# Set 3. Acid/Base reactions

1. A diprotic acid $H_2X$ is fully ionised in water. The concentrations of the $X^{2-}$ ions and the hydronium ions in an aqueous solution containing $1.0 \times 10^{-5}$ moles of $H_2X$ in 0.100 L of water are, respectively:

   (a) $1.0 \times 10^{-4}$; $2.0 \times 10^{-4}$ (b) $1.0 \times 10^{-4}$; $1.0 \times 10^{-4}$

   (c) $2.0 \times 10^{-9}$; $1.0 \times 10^{-4}$ (d) $1.0 \times 10^{-4}$; $2.0 \times 10^{-10}$

   (e) $2.0 \times 10^{-4}$; $1.0 \times 10^{-4}$

2. Given the following $K_a$ values, determine which one is the strongest base.

   $HSO_4^- = 1.2 \times 10^{-2}$; $H_2PO_4^- = 6.3 \times 10^{-8}$; $HCO_3^- = 4.7 \times 10^{-11}$; $H_2CO_3 = 2.50 \times 10^{-4}$

   (a) $H_2CO_3$ (b) $HPO_4^{2-}$ (c) $H_2SO_4$ (d) $SO_4^{2-}$

   (e) $CO_3^{2-}$

3. Which one(s) of the following salts, when dissolved in water, will produce a neutral solution?

   1) Calcium chloride 2) Strontium nitrate 3) Potassium carbonate

   (a) only 1 (b) only 2 (c) 2 and 3 (d) only 3 (e) 1 and 2

4. Which of the following salts when dissolved in water produce a basic solution?

   1) Sodium nitrate 2) Potassium sulfide 3) Sodium carbonate

   (a) only 2 (b) 1 and 2 (c) only 3 (d) only 1 (e) 2 and 3

5. A 0.600 g sample of succinic acid is dissolved in water and titrated with 0.500 mol $L^{-1}$ sodium hydroxide to equivalence point. The volume of base used is 20.4 mL. What is the molecular weight of succinic acid which contains two dissociable protons?

   (a) 83 (b) 118 (c) 156 (d) 230 (e) 59

6. A concentrated solution of $K_2CrO_4$ is 15.0% by mass and the density is 1.129 g $cm^{-3}$. What volume of this solution is required to prepare 200.0 mL of a 0.150 mol $L^{-1}$ solution?

   (a) 33.4 mL (b) 36.0 mL (c) 34.4 mL (d) 36.9 mL (e) 35.2 mL

7. A concentrated solution of HI is 47% by mass and has a density of 1.50 g $mL^{-1}$. What volume of this solution is required to prepare 250.0 mL of a 1.50 mol $L^{-1}$ HI solution?

   (a) 102 (b) 48.0 (c) 68.0 (d) 62.3 (e) 66.4

8. A solution containing $Mn^{2+}$ ions is prepared by dissolving 1.485 g of pure manganese in nitric acid and diluting it to 1.00 L. A 100.0 mL aliquot is then diluted to 500.0 mL.

What is the concentration of the final solution of $Mn^{2+}$ ion in mol $L^{-1}$?

(a) $5.06 \times 10^{-3}$ (b) 0.0253 (c) 0.0506

(d) $2.53 \times 10^{-4}$ (e) $5.41 \times 10^{-3}$

9. Which one of the following substances is the most suitable as a primary standard for acid–base titrations?

(a) sodium hydroxide (b) nitric acid (c) oxalic acid

(d) sodium carbonate

10. A 10.0 mL sample of concentrated HF (16.5 mol $L^{-1}$) is diluted to a final volume of 250.0 mL. What is the concentration of the final solution in mol $L^{-1}$?

(a) 0.570 (b) 0.690 (c) 0.630 (d) 0.600

(e) 0.660

11. In a $HCl/Na_2CO_3$ titration, where the $Na_2CO_3$ solution is placed in the conical flask, the correct rinsing procedure for the pipette is:

(a) detergent, distilled water, acid (b) detergent, distilled water, base

(c) detergent, distilled water (d) detergent, base

(e) distilled water, acid

12. To 100 mL of a 0.200 mol $L^{-1}$ HCl, 100 mL of a 0.40 mol $L^{-1}$ of sodium hydroxide is added. After equilibrium is established, the $[H^+]$ and $[OH^-]$ in mol $L^{-1}$ respectively are

(a) $2.0 \times 10^{-1}$, $5.0 \times 10^{-13}$ (b) $5.0 \times 10^{-13}$, $2.0 \times 10^{-2}$

(c) $1.0 \times 10^{-7}$, $1.0 \times 10^{-7}$ (d) $1.0 \times 10^{-1}$, $1.0 \times 10^{-13}$

(e) $1.0 \times 10^{-13}$, $1.0 \times 10^{-1}$

Questions 13 and 14 are based on the following information. The equations shown below represent reactions which occur to an extent greater than 90% in the direction indicated.

$$HNO_3(aq) + H_2O(l) \rightarrow H_3O^+ + NO_3^-$$

$$H_3O^+ + CN^-(aq) \rightarrow HCN(aq) + H_2O(l)$$

$$HCN(aq) + OH^-(aq) \rightarrow H_2O(l) + CN^-(aq)$$

$$H_2O(l) + CH_3O^-(aq) \rightarrow CH_3OH(aq) + OH^-(aq)$$

13. The strongest base among all the above substances is

(a) $CH_3O^-$ (b) $H_2O$ (c) $CN^-$ (d) $NO_3^-$

(e) $CH_3OH$

14. An acid stronger than $H_2O$ but weaker than $H_3O^+$ is

(a) $HNO_3$ (b) $CH_3OH$ (c) HCN (d) $NO_3^-$ (e) $CN^-$

15. A buffer solution is made by adding 0.1 mol of $CH_3COOH$ (aq) to 0.1 mole of potassium ethanoate solution. As small amount of a strong base is now added to the solution.

$$CH_3COOH_{(aq)} + H_2O_{(l)} \rightleftharpoons CH_3COO^-_{(aq)} + H_3O^+_{(aq)}$$

Once the equilibrium has been established, the final effect would be:

(a) The equilibrium shifts to the left

(b) An overall increase in $CH_3COO^-$ ions

(c) A substantial increase in $OH^-$ ions

(d) An increase in the $K_a$ value for the acid

16. Which one of the following correctly identifies the acidity, basicity or neutrality of each of the given solutions?

| | **Potassium phosphate** | **Sodium hydrogensulfate** | **Ammonium chloride** | **Magnesium nitrate** |
|---|---|---|---|---|
| (a) | Acidic | Acidic | Acidic | Basic |
| (b) | Basic | Neutral | Neutral | Acidic |
| (c) | Basic | Acidic | Acidic | Neutral |
| (d) | Neutral | Basic | Basic | Neutral |

17. A student obtained the following results when titrating ethanoic acid solution with 20.00 mL of sodium hydroxide solution.

| | **Trial 1** | **Trial 2** | **Trial 3** | **Trial 4** |
|---|---|---|---|---|
| Vol of HCC (mL) | 21.6 | 22.4 | 20.3 | 21.8 |

Which one of the following could lead to such a set of results?

(a) Using only a few drops of phenolphthalein indicator

(b) Washing the conical flasks with distilled water and then leaving some water inside.

(c) Washing the burette with water and then leaving some water inside

(d) Always reading to the bottom of the meniscus in the burette

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) $1 \times 10^{-10}$ mol $L^{-1}$ sodium hydroxide

(b) $5 \times 10^{-5}$ mol $L^{-1}$ barium hydroxide

(c) $1 \times 10^{-4}$ mol $L^{-1}$ calcium hydroxide

(d) $1 \times 10^{-10}$ 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.

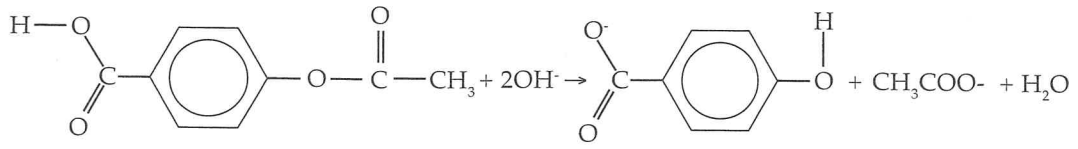
(b) The number of moles of sodium hydroxide initially in the flask.

(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.

30. An analysis of Aspirin involves a back-titration where NaOH is used to react with the COOH group and the CO group in the molecule shown below.




2.00 g of powdered Aspirin was boiled with 150 mL of 0.45 M sodium hydroxide solution until dissolved. A 20 mL aliquot of the solution was then titrated with a standard 0.344 M HCl solution until an endpoint was reached at a volume of 17.65 mL.

(i) Draw up a flow-chart of the titration process and using it calculate the percentage of acetyl salicylic acid in the Aspirin tablet (molar mass of aspirin = 168.144 g $mol^{-1}$).

(ii) By law, the amount of actual acetyl salicylic acid in the table must exceed 90% of the total mass. Does the sample conform to this law? Explain.