will corrode the tank due to the OH^- ion present. In order to remove the ion the ex-chemist farmer realises that he can use copper sulfate to precipitate it as $Cu(OH)_2$.

    If either the OH^- ion or Cu^{2+} ion is left in excess this would be dangerous.

    The tank holds 10000 L of water and 4.00 kg of Swab-It was tipped into the tank. Swab-It solution contains 20.0% by mass NaOH solution and the concentration of the 45 kg mass of copper sulfate solution the farmer added was 5.00% by weight of $CuSO_4.5H_2O$.

    (i) Calculate which ion OH^- or Cu^{2+} was in excess in the tank after addition, and by how much. What is the final concentration of the excession in the tank?

    (ii) Suggest a substance that could be added to the water to remove the excess component and what mass would be needed.

27. Washing soda, sodium carbonate decahydrate ($Na_2CO_3.10H_2O$), is used to soften water. In a short period of time, the washing soda loses some of its water of crystallisation whilst in a cupboard. The amount of sodium carbonate in washing soda may be determined by adding excess hydrochloric acid to the washing soda and then determining the amount of unreacted acid by titration with a standard solution of sodium hydroxide.

    A sample of washing soda weighing 1.682 g was added to 20.00 mL of 1.00 mol L^{-1} hydrochloric acid. When the reaction was complete, the unreacted acid was titrated with a standardised solution of sodium hydroxide. Using bromothymol blue, which changes colour at a pH of 7 as the indicator to detect the endpoint, the titration of the acid required an average volume of 19.66 mL of 0.150 mol L^{-1} sodium hydroxide.

(a) Write an equation for the reaction of hydrochloric acid with sodium carbonate.

(b) Write an equation for the reaction of hydrochloric acid with sodium hydroxide.

(c) Calculate the number of moles of hydrochloric acid which reacted with sodium hydroxide.

(d) Calculate the number of moles of hydrochloric acid that was added to the washing soda.

(e) Calculate the number of moles and the mass of sodium carbonate in the sample of washing soda.

(f) Calculate the percentage mass of sodium carbonate in the sample of washing soda.

(g) Why should you use sodium hydroxide solution that has been standardised most recently?

(h) If phenolphthalein is used as an indicator for the hydrochloric acid – sodium hydroxide titration – instead of methyl orange, what effect would this have on the calculated percentage of sodium carbonate in washing soda? (Phenolphthalein changes colour at pH 9 and methyl orange at pH5). Explain your answer.

28. An aspirin tablet of mass 0.4376 g was heated in a flask containing 50.0 mL of 0.196 mol L^{-1} sodium hydroxide solution. The active ingredient in aspirin reacts according to the equation

$$C_6H_4(OCOCH_3)COOH + 2NaOH \rightarrow C_6H_4(OH)COO\,Na + CH_3COONa + H_2O$$

After cooling, the resulting solution was titrated with 0.298 mol L^{-1} hydrochloric acid in order to determine the amount of excess sodium hydroxide. A titre of 18.64 mL of the acid was obtained. Calculate:

(a) The number of moles of sodium hydroxide that reacted with the hydrochloric acid.

(b) The number of moles of sodium hydroxide initially in the flask.

(c) The percentage by mass of aspirin in the sample.

29. In a back-titration experiment to find the percentage of MgO in antacid tablets a 4.47 g tablet was crushed and dissolved in 200 mL of 0.56 mol L^{-1} HCl. Of the remaining acid 25 mL was titrated with 0.050 mol L^{-1} NaOH solution and an endpoint was reached when 9.86 mL had been added.

Draw up a flow-chart of the titration process. Calculate the percentage of MgO in the antacid tablet.

$CH_3COO^- + H_2O \rightarrow CH_3COOH + OH^-$
(CH_3COO^- is a stronger base than H_2O)

18. *pH of 6 means $[H^+] = 1 \times 10^{-6}$ mol L^{-1} and a pH of 8 means $[H^+] = 1 \times 10^{-8}$ mol L^{-1} which is 100 times less than the first concentration.*

19. *(a) $(NH_4)_2CO_3(s)$ + water $\rightarrow 2NH_4^+(aq) + CO_3^{2-}(aq)$*
This reaction (reaction 1) is an ionisation reaction.
$NH_4^+(aq)$ produces H_3O^+ ions (reaction 2). It is from an acidic salt. Anions of basic salts produce H_3O^+ ions.
$CO_3^{2-}(aq)$ produces OH^- ions (reaction 3). It is from a basic salt. Cations of acidic salts produce OH^- ions.
Reactions 2 and 3 are hydrolysis reactions. NH_4^+ ion is a weak acid. It does not produce many H_3O^+ ions. Although the carbonate ion is in the minority, it has a higher K value so it will react with water to give an excess of OH^- ions.

20. *In a series, acids such as H_3PO_4, $H_2PO_4^-$ and HPO_4^{2-} the extent of dissociation decreases as H^+ ions had to be removed from negative ions and consequently their strength decreases also. (H_3PO_4 is the relatively strongest one of the three).*

Set 3 Acids/Base Reactions

Multiple Choice Answers

1. a, 2. e, 3. e, 4. e, 5. b, 6. c, 7. c, 8. e, 9. d, 10. e, 11. b, 12. b, 13. c, 14. c, 15. b, 16. c, 17. c, 18. b, 19. b, 20. c.

Acid Base Calculations

1. *No. of moles of $Ca(OH)_2 = cV = 0.015 \times 0.02 = 3.0 \times 10^{-4}$ mol*
$n(OH^-) = 2 \times 3.0 \times 10^{-4}$ mol $= 6.0 \times 10^{-4}$ mol ($Ca(OH)_2 \rightarrow 2OH^-$).
$n(H^+)$ from $HNO_3 = 0.010 \times 0.080 = 8.0 \times 10^{-4}$ mol.
OH^- is the limiting reagent. So 6.0×10^{-4} moles of H_2O is formed and $n(H^+)$ left will be $8.0 \times 10^{-4} - 6.0 \times 10^{-4} = 2.0 \times 10^{-4}$ mol.
Total volume of mixed solution = 20 + 80 = 100 mL so
$[OH^-] = n/V = 2.0 \times 10^{-4}/0.10 = 2.0 \times 10^{-3}$ mol L^{-1}
pH = 2.7

2. *$NaOH(aq) + HNO_3(aq) \rightarrow NaNO_3(aq) + H_2O(l)$*
$n(NaOH) = c \times V = 0.0250 \times 0.200$
$= 5.00 \times 10^{-3}$ mol
$n\ (HNO_3) = c \times V = 0.030 \times 0.175$
$= 5.25 \times 10^{-3}$ mol
From the equation 1 mol of NaOH reacts with 1 mol of HNO_3.
$\therefore$ 5.00×10^{-3} mol of NaOH will react with 5100×10^{-3} mol HNO_3.
$\rightarrow$ HNO_3 is in excess by 0.25×10^{-3} mol and $[H^+] = n/V = (0.25 \times 10^{-3}/ 0.055)$
$= 4.55 \times 10^{-3}$ mol L^{-1}
$\therefore$ pH = 2.35

3. *$Ba(OH)_2 + 2HNO_3 \rightarrow Ba(NO_3)_2 + 2H_2O(l)$*
$n\ (Ba(OH)_2) = 0.0500 \times 0.200 = 0.0100$ mol
$n\ (HNO_3) = 0.200 \times 0.400 = 0.0800$ mol
From the equation, 1 mole of $Ba(OH)_2$ reacts with 2 mols of HNO_3.
Accordingly, 0.0100 mol of $Ba(OH)_2$ reacts with 0.0200 mol of HNO_3.
HNO_3 is in excess by 0.0600 mol.
The final concentration after diluting to 6.00 L is [0.0600 /6.00 L] = 0.01 M
$[H^+] = 1.0 \times 10^{-2}$ M and, pH = 2.0

4.

(a) *pH = 2*
$\therefore$ $[H^+] = 1.0 \times 10^{-2}$ M; volume = 0.300 L
$\therefore$ $n\ (H^+)$ needed $= 1.0 \times 10^{-2} \times 0.300$
$= 3.00 \times 10^{-3}$ mol
Hence, n (HCl) needed $= 3.00 \times 10^{-3}$ mol
$\therefore$ m (HCl) $= 3.00 \times 10^{-3} \times 36.46 = 0.109$ g

(b) *n (HCl) = 0.0730 / 36.46 $= 2.00 \times 10^{-3}$ mol.*
$\therefore$ $n\ (H^+) = 2.00 \times 10^{-3}$ mol.
$[H^+] = (2.00 \times 10^{-3} /2.00\ L) = 1.0 \times 10^{-3}$ M
$\therefore$ pH = 3.00

5.

(a) *pH = 13, and hence $[H^+] = 1.0 \times 10^{-3}$ M and $[OH^-] = 1.0 \times 10^{-1}$ M*
V = 0.600 L and,
n (NaOH) $= c \times v = 1 \times 10^{-1} \times 0.600$
$= 6.00 \times 10^{-2}$ mol
m (NaOH) $= 6.00 \times 10^{-2} \times 40.0 = 2.40$ g.

(b) *m (NaOH) = 0.600 g and n (NaOH)*
= 0.600/40.0 = 0.0150 mol
[NaOH] = n/V = 0.0150/ 1.500 = 0.01 M, and $[OH^-] = 1.0 \times 10^{-2}$ M
$\therefore$ $[H^+] = 1.0 \times 10^{-12}$ M, thus pH = 12.0

6. *n (HCl) $= 0.100 \times 0.020 = 2.00 \times 10^{-3}$ mol*
pH required is 3. Therefore, $[H^+]$ should be 1.0×10^{-3} M.
Since the number of moles are the same before and after dilution,
$0.100 \times 0.020 = 1.0 \times 10^{-3} \times V$
$V = [(0.100 \times 0.020) /1.0 \times 10^{-3}] = 2.0$ L.
$\therefore$ Volume of water to be added
= 2.0 L – 0.020 L = 1.98 L

7. *pH = 4 and so $[H^+] = 1.0 \times 10^{-4}$ M.V = 1.00 L*
n (HCl) $= n(H^+) = c \times V = 1.0 \times 10^{-4} \times 1.00$
$= 1.0 \times 10^{-4}$ mol
V (HCl @ STP) $= n \times 22.71$
$= 1.0 \times 10^{-4} \times 22.71 = 2.27$ mL

8. *All these hydrolyse to produce OH^- ions.*

$CO_3^{2-}(aq) + H_2O(l) \rightarrow HCO_3^-(aq) + OH^-(aq)$
$S^{2-} + H_2O(l) \rightarrow HS^-(aq) + OH^-(aq)$
$CH_3COO^-(aq)+H_2O \rightarrow CH_3COOH+OH^-(aq)$

9.

(a) $[Ca(OH)_2] = 0.0050$ *M.*
$[OH^-] = 2 \times 0.005 = 0.01$ *so* $pOH = 2$ *and* $pH = 12$

(b) *Using the dilution formula,* $0.010 \times 0.010 = c \times 1.0$ *L.*
Therefore, the final $[OH^-]$
$= 0.01 \times 0.010/1.0$ L $= 1.00 \times 10^{-4}$ M
$\therefore [OH^-] = 2 \times 5.00 \times 10^{-5} = 1.00 \times 10^{-4}$
$pOH = 4$ *so* $pH = 10.00$
Change is from 12.00 to 10.00

(c) $n\ (Ca(OH)_2 = cV = 0.00500 \times 0.010$ L
$= 0.000050$ *mol*
Number of moles of the substance does not alter during dilution.
$n(Ca(OH)_2 = n \times Mr = 0.0000500 \times 74.096$
$= 0.0037$ g

(d) $Ca(OH)_2(aq) + CO_2(g) \rightarrow CaCO_3(s) + H_2O(l)$
$n(CO_2) = n(Ca(OH)_2 = 0.0000500$ *mol*
Using the relationship $PV = nRT$ *and* $V = nRT/P$:
$V = [(0.000050 \times 8.314 \times 298)/ 110]$
$= 0.0113$ L $= 11.3$ mL

10. $NaOH(aq) + HCl(aq) \rightarrow NaCl\ (aq) + H_2O(l)$
$n\ (HCl) = 0.131 \times 0.0236 = 3.091 \times 10^{-3}$ *mol*
$n\ (NaOH) = n(HCl) = 3.091 \times 10^{-3}$ *mol;*
$V(NaOH) = 0.025$ L
$\therefore [NaOH] = n/ V = 3.091 \times 10^{-3}/0.025$
$= 0.124$ L

11. $m(\text{pure } Na_2CO_3) = 0.1223 \times 0.9995$
$= 0.1222$ g.
$n(Na_2CO_3) = 0.1222/105.9$
$= 1.153 \times 10^{-3}$ *mol*
$Na_2CO_3(aq) + 2HCl(aq) \rightarrow$
$2NaCl(aq) + H_2O(l) + CO_2(g)$
From the equation, 1 mole of Na_2CO_3 *reacts with 2 moles of HCl.*
$\therefore n\ (HCl) = 2 \times n\ (NaOH)$
$= 2 \times 1.153 \times 10^{-3} = 2.306 \times 10^{-3}$ *mol*
$\therefore [HCl] = n/V = 2.036 \times 10^{-3}/0.02265$
$= 0.090$ M

12. $CH_3COOH(aq) + NaOH(aq) \rightarrow$
$CH_3COONa + H_2O(l)$
$n(CH_3COOH) = c\ V = 0.100 \times 0.050$
$= 0.0050$ *mol*
$n\ (NaOH) = 0.100 \times 0.030 = 0.0030$ *mol*
(Since the reacting mole ratio is 1:1),
CH_3COOH *is in excess by (00.50 – 0.0030)*
$= 0.0020$ *mol*
$\therefore [CH_3COOH]$ *final* $= (0.0020/0.080)$
$= 0.0250$ M

13. $NaHCO_3 + HCl \rightarrow NaCl + H_2O + CO_2$
$n\ (NaHCO_3) = 0.020 \times 0.050$
$= 1.0 \times 10^{-3}$ *mol*
$n\ (HCl) = 0.020 \times 0.0250 = 5.00 \times 10^{-4}$ *mol*
Since the reacting mole ratio between $NaHCO_3$ *and HCl is 1:1,* $NaHCO_3$ *is in excess by* $(1.0 \times 10^{-3} - 5.00 \times 10^{-4})$
$= 5.0 \times 10^{-4}$ *mol*
$[NaHCO_3$ *left over*$] = (5.0 \times 10^{-4}/ 0.075)$
$= 6.67 \times 10^{-3}$ M

14. $n(HNO_3) = 0.0305 \times 0{,}131 = 4.00 \times 10^{-3}$ *mol*
Each mole of HNO_3 *requires ½ mole of* $CaCO_3$ *to react* $= 2.00 \times 10^{-3}$ *mol*
So $n(CaCO_3) = 2.00 \times 10^{-3}$ *mol and*
$m(CaCO_3) = 2.00 \times 10^{-3} \times 105.99 = 0.212$ g
$\therefore m(H_2O) = 0.561 - 0.212 = 0.349$ g
$n(H_2O) = 0.349/ 18.016 = 0.0194$ *mol.*
Ratio of H_2O *to* $CaCO_3$ *is*
$1.94 \times 10^{-2}: 2.00 \times 10^{-3}$ *which is close to 10:1*
Hence formula is $CaCO_3 \cdot 10H_2O$

15. *The general reaction equation is:* $NaOH(aq) + HBr(aq) \rightarrow NaBr(aq) + H_2O(l)$

(a) $HBr(1) = 20.0$ mL $n\ (NaOH)$
$= 0.100$ M $\times 0.0275$ L $= 0.00275$ *mol*
$\therefore n\ (HBr) = 0.00275$ *mol*
$c[HBr] = (0.00275/ 0.020) = 0.1375$ M

(b) $HBr(2) = 20.0$ mL
$n\ (NaOH) = 0.100 \times 0.0218 = 0.00218$
$n\ (HBr) = 0.00218$ *mol*
$[HBr] = n \div V = 0.00218/ 0.020 = 0.109$ M

(c) $HBr(3) = 20.0$ mL
$n\ (NaOH) = 0.100$ M $\times 0.0489$
$= 0.00489$ *mol*
$n\ (HBr) = 0.00489$ *mol*
$[HBr] = n/V = 0.00489/ 0.020 = 0.2445$ M

(d) $HBr(4) = 20.0$ mL
$n\ (NaOH) = 0.100 \times 0.0255 = 0.00255$ *mol*
$n\ (HBr) = 0.00255$
$[HBr] = n/V = 0.00255 \div 0.020 = 0.1275$ M

16. *The general equation for the reaction is:*
$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$
The reacting ratio is 1:1.

(a) $n\ (HCl) = 0.200 \times 0.020 = 4.00 \times 10^{-3}$ *mol*
$n\ (NaOH) = c \times V = 0.200 \times 0.0050$
$= 1.00 \times 10^{-3}$ *mol*
HCl is in excess by $(4.00 \times 10^{-3} - 1.00 \times 10^{-3})$
3.00×10^{-3} *mol*
$\therefore n\ (H^+)$ *is in excess by* 3.00×10^{-3} *mol*
$[H+] = (n/ v) = (3.00 \times 10^{-3}/0.025) = 0.12$ M
$\therefore pH = -\log 0.12 = 0.921$

(b) $n\ (HCl) = c \times v = 4.00 \times 10^{-3}$ *mol*
$n\ (NaOH) = c \times V = 0.200 \times 0.015$
$= 3.00 \times 10^{-3}$ *mol*
HCl is in excess by $(4.00 \times 10^{-3} - 3.00 \times 10^{-3})$
$= 1.00 \times 10^{-3}$ *mol*
$\therefore n\ (H^+)$ *in excess* $= 1.00 \times 10^{-3}$ *mol*
$[H^+] = (n/ v) = (1.00 \times 10^{-3}/0.035)$
$= 0.0286$ M

$pH = -\log 0.0286 = 1.54$

(c) $n(HCl) = 4.00 \times 10^{-3}$ mol
$n(NaOH) = 0.200 \times 0.0199$
$= 3.98 \times 10^{-3}$ mol
HCl is in excess by $(4.00 \times 10^{-3} - 3.98 \times 10^{-3})$
$= 0.02 \times 10^{-3} = 2.0 \times 10^{-5}$ mol
$\therefore n(H^+)$ is in excess by 2.0×10^{-5} mol
$[H^+] = (n/v) = (2.0 \times 10^{-5}/0.0399)$
$= 5.01 \times 10^{-4}$ M
$pH = -\log 5.01 \times 10^{-4} = 3.30$

17. The stated claim is that each contains 300 mg of aspirin. The equation for the reaction is: $C_6H_4(OCOCH_3)COOH + 2NaOH(aq) \rightarrow C_6H_4(OH)COONa(aq) + CH_3COONa(aq) + HCl(aq)$

(a) The tablets are reacted with 50.0 mL of 0.5090 M NaOH.
$n(NaOH)$ used in the first titration $= c \times V$
$= 0.5090 \times 0.050 = 0.02545$ mol $= n_1$
On back titration, the original 50.0 mL was diluted to 100.0 mL and 20.0 mL aliquot was used for the second titration.
Equation for the second titration:
$NaOH + HCl \rightarrow NaCl + H_2O$
$n(HCl)$ that reacted with the 20.0 mL aliquot
$= 0.1232 \times 0.02510 = 3.09232 \times 10^{-3}$ mol in 20 mL
$= 3.09232 \times 10^{-3}$ mol (reactant ratio is 1 to 1)
$\therefore n(NaOH)$ in the 100.0 mL
$= 3.09232 \times 10^{-3} \times (100/20)$
$= 0.0154616$ mol $= n_2$
$\therefore n(NaOH)$ that reacted in the first reaction (equation is supplied in the problem)
$= n_1 - n_2 =$ 0.02545 mol – 0.0154616 mol
$= 0.0099884$ mol
According to the balanced equation supplied,
$n[C_6H_4(OCOCH_3)COOH] = n(NaOH)/2$
$= 0.0099884/2$
$= 4.9942 \times 10^{-3}$ mol
$m[C_6H_4(OCOCH_3)COOH]$
$= 4.9942 \times 10^{-3} \times 180.154 = 0.8997$ g
$\therefore$ Mass of this compound in one tablet $= 0.8997/3 = 0.2999$ g.
The average mass of the compound in each tablet = 299.9 mg.

(b) Within the limits of experimental or rounding off error, the claim is true.

18.

(a) Acid added to this cloudy ammonia
= 100.0 mL of 0.6342 M, HCl.
The mixture volume is made up to
= 250.0 mL.
Aliquot taken for titration purpose
= 20.0 mL.
The first reaction is between NH_3 in the "cloudy ammonia" and HCl.

(b) The reaction is $NH_3 + HCl \rightarrow NH_4Cl$
The second reaction is between the left over HCl and NaOH
The second reaction is
$HCl + NaOH \rightarrow NaCl + H_2O$

(c) $n(NaOH)$ that reacted with 20.0 mL of the excess HCl in reaction 2,
[Since, $n(HCl) = n(NaOH)] = c \times V =$
$0.6342 \times 0.01875 = 0.00205875$ mol
$n(NaOH)$ that would have reacted with 250.0 mL of the excess HCl in reaction 2,
$= 0.00205875 \times (250/20.0)$
$= 2.5734 \times 10^{-2}$ mol
$n(HCl)$ initially present before the reaction commenced,
$cV = 0.6342 \times 0.100 = 0.06342$ mol
$\therefore n(HCl)$ that actually reacted with 250.0 mL of original solution,
$= 0.06342 - 0.025734 = 0.037686$ mol
From the equation for the first reaction, $n(NH_3) = n(HCl) = 0.037686$ mol
$\therefore m(NH_3) = n \times Mr = 0.037686 \times 17.034$
$= 0.642$ g
% of NH_3 in the cloudy ammonia
$= (0.642/15.4) \times 100$
$= 4.24\%$

(d) Not necessarily. If the calculated value is less than the claimed value and falls with in the limits of experimental error, the claim could still be true.

19.

(a) $H_2SO_4(aq) + Ba(OH)_2(aq) \rightarrow BaSO_4(s) + 2H_2O(l)$

(b) The back-titration reaction is: $Ba(OH)_2 + 2HCl \rightarrow BaCl_2 + 2H_2O(l)$
$n(HCl)$ used $= c \times v = 0.100 \times 0.0345$
$= 0.00345$ mol
Therefore, according to the reacting mole ratio, the number of moles of $Ba(OH)_2$ that reacted in the back titration is $(0.00345/2)$
$= 0.001725$ mol

(c) Any indicator will be suitable for this back titration because the change of pH occurs over a pH range of 3 to 11. Any indicator with an end point change that occurs in this range would be suitable.

(d) Since the amount of $Ba(OH)_2$ used in the back titration is 0.001725 mol (0.2955 g), the mass of $Ba(OH)_2$ that reacted in the first titration is $= (3.0 - 0.2955) = 2.7045$ g.
$n(Ba(OH)_2$ that reacted in the first titration
$= (2.7045/171.316) = 1.58 \times 10^{-2}$ mol.
According to the mole ratio in equation 1,
$n(H_2SO_4) = n(Ba(OH)_2$
$= 1.58 \times 10^{-2}$ mol
$[H_2SO_4] = (n/V) = (1.58 \times 10^{-2}/0.020)$
$= 0.79$ M

20.

(a) *The burette should be rinsed with the filling solution (HCl). Rinsing with distilled water reduces the concentration of the filling solution. This makes [HCl] appear greater.*

(b) *This is not a mistake and there is no effect as there are the same no. of moles, even if diluted.*

(c) *The pipette should be rinsed with the filling solution (Na_2CO_3). Rinsing it with water will dilute the concentration of the filling solution. This makes [Na_2CO_3] appear weaker and less HCl will be used so [HCl] appears greater.*

(d) *The correct indicator – methyl orange, should be used. Using phenolphthalein would produce colour change soon, so the volume of HCl needed would decrease. This makes [HCl] appear greater.*

21.

(a) *i) Calculate the amount of Na_2CO_3 needed (106 g).*

ii) Weigh out close to 1.06 g; not necessarily the exact mass.

iii) Transfer the Na_2CO_3 to a clean 250.0 mL volumetric flask. Often this is done using a clean, dry funnel, carefully rinsing all traces of solid into the flask using distilled water.

iv) Fill the flask about one half with distilled water and swirl until all the solid is dissolved.

v) Add distilled water exactly up to the 250 mL calibration mark. Often the last few drops are added from a pipette or eye-dropper.

vi) Mix the solution thoroughly by inverting the flask. Then calculate the exact concentration from the actual mass used.

(b) *Note: The dilution is ten times the original volume. Remember that you should always add acid to water and not the other way otherwise 'spitting' occurs!*

i) Put a small amount of water in the flask first.

ii) Transfer the 25.0 mL of 5.0 M sulfuric acid to a graduated cylinder, which has a volume of 250.0 mL.

iii) Add distilled water to about half the volume of the flask. Stopper it and swirl it a few times until the bubbles die out.

iv) Add distilled water up to the 250 mL calibration mark. Add the last few drops with a pipette or eye-dropper.

(c) *Note: Because the concentration of this solution does not need to be accurately known, you can use a graduated cylinder for measuring.*

i) Place about 50 mL of distilled water into a graduated cylinder.

ii) Measure 1 mL of 10 M HCl using a clean, dry, graduated cylinder or graduated pipette.

iii) Add the acid to the water in the graduated cylinder, stir and make up volume up to 100.0 mL.

22.

(a) *methyl orange* (b) *phenolphthalein*

(c) *any indicator* (d) *phenolphthalein*

23.

(a) $CO_2(g) + H_2O(l) \rightarrow H_2CO_3(aq)$

(b) *Since H_2CO_3 is a very weak acid, it can be analysed volumetrically using NaOH and a phenolphthalein indicator following the usual volumetric analysis procedure – or use a pH meter.*

24. (i) *Loss of mass of hydrated acid*

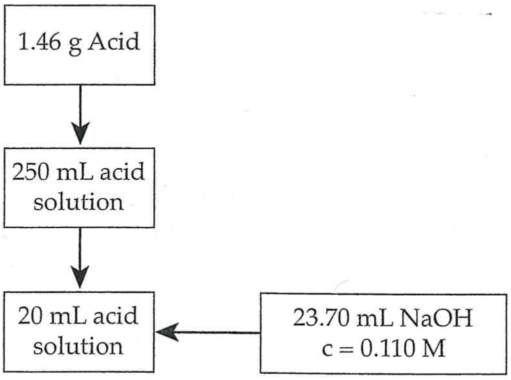
$= 0.808 - 0.576 = 0.232$ *g of* H_2O

% water $= (0.232/0.808) \times 100 = 28.71\%$

% Anhydrous acid $= 71.29\%$

(ii) *2.05 g of hydrated acid will contain* 0.7129×2.05 *g of anhydrous acid* $= 1.46$ *g*

Flow chart:



$n(NaOH) = 0.110 \times 0.02370$

$= 2.607 \times 10^{-3}$ mol

Ratio of acid to NaOH = 2 : 1

$n(Acid) = \tfrac{1}{2} \times n(NaOH)$

$= 1.3035 \times 10^{-3}$ *mol in 20 mL*

In 250 mL $n(Acid) = 1.3035 \times 10^{-3} \times \dfrac{250}{20}$

$= 0.01629$ mol

$$M_r = \frac{m}{n} = \frac{1.46}{0.01629} = 89.6 \text{ g mol}^{-1}$$

(iii) *Empirical mass of* $CHO_2 = 45.01$ *which is ½ of 89.6 approx, so molecular = 2 × empirical mass*

Molecular formula is $C_2H_2O_4$ *possible isomer is HOOCCOOH (oxalic acid).*

(iv) *Mass of water in 2.05 g sample*

$= 2.05 \times 0.2871 = 0.588$ *g*

$n(H_2O) = 0.588/18.016 = 0.03267$ mol
Ratio of H_2O to $C_2H_2O_4$ is 0.03267: 0.01629
= 2.005:1
So hydrated acid formula is $C_2H_2O_4.2H_2O$.

25. $n(NaOH) = 0.698 \times 0.0107$
$= 7.469 \times 10^{-3}$ mol = total $n(H^+)$ in the solution.
$n(BaSO_4) = 0.541/233.37 = 2.318 \times 10^{-3}$ mol which must equal $n(H_2SO_4)$ in 25 mL
$n(H_2SO_4)$ in 20 mL is which would contribute double the H^+
$2 \times 1.855 \times 10^{-3}$ mol of $H^+ = 3.71 \times 10^{-3}$ mol.
∴ n(HCl) in solution X
$= 7.469 \times 10^{-3} - 3.710 \times 10^{-3}$ mol
$= 3.759 \times 10^{-3}$ mol.
$[HCl]$ in solution X = $\dfrac{3.759 \times 10^{-3}}{0.020}$
$= 0.188$ mol L^{-1}

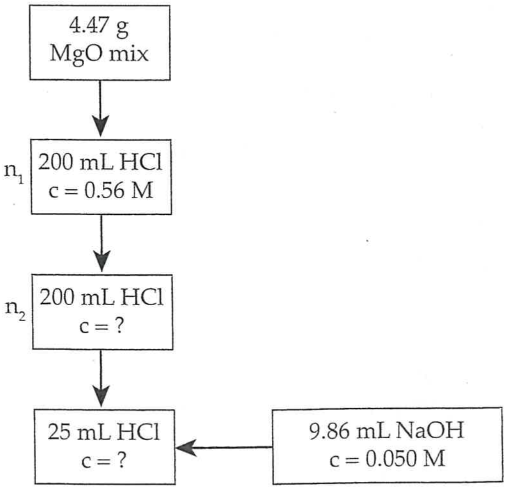
26. (i) Mass of NaOH = $4000 \times 0.2 = 800$ g
$n(NaOH) = 800/39.998 = 20.0$ mol
$m(CuSO_4.5H_2O) = 45000 \times 0.05 = 2250$ g
$n(CuSO_4.5H_2O) = 2250/ 249.7 = 9.01$ mol

Reaction: $CuSO_4 + 2NaOH \rightarrow Cu(OH)_2 + Na_2SO_4$
So 9.01 mol of $CuSO_4$ would need 18.02 mol of NaOH to be completely used up.
20.0 mol of NaOH is available so all the $CuSO_4$ is used up = Limiting Reagent
Hence NaOH and OH^- ion is in excess.
Amount of excess NaOH is 20 – 18.02
= 1.978 mol
(ii) HCl could be used to neutralise the OH^- ions. The farmer would need to add 1.978 mol
m(HCl) needed = $1.978 \times 36.458 = 72.1$ g.

27.
(a) $2HCl + Na_2CO_3 \rightarrow 2NaCl + H_2O + CO_2$
(b) $HCl + NaOH \rightarrow NaCl + H_2O$
(c) n (NaOH) = c × V
$= 0.150$ mol $L^{-1} \times 0.01966 = 2.94 \times 10^{-3}$ mol
Therefore, n (HCl) = 2.94×10^{-3} mol
(d) Initial moles of HCl that was added to washing soda = cV
$= 1.00 \times 0.0200 = 0.0200$ mole
(e) Therefore, n(HCl) that actually reacted = Initial moles of HCl – Excess moles of HCl Left over
$= 0.02$ mol $- 2.94 \times 10^{-3}$ mol $= 0.01706$ mol
Therefore, $n(Na_2CO_3) = n(HCl/2) =$ 0.01706/2 = 0.00853 mol
Therefore, $m(Na_2CO_3) = n \times M$
$= 0.00853 \times 105.99 = 0.904$ g
(f) % of Na_2CO_3 in the sample
$= [(0.904/1.682) \times 100] = 53.7$ %
(g) Sodium hydroxide absorbs both H_2O and CO_2 from air when exposed and this alters its concentration. Therefore, NaOH should be used as soon as it is standardised.
(h) There won't be any effect since HCl (a strong acid) is titrated with NaOH (a strong base).

28.
(a) The mass of aspirin tablet = 0.4376 g
(The tablet contains acetylsalicylic acid, $[C_6H_4(OCOCH_3)COOH)]$
The number of moles of HCl added = cV
$= 0.298 \times 0.01864$ L $= 5.555 \times 10^{-3}$ mol
Since, $HCl + NaOH \rightarrow NaCl + H_2O$
The number of moles of NaOH reacted
$= 5.555 \times 10^{-3}$ mol
(b) Initial amount of NaOH added to aspirin
= n (NaOH)
$= c \times V = 0.196$ mol $L^{-1} \times 0.050$ L
$= 9.800 \times 10^{-3}$ mol
(c) Therefore, n(NaOH) that actually reacted with the acetylsalicylic acid in the tablet,
= [initial moles of NaOH – left over excess moles of NaOH]
$= (9.800 \times 10^{-3} - 5.555 \times 10^{-3})$
$= 4.245 \times 10^{-3}$ mol
$C_6H_4(OCOCH_3)COOH + 2NaOH \rightarrow C_6H_4(OH)COONa + CH_3COONa + H_2O$
$nC_6H_4(OCOCH_3)COOH = ½ \times n$ (NaOH)
$= 2.123 \times 10^{-3}$ mol
Therefore, $m[C_6H_4(OCOCH_3)COOH]$
$= n \times M = 2.123 \times 10^{-3} \times 180.164$
= 0.3825 g
Therefore % mass of the acid in the tablet
= [(0.3825/ 0.4376) × 100]
= 87.4%

29.



$n(NaOH) = 0.05 \times 0.00986$
$= 4.93 \times 10^{-4}$ mol
1:1 ratio ∴ n(HCl)
$= 4.93 \times 10^{-4}$ mol in 25 mL
∴ in 200 mL n(HCl)
$= 4.93 \times 10^{-4} \times \dfrac{200}{25} = 3.944 \times 10^{-3}$ mol

$n_2 = 3.944 \times 10^{-3}$ mol
$n_1 = 0.56 \times 0.2 = 0.112$ mol

Amount of HCl used $= n_1 - n_2$
$= 0.112 - 3.944 \times 10^{-3}$
$= 0.1081$ mol

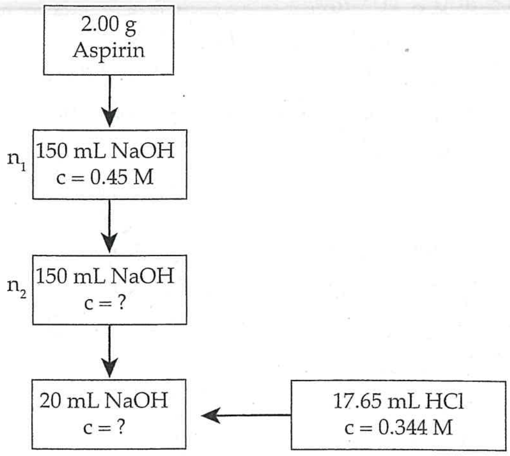
Ratio MgO : HCl is 2:1 so
n(MgO) = ½ × 0.1081 = 0.05403 mol

m(MgO) = 0.05403 × (24.31 + 16)
= 2.18 g

$$\% \text{ of MgO} = \frac{2.18}{4.47} = \times 100\%$$

% Purity = 48.7%

30.
(i)



n(HCl) = 0.344 × 0.01765
$= 6.072 \times 10^{-3}$ mol
Ratio NaOH to HCl is 1:1 so
n(NaOH) $= 6.072 \times 10^{-3}$ mol in 20 mL
∴ in 150 mL n(NaOH) =

$$6.072 \times 10^{-3} \times \frac{150}{20} = 0.0455 \text{ mol}$$

$n_2 = 0.0445$ mol
$n_1 = 0.45 \times 0.15 = 0.0675$ mol

Amount of HCl used $= n_1 - n_2$
= 0.0675 – 0.0455
= 0.0220 mol

Ratio Aspirin to NaOH is 1:2
So n(Aspirin) = ½ n(NaOH)
= 0.0110 mol
m(Aspirin) = 0.0110 × 168.144 = 1.85 g

$$\% \text{ of Aspirin} = \frac{1.85}{2.00} \times 100\%$$

% Purity = 92.5%

(ii) This value exceeds the 90% set value and so conforms to the law.

Chapter 3.
Redox Reactions

Set 1 Oxidation and Reduction

1.	Species Oxidised	Na
	Species reduced	O_2
	Oxidant	O_2
	Reductant	Na
2.	Species Oxidised	Zn
	Species reduced	Cr^{3+}
	Oxidant	Cr^{3+}
	Reductant	Zn
3.	Species Oxidised	H_2
	Species reduced	O_2
	Oxidant	O_2
	Reductant	H_2
4.	Species Oxidised	H_2S
	Species reduced	$Cr_2O_7^{2-}$
	Oxidant	$Cr_2O_7^{2-}$
	Reductant	H_2S
5.	Species Oxidised	Cl^-
	Species reduced	H_2O_2
	(ON of Cl is $^+1$ in HClO)	
	Oxidant	H_2O_2
	Reductant	Cl^-
6.	4+ 7. 5+ 8. 4+ 9. 2+ 10. 7+	
7.	Species Oxidised	HBr
	Species reduced	H_2SO_4
8.	Species Oxidised	$SnCl_2$
	Species reduced	O_2
9.	Species Oxidised	Fe^{2+}
	Species reduced	$Cr_2O_7^{2-}$
10.	Species Oxidised	None
	Species reduced	None
11.	Species Oxidised	I^-
	Species reduced	Cl_2

Set 2 Oxidation

Multiple Choice Answers

1. d, 2. b, 3. d, 4. b, 5. c, 6. c, 7.a, 8. b, 9. a, 10. a, 11. e, 12. b

Written Answers

1.
(a) S = +6
(b) Mn = +7
(c) N = +5
(d) C = +4,
(e) N = +4
(f) S = +6
(g) S = +6
(h) S = -2
2.
(a) H = +1, S = -2
(b) P = +5, O = -2
(c) Na = +1, P = -3