Week 4 Analysing Acids and Bases

Acid

A substance that donates a hydrogen ion (proton)
A proton is donated in the acid-base reaction:

$HCl\ (aq) + H_2O\ (l) \longrightarrow H_3O\ (aq) + Cl^-\ (aq)$

Strong acids completely ionise in water
Weak acids weakly deionise *e.g.*

$CH_3COOH\ (l) + H_2O \leftrightarrow CH_3COO^-\ (aq) + H_3O\ (aq)$

At any instance, most ethanoic acid molecules are not ionised.

Base

A substance that accepts a hydrogen ion (proton)
Strong bases readily accept protons *e.g.* NaOH, KOH.
Weak bases accept protons less readily *e.g.* ammonia (NH_3)

Base

The concentration of H_3O^+ ions is referred to as the solution's acidity.
Acidity is measured using a logarithmic scale called the pH scale.

The definition of pH is:

$pH = -\log[H_3O^+]$

Where $[H_3O^+]$ is the concentration of H_3O^+ ions measured in mol L^{-1}

Acidic solutions have a pH < 7
Basic solutions have a pH > 7

Indicators

Used in acid-base titrations to identify the equivalence point.

Acid-base indicator : a substance whose color depends on the concentration of H_3O^+ ions in solution.
They are weak acids: acid form has one color and conjugate base another.

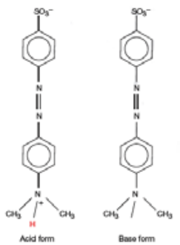


Figure 4.2
The acid–base forms of methyl orange indicator.

Table 4.1 Common indicators

Indicator	Colour of acid form	Colour of base form	pH range
Phenolphthalein	Colourless	Pink	8.2–10.0
Methyl orange	Pink	Yellow	3.2–4.4
Bromothymol blue	Yellow	Blue	6.0–7.6

Indicators must be chosen carefully to ensure that color change occurs at the titration end point – the equivalence point of the reaction.

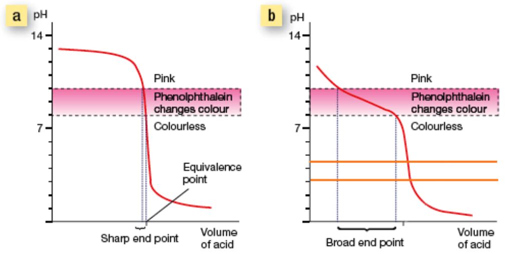
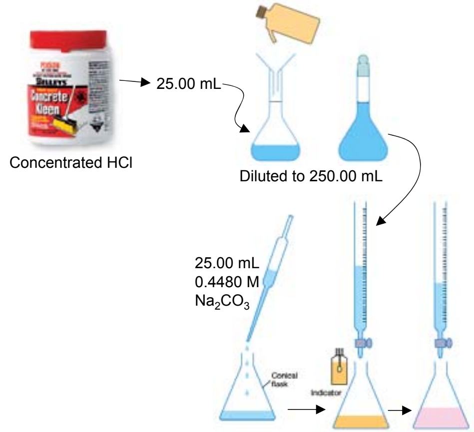


Figure 4.4
pH curves showing change of pH during a titration of **a** a strong base with a strong acid, and **b** a weak base with a strong acid. Phenolphthalein, which changes colour in the pH range 8.2–10, gives a sharp end point in **a** but a broad end point in **b**. Methyl orange, which changes colour between pH 3.1 and 4.5, would be a more suitable indicator for the second titration.

Strong acid with weak base: EP occurs between pH 3 – 7; methyl orange
Weak acid with strong base: EP occurs between pH 7 – 11; phenolpthalein
Weak acid with weak base: pH change too gradual for indicators

Worked example 4.3b



The methyl orange indicator changed permanently from yellow to pink when 19.84 mL of the diluted cleaner was added. Calculate the concentration of hydrochloric acid in the concrete cleaner.

Solution

$2HCl\ (aq) + Na_2CO_3 \longrightarrow 2NaCl\ (aq) + H_2O\ (aq) + CO_2\ (g)$

In 20.00 mL of Na_2CO_3 solution

$n(Na_2CO_3) = c(Na_2CO_3) \times V(Na_2CO_3)$
$= 0.4480\ \text{mol L}^{-1} \times 0.020\ \text{L}$
$= 0.008960\ \text{mol}$

From the equation, 2 mol of HCl reacts with 1 mol of Na_2CO_3

So the ratio $\frac{n(HCl)}{n(Na_2CO_3)} = \frac{2}{1}$

$n(HCl) = 2 \times n(Na_2CO_3)$
$= 2 \times 0.008960$
$= 0.01792\ \text{mol}$

$c(HCl) = \frac{n(HCl)}{V(HCl)}$
$= \frac{0.01792\ \text{mol}}{0.01984\ \text{L}}$
$= 0.9032\ \text{mol L}^{-1}$

The concentration of the diluted cleaner is 0.9032 M

Since the cleaner had been diluted before titration, the concentration of the concrete cleaner is

$c(HCl) = 0.9032 \times \frac{250}{10}$
$= 9.032\ \text{M}$

Chapter review

Acid-base reactions

10. Write full equations for the acid-base reactions that occur when:

a. Nitric acid is added to sodium hydroxide
$HNO_3\ (aq) + NaOH\ (aq) \longrightarrow NaNO_3\ (aq) + H_2O\ (l)$

b. Sulfuric acid is added to potassium hydroxide
$H_2SO_4\ (aq) + 2KOH\ (aq) \longrightarrow K_2SO_4\ (aq) + 2H_2O\ (l)$

c. Hydrochloric acid is added to ammonia solution
$HCl\ (aq) + NH_3 \longrightarrow NH_4Cl\ (aq)$

d. Ethanoic acid solution is added to potassium hydroxide solution
$CH_3COOH\ (aq) + KOH\ (aq) \rightarrow CH_3COOK\ (aq) + H_2O\ (l)$

11. Write ionic equations for the reactions in Question 10.

   a. Nitric acid is added to sodium hydroxide
      $H^+ (aq) + OH^- (aq) \longrightarrow H_2O (l)$
   b. Sulfuric acid is added to potassium hydroxide
      $H^+ (aq) + OH^- (aq) \longrightarrow H_2O (l)$
   c. Hydrochloric acid is added to ammonia solution
      $H^+ (aq) + NH_3 (aq) \longrightarrow NH_4^+ (aq)$
   d. Ethanoic acid solution is added to potassium hydroxide solution
      $CH_3COOH (aq) + OH^- (aq) \longrightarrow CH_3COO^- (aq) + H_2O (l)$

12. What mass of sodium sulfate is produced when 25.0 mL of 0.100 M sulfuric acid is added to 20.0 mL of 0.15 M sodium hydroxide solution? 0.21 g

13. What volume of 0.100 M sulfuric acid would be required to neutralise a solution containing 0.500 g of sodium hydroxide and 0.800 g of potassium hydroxide? 0.134 L

16. The concentration of sodium hydroxide in waste water from an alumina refinery was found by titrating 20.00 mL aliquots of waste water against 0.150 M hydrochloric acid, using phenolpthalein as indicator. The average titre of several titrations was 11.40 mL.

   a. Why is an indicator used?
      To detect the equivalence point as both reactants are colorless.

   b. Write an equation for the reaction that occurred.
      $NaOH (aq) + HCl (aq) \longrightarrow NaCl (aq) + H_2O (l)$

   c. What was the molarity of sodium hydroxide in the waste water?
      0.08555 M

   c. What mass of sodium hydroxide would be present in 100 L of the waste water?
      342 g

17. A 42.7 mL volume of a hydrochloric acid solution is required to react completely with 20.0 mL of 0.612 M sodium carbonate solution.

   a. Write an equation for the reaction.
      $2HCl (aq) + Na_2CO_3 (aq) \rightarrow 2NaCl (aq) + H_2O (aq) + CO_2 (g)$

   b. Calculate the concentration of the hydrochloric acid, in mol L^{-1}.
      0.573 M

18. A 1.20 g antacid tablet contains 80.)% by mass of magnesium hydroxide as the active ingredient. What volume of 0.1500 M hydrochloric acid would the antacid tablet neutralise?
    220 mL

20. A 50 mL sample of vinegar was diluted to 250 mL in a volumetric flask. A 20.00 mL aliquot of this solution required the addition of 27.98 mL of 0.134 M sodium hydroxide solution in order to be neutralised.

   a. Write an equation for the neutralisation equation.
      $CH_3COOH (aq) + NaOH (aq) \rightarrow CH_3COONa (aq) + H_2O (l)$

   b. What is the molarity of the ethanoic acid in the original vinegar?
      0.937 M

   c. Express your answer to Part B in g L^{-1}
      56.3 g L^{-1}

22. In order to standardise a solution of hydrochloric acid, a student titrated the solution against 20.00 mL aliquots of a standard solution of sodium carbonate. Methyl orange indicator was used to identify the end point of the reaction:

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

The sodium carbonate solution had been prepared by dissolving 1.236 g of anhydrous Na_2CO_3 in water and making the solution up to 250.0 mL in a volumetric flask. The titres recorded were 21.56 mL, 20.98 mL, 20.96 mL and 21.03 mL.

a. What value for the titre of sodium carbonate solution should the student use in the calculation of the acid concentration? Explain your answer.
20.99 mL

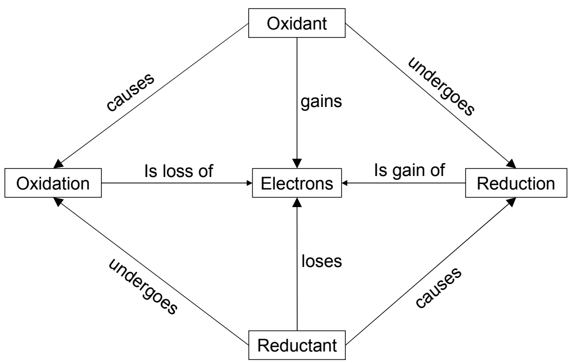
b. What is the molarity of the sodium carbonate solution?
0.04666 M

c. Calculate the concentration of the hydrochloric acid in mol L^{-1}.
0.08892 mol L^{-1}

What is a redox reaction?

Involves the transfer of electrons

- One of the reactants loses electrons: oxidation
- One of the reactants gains these electrons: reduction
- Oxidation and reduction occur simultaneously



Consider

The fate of magnesium in fireworks

Oxidation part of the overall reaction
$Mg \longrightarrow Mg^{2+} + 2e^-$

Reduction part of the overall reaction
$O_2 + 4e^- \longrightarrow 2O_2^-$

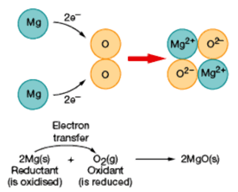


Figure 5.3
A representation of the electron transfer reaction between magnesium and oxygen.

The number of electrons produced during the oxidation is the same as the number consumed in the reduction

1. Name the chemicals that undergo oxidation in the following reactions
   a. $2Zn\ (s) + O_2\ (g) \longrightarrow 2ZnO\ (s)$
   b. $Ca\ (s) + Cl_2\ (g) \longrightarrow CaCl_2$
   c. $2AgBr\ (s) \rightarrow 2Ag\ (s) + Br_2\ (g)$
2. Indentify the oxidants and reductants in each of the reactions above.

Oxidation state
A measure of the degree of oxidation of an atom in a substance. It is defined as the charge an atom might be imagined to have when electrons are counted according to an agreed-upon set of rules

Rules for determining oxidation numbers

Species	Oxidation number	Examples
Free elements	0	Cl; Mg; C; O_2; H_2
Ionic compounds	Equal to the charge on ion	$\overset{+1}{Na}\overset{-1}{Cl}$ $\overset{+3}{Al_2}\overset{-2}{O_3}$ $\overset{+2}{Ca}\overset{-1}{Cl_2}$
Oxygen in compounds	Defined as -2 in its compounds. H_2O_2 is an exception, where it is -1	O = -2 in H_2O, CO_2, Na_2O
Hydrogen in compounds	Defined as +1 in compounds with non-metals	H = +1 in HCl, H_2S, CH_4
Molecular ions and molecules	The sum of the oxidation numbers equals the charge on the molecular ion (0 in the case of neutral molecules). The most electronegative element has the negative oxidation number	For Mno_4^- oxygen is defined as -2. Because there are 4 oxygen atoms, to have an overall charge of -1, Mn must have an oxidation number of +7

Worked example 5.2b

For CO_3^{2-}, the sum of the oxidation numbers equals the ionic charge of 2^-. The oxidation number of O is fixed as -2. Find the oxidation number of carbon.

Solution

(oxidation number of C) + 3 X (oxidation number of O) = -2
If, (oxidation number of C) + 3(-2) = -2
then the oxidation number of C must = +4

The oxidation numbers are $\overset{+4}{C}\overset{-2}{O_3}{}^{2-}$

Variable oxidation number

The oxidation number of the transition metals vary depending upon the compound. The different oxidation states often have characteristic colors *e.g.* as in vanadium compounds

Solutions of vanadium compounds that have various oxidation numbers

Using oxidation numbers to name chemicals
e.g. there are 2 iron chlorides. Roman numerals are used to represent the oxidation state:

$FeCl_2$ is iron (II) chloride
$FeCl_3$ is iron (III) chloride

3. State the oxidation number of carbon in
   a. CO +2
   b. CO_2 +4
   c. CH_4 -4
   d. C 0
   e. HCO_3^- +4
4. Which one of the following substances contain manganese in the +6 oxidation state: $MnCl_2$, $MnCl_3$, MnO_2, K_2MnO_4, $KMnO_4$ K_2MnO_4
5. Find the oxidation numbers of each element in the following compounds or ions. Hint: For ionic compounds, use the charge on each ion to help you.
   a. CaO Ca +2 O -2
   b. $CaCl_2$ Ca +2 Cl -1
   c. HSO_4^- H +1 S +6 O -2
   d. MnO_4^- Mn +7 O -2
   e. F_2 F 0
   f. SO_3^{2-} S +4 O -2
   g. $NaNO^3$ Na +1 N +5 O -2
   h. $K_2Cr_2O_7$ K +1 Cr +6 O -2

6. Assign oxidation numbers to each element in these equations, and hence identify the oxidant and the reductant:
   a. $Mg (s) + Cl_2 \longrightarrow MgCl_2 (s)$
      Oxidant: Cl_2; Reductant: Mg
   b. $2SO_2 (g) + O_2 (g) \longrightarrow 2SO_3$
      Oxidant: CO_2; Reductant: SO_2
   c. $Fe_2O_3 (s) + 3CO (g) \longrightarrow 2Fe (s) + 3CO_2 (g)$
      Oxidant: Fe_2O_3; Reductant: CO
   d. $2Fe^{2+} (aq) + H_2O_2 + 2H^+ \longrightarrow 2Fe^{3+} (aq) + 2H_2O (l))$
      Oxidant: H_2O_2; Reductant: Fe^{2+}

Half equations

$2(Mg \longrightarrow Mg^{2+} + 2^{e^-})$	Oxidation half equation
$O_2 + 4^{e^-} \longrightarrow 2O^{2-}$	Reduction half equation
$2Mg (s) + O_2 (g) \longrightarrow 2MgO (s)$	Overall equation

The number of electrons lost must be equal to the number of electrons gained during the reaction.

Rules for balancing redox equations

Rule	Example
Balance all elements except hydrogen and oxygen	$Cr_2O_7^{2-} (aq) \longrightarrow 2Cr^{3+} (aq)$
Balance oxygen using H_2O molecules	$Cr_2O_7^{2-} (aq) \longrightarrow 2Cr^{3+} (aq) + 7H_2O (l)$
Balance hydrogen using H^+ ions	$Cr_2O_7^{2-} (aq) + 14 H^+ (aq) \longrightarrow 2Cr^{3+} (aq) + 7H_2O (l)$
Balance charge using electrons	$Cr_2O_7^{2-} (aq) + 14 H^+ + 6^{e^-} (aq) \longrightarrow 2Cr^{3+} (aq) + 7H_2O (l)$

Worked example 5.3

When a pale green solution containing Fe2+ ions is mixed with a purple-colored solution of MnO4- ions, the purple color disappears. Fe3+ and Mn2+ ions are formed. Write a balanced equation for this reaction.

Solution

$Fe^{2+} (aq)$ $Fe^{3+} (aq) + e^-$

$MnO_4^- \longrightarrow Mn^{2+}$

$MnO_4^- \longrightarrow Mn^{2+} + 4H_2O$ (add water)

$MnO_4^- + 8H^+ \longrightarrow Mn^{2+} + 4H_2O$ (add H^+)

$MnO_4^- (aq) + 8H^+ (aq) + 5e^- \longrightarrow Mn^{2+} (aq) + 4H_2O (l)$ (add e^-)

To write an overall equation, the half equations are multiplied so that the number of electrons on each side is the same. They are added together and simplified if required:

$5 \times Fe^{2+} (aq) \longrightarrow Fe^{3+} (aq) + e^-$

$MnO_4 (aq) + 8H^+ (aq) + 5e^- \longrightarrow Mn^{2+} (aq) + 4H_20 (l)$

$MnO_4^- (aq) + 8H^+ (aq) + 5Fe^{2+} (aq) \longrightarrow Mn^{2+} (aq) + 5Fe^{3+} (aq) + 4H_2O (l)$

Redox titrations

The concentration of redox reactants can be found by volumetric analysis: redox titrations.

TABLE 5.2 Analysis of oxidants and reductants in common products

Item	Ingredient for analysis	Titrate with
Wine	Ethanol	Iron(II) solution, after reaction with an excess of potassium dichromate solution
Wine	Sulfur dioxide	Iodine solution
Fruit juice	Vitamin C (ascorbic acid)	Iodine solution
Household bleach	Hypochlorite ion	Sodium thiosulfate solution, after reaction with an excess of acidified potassium iodide solution
Hair bleach	Hydrogen peroxide	Potassium permanganate solution

Worked example 5.4

A 10 mL sample of white wine was placed in a volumetric flask and water was added to make 100 mL of solution. Then 20.0 mL aliquots of the diluted wine were titrated against 0.100 M acidified potassium dichromate solution. The mean titre was 24.61 mL. Calculate the concentration of ethanol in the sample of white wine.

$2Cr_2O7^{2-}$ (aq) + $3CH_3CH_2OH$ (aq) + $16H^+$ (aq) $\rightarrow$ $4Cr^{3+}$ (aq) + $3CH_3COOH$ (aq) + $11H_2O$ (l)

Solution

$n(Cr_2O_7^{2-}) = c(Cr_2O_7^{2-}$ X $V(Cr_2O_7^{2-})$

= 0.100 mol L-1 X 0.02461 L = 0.002461 mol

From the equation, 2 mol of $Cr_2O_7^{2-}$ reacts with 3 mol of CH_3CH_2OH

So, the ratio is $\frac{n(\text{ethanol})}{n(\text{dichromate})} = \frac{3}{2}$

$n(\text{ethanol}) = \frac{3}{2}$ X 0.002461 = 0.003692 mol

The amount of ethanol in the 20.0 mL of diluted wine is 0.003692 mol. Since this volume of wine was taken from a total volume of 100.0 mL,
there would be 100/20 or 5X this amount in the original 10.0 mL sample:
0.003692 X 5 = 0.01846 mol

$c(\text{ethanol}) = \frac{n(\text{ethanol})}{V(\text{ethanol})} = \frac{0.01846\text{ mol}}{0.100\text{ L}} = 1.846\text{ mol L}^{-1}$

The concentration of alcohol in the wine is 1.85 M

12. Potassium permanganate reacts with hydrogen peroxide:
    $2MnO_4^-$ (aq) + $5H_2O_2$ (aq) + $6H^+$ (aq) $\longrightarrow$ $2Mn^{2+}$ (aq) + $8H_2O$ (l) + $5O_2$ (g)
    25.0 mL of 0.02 M $KMnO_4$ solution is reduced by 20.0 mL of H_2O_2 solution. What is the concentration of the hydrogen peroxide solution?

    0.0625 M

13. An artist uses 10.0 mL of 15.0 M HNO3 to etch a design into a copper sheet. What mass of copper will have reacted with the acid?

    Cu (s) + $4HNO_3$ (aq) $\longrightarrow$ $Cu(NO_3)_2$ (aq) + $2H_2O$ (l) + $2NO_2$ (g)

    2.38 g

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Questions 14 a, c; 15 a,c,e; 17; 21; 23; 24; 25; 27; 28