7.2 BRONSTED LOWRY THEORY OF ACIDS AND BASES

Learning outcomes

Candidates should be able to:

1. state the names and formulae of the common acids, limited to hydrochloric acid, HCl, sulfuric acid, H_2SO_4, nitric acid, HNO_3, ethanoic acid, CH_3COOH
2. state the names and formulae of the common alkalis, limited to sodium hydroxide, NaOH, potassium hydroxide, KOH, ammonia, NH_3
3. describe the Brønsted–Lowry theory of acids and bases
4. describe strong acids and strong bases as fully dissociated in aqueous solution and weak acids and weak bases as partially dissociated in aqueous solution
5. appreciate that water has pH of 7, acid solutions pH of below 7 and alkaline solutions pH of above 7
6. explain qualitatively the differences in behaviour between strong and weak acids including the reaction with a reactive metal and difference in pH values by use of a pH meter, universal indicator or conductivity
7. understand that neutralisation reactions occur when $H^+(aq)$ and $OH^-(aq)$ form $H_2O(l)$
8. understand that salts are formed in neutralisation reactions
9. sketch the pH titration curves of titrations using combinations of strong and weak acids with strong and weak alkalis
10. select suitable indicators for acid-alkali titrations, given appropriate data (pK_a values will not be used)

Initial assessment

Define acid, base and salts.

Explain what you know about pH.

Give some examples of acid, base and salts.

Define neutralization?

Give some examples of neutralization.

Introduction

We can use universal indicator or a pH meter to deduce whether a substance is acidic, alkaline or neutral.

acids have pH values below pH 7

alkalis have pH values above pH 7

a neutral solution has a pH value of exactly 7.

Common acids		Common bases	
Hydrochloric acids	HCl	Sodium hydroxide	NaOH
Sulfuric acid	H_2SO_4	Potassium hydroxide	KOH
Nitric acid	HNO_3	Ammonia	NH_3
Ethanoic acid	CH_3COOH		

A **base** is a compound that contains oxide or hydroxide ions and reacts with an acid to form a salt and water. Alkalis are bases which are soluble in water.

Neutralization: the reaction of an acid with an alkali to form a salt & water.

Salt: a substance formed when an acid reacts with a salt, an alkali, a metal oxide or a carbonate.

1. SiO_2 has a melting point of 1713 °C. It reacts with hot NaOH(aq) to form sodium silicate, Na_2SiO_3, and water. No reaction occurs when SiO_2 is added to hot H_2SO_4(aq).
   What can be deduced from this information?

	Chemical behaviour of SiO_2	Structure of SiO_2
A	amphoteric	giant
B	amphoteric	simple
C	acidic	giant
D	acidic	simple

The Brønsted–Lowry theory

The Brønsted–Lowry theory is the most commonly used description of acidity. It describes an acid as a substance capable of donating protons (H+) and a base as a substance capable of accepting them.

$HCl + NH_3 \rightarrow Cl^- + NH_4^+$

• In this reaction hydrogen chloride acts as an acid by donating a proton to ammonia, which acts as a base.
• In the reverse of this reaction, the chloride ion accepts a proton from the ammonium ion. This means that the ammonium ion would be acting as an acid in donating the proton to the chloride ion, which would be acting as a base.
• In this reaction, the chloride ion is known as the **conjugate base** of hydrogen chloride and the ammonium ion as the **conjugate acid** of ammonia.

1. Calcium nitrate, $Ca(NO_3)_2$, reacts with ammonia, carbon dioxide and water to form a mixture of ammonium nitrate and calcium carbonate.
   $Ca(NO_3)_2 + 2NH_3 + CO_2 + H_2O \rightarrow 2NH_4NO_3 + CaCO_3$
   Explain why ammonia is described as a Bronsted-Lowry base in this reaction. [1]

2. When ClO^-(aq) is added to water, it behaves as a Brønsted-Lowry base.
   (i) Define the term Brønsted-Lowry base. [1]

   (ii) Write an ionic equation for the reaction between ClO^- and H_2O. [1]

1. In which reaction is water behaving as a Brønsted–Lowry base?

   A $H_2O + Na \rightarrow NaOH + 1/2H_2$

   B $H_2O + H_3PO_4 \rightarrow H_3O^+ + H_2PO_4$

   C $H_2O + CaO \rightarrow Ca(OH)_2$

   D $NH_3 + [Cu(H_2O)_6]^{2+} \rightarrow NH_4^+ + [Cu(H_2O)_5(OH)]^+$

2. Diethylzinc, $(C_2H_5)_2Zn$, is added to NaOH(aq). Two reactions occur.

   reaction 1 $(C_2H_5)_2Zn + H_2O \rightarrow ZnO + 2C_2H_6$

   reaction 2 $H_2O + ZnO + 2OH^- \rightarrow Zn(OH)_4^{2-}$

   In these reactions, which compounds act as Brønsted–Lowry acids?

	reaction 1	reaction 2
A	$(C_2H_5)_2Zn$	H_2O
B	H_2O	H_2O
C	H_2O	ZnO
D	the reaction is not acid /base	ZnO

3. Ammonia can undergo an acid–base reaction with hydrogen chloride to form ammonium chloride.
Which statement is correct?

A The ammonium ion is basic.

B The hydrogen atom from HC*l* donates a lone pair of electrons to the nitrogen atom.

C The H–N–H bond angle in ammonia is the same as the H–N–H bond angle in the ammonium ion.

D The H–N–H bond angle in the ammonium ion is the same as the H–C–H bond angle in methane.

Conjugate acid–base pairs. In the Bronsted-Lowry theory, an acid produces a conjugate base. For example, HCl forms a proton, H+, and a chloride ion, Cl-. The chloride ion is the conjugate base of HCl. Similarly, bases form conjugate acids,
e.g. $NH_3 + H_2O \rightarrow NH_4^+ + OH^-$
Here, NH_4^+ is the conjugate acid of NH_3.

3. Give the formula of the conjugate base of H_3PO_3. [1]

4. Hydrogen sulfide gas, $H_2S(g)$, is slightly soluble in water. It acts as a weak acid in aqueous solution.
Give the formula of the conjugate base of H_2S. [1]

5. Hypophosphorous acid is an inorganic acid.
The conjugate base of hypophosphorous acid is $H_2PO_2^-$.
Give the formula of hypophosphorous acid.

.... [1]

6. An exothermic reaction occurs when $NH_4^+(aq)$ is added to $OH^-(aq)$.
(i) Identify the type of reaction. [1]

(ii) Construct an ionic equation for the reaction of NH_4^+ and OH^-. [1]

Strong and weak acids and bases

It is important to understand the difference between **dilute** and **weak**, and **concentrated** and **strong** when you are writing about acids and bases:

• A **strong acid** or **strong base** is **completely** ionised in solution. We often refer to the compound as being completely dissociated.

• A **weak acid** or **weak base** is only **partially** ionised in solution. We often refer to the compound as being partly dissociated.

• A **concentrated acid** or **concentrated base** has a **large** number of moles per unit volume of the acid or base.

• A **dilute** solution has a **small** number of moles relative to the solvent

- The mineral acids, hydrochloric acid, sulfuric acid and nitric acid, are all strong acids.

Sulfuric acid has two hydrogen ions that can ionise. The first hydrogen to ionise dissociates almost completely:

$H_2SO_4 \rightarrow H^+ + HSO_4^-$.

HSO_4^-, however, behaves as a weak acid:

$HSO_4^- \rightleftharpoons H^+ + HSO_4^{2-}$

Weak acids include most organic acids, hydrocyanic acid (HCN), hydrogen sulfide and 'carbonic acid'.

The Group 1 metal hydroxides are strong bases.

Ammonia, amines and some hydroxides of transition metals are weak bases.

Degree of dissociation: the extent to which a molecule of an acid ionises in a solvent to produce H^+ ions or the extent to which a base produces OH^- ions in a solvent.

Hydrogen ions in aqueous solution are correctly written as H_3O^+ (hydroxonium or oxonium ion). It is often acceptable to simplify its structure as H^+.

For example: Ionisation of a strong acid: $HCl \rightarrow H^+ + Cl^-$

Ionisation of a weak acid: $CH_3COOH \rightleftharpoons CH_3COO^- + H^+$

7. HC*l* is a strong Brønsted-Lowry acid.
   Describe what is meant by a strong Brønsted-Lowry acid. [1/2]

8. The hydrogen halides dissolve in water to form strong Brønsted–Lowry acids.
   The concentration of a strong acid can be determined by titration.
   State what is meant by strong Brønsted–Lowry acid. [1]

9. $H_3PO_3(aq)$ and HI(aq) are both strong Brønsted–Lowry acids.
   Give the meaning of the term *strong Brønsted–Lowry acid*.

10. Ethyne, HCN and **Q** (H—C≡C—C≡N) are all weak Brønsted–Lowry acids.
    Explain what is meant by the term weak Brønsted–Lowry acid. [2]

11. Hydrogen sulfide gas, $H_2S(g)$, is slightly soluble in water. It acts as a weak acid in aqueous solution.
    State the meaning of weak acid. [1]

12. NCl_3 reacts with water to form HOCl, a weak Brønsted-Lowry acid.
    Explain fully what is meant by the term weak Brønsted-Lowry acid.

13. The two most common oxides of sulfur are SO_2 and SO_3.
    When SO_2 dissolves in water, a small proportion of it reacts with water to form a weak Brønsted-Lowry acid.
    Explain the meaning of the term weak Brønsted-Lowry acid. [2]

14. H_3PO_4 is a weak Brønsted–Lowry acid.
Define weak Brønsted–Lowry acid. [2]

Electrical conductivity

Dilute solutions of a strong acids have greater electrical conductivity than those of weak acids of the same concentration. This is because the concentration of hydrogen ions (and other ions) is greater in strong acids.

Distinguishing a weak acid from a strong acid

We can distinguish between a strong and weak acid by their pH values, electrical conductivity and reactivity. When making these comparisons, we must use dilute solutions of strong and weak acids of the same concentration.

pH values

Dilute solutions of a strong acids have lower pH values than those of weak acids of the same concentration. This is because the concentration of hydrogen ions is greater in strong acids.

Acid or base	pH of 1.0 mol dm^{-3} solution	pH of 0.1 mol dm^{-3} solution	pH of 0.01 mol dm^{-3} solution
hydrochloric acid (strong acid)	0	1	2
ethanoic acid (weak acid)	2.4	2.9	3.4
sodium hydroxide (strong base)	14	13	12
ammonia (weak base)	11.6	11.1	10.6

Table 8.10: pH values of some typical strong and weak acids and bases.

We can determine pH by;

- Dipping a pH electrode into a solution of the acid: a pH meter connected to the pH electrode shows the pH value.
- Dipping universal indicator paper into a solution of the acid and noting the colour change. We then compare the colour with that on a chart which shows the colours at different pH values.

Table 8.10 compares the pH values of some typical strong and weak acids and bases.

We can determine electrical conductivity by dipping a conductivity electrode into a solution of the acid: a conductivity meter connected to the electrode shows the conductivity.

Reaction with reactive metals

Dilute solutions of weak and strong acids of the same concentration have different reactivity with reactive metals such as magnesium. When a piece of magnesium ribbon is added to a strong acid, a steady stream of hydrogen bubbles is observed.

$$Mg(s) + 2HCl \rightarrow MgCl_2(aq) + H_2(g)$$

When we add a piece of magnesium ribbon to a weak acid of the same concentration, only a few bubbles are observed. This is because the concentration of hydrogen ions is greater in strong acids.

15. NH_3 is a weak base.
Construct an equation that shows the behaviour of NH_3 as a weak Brønsted-Lowry base when dissolved in water. [1]

16. When $NH_4^+(aq)$ is heated with NaOH(aq), a pungent gas is produced.
Write an ionic equation for this reaction. [1]

4. Solid ammonium nitrate is put into a test tube and solution X is added to it. The resulting mixture is warmed and the gas given off is tested with damp red litmus paper. The litmus paper changes colour from red to blue.
What could be the identity of X and its role in the reaction?

	identity of X	role of X
A	NaOH(aq)	proton donor
B	NaOH(aq)	proton acceptor
C	HC*l*(aq)	proton donor
D	HC*l*(aq)	proton acceptor

17. The enthalpy change of neutralisation of $CH_3COOH(aq)$ and NaOH(aq) is $-55.2 kJmol^{-1}$.
(i) Complete the equation for the reaction.

.........CH_3COOH + ...NaOH .... [1]

(ii) Values for the enthalpy change of neutralisation, ΔH_{neut}, are shown in the following table.

reagents	$\Delta H_{neut}/kJmol^{-1}$
NaOH + HCl	–57.1
NaOH + CH_3COOH	–55.2

Suggest why the value for ΔH_{neut} of the weak acid, CH_3COOH, reacting with NaOH is different to the value obtained using the strong acid, HCl. Assume that the values are determined under the same conditions. [1]

ANS: Weak acid or base will not ionise completely in water. Some remains as undissociated molecules in water. Some amount of heat of neutralization is used to ionise undissociated molecules. As some amount of energy consumed, energy release is less in case of weak acid or alkali. Here Ethanoic acid (acetic acid) is a weak acid.

18. (i) Complete the equation for the reaction that occurs when a solution of $Ba(OH)_2$ is added to aqueous sulfuric acid. Include state symbols.

..... $H_2SO_4(aq)$ + ... $Ba(OH)_2(aq)$ ……………………………… [2]

(ii) **Suggest why the enthalpy change of neutralisation cannot be determined using the addition of dilute sulfuric acid to aqueous barium hydroxide. [1]**

5. Separate samples of 25.0 cm^3 of 0.1 mol dm^{-3} NaOH(aq) are added to each of three different acid solutions, as described. The temperature of each of the solutions was 298 K before mixing.

sample	acid	type of acid	concentration / mol dm^{-3}	volume / cm^3
1	H_2SO_4	strong	0.05	25.0
2	HCl	strong	0.05	25.0
3	CH_3CO_2H	weak	0.05	25.0

Which statement describes the temperature rises that occur on mixing each of these three acids separately with NaOH?

A The temperature rise in all three mixtures is the same.
B The temperature rise using H_2SO_4 and HCl is the same.
C The temperature rise using CH_3CO_2H is greater than using HCl.
D The greatest temperature rise occurs using H_2SO_4.

6. Which statement about acids and bases is always correct?

A An acid with two H atoms per molecule will be stronger than an acid with one H atom per molecule.
B A concentrated solution of a strong acid will have a lower pH than a dilute solution of a weak acid.
C A concentrated solution of a strong base will have a lower pH than a dilute solution of a weak base.
D A strong acid is more dissociated in solution than a strong base.

7. The product of the Contact process is Z.
Which reaction or process leads to the formation of a gas that can neutralise an aqueous solution of Z?

A atmospheric lightning
B combustion of fuel in an internal combustion engine
C the Haber process
D thermal decomposition of Group 2 nitrates

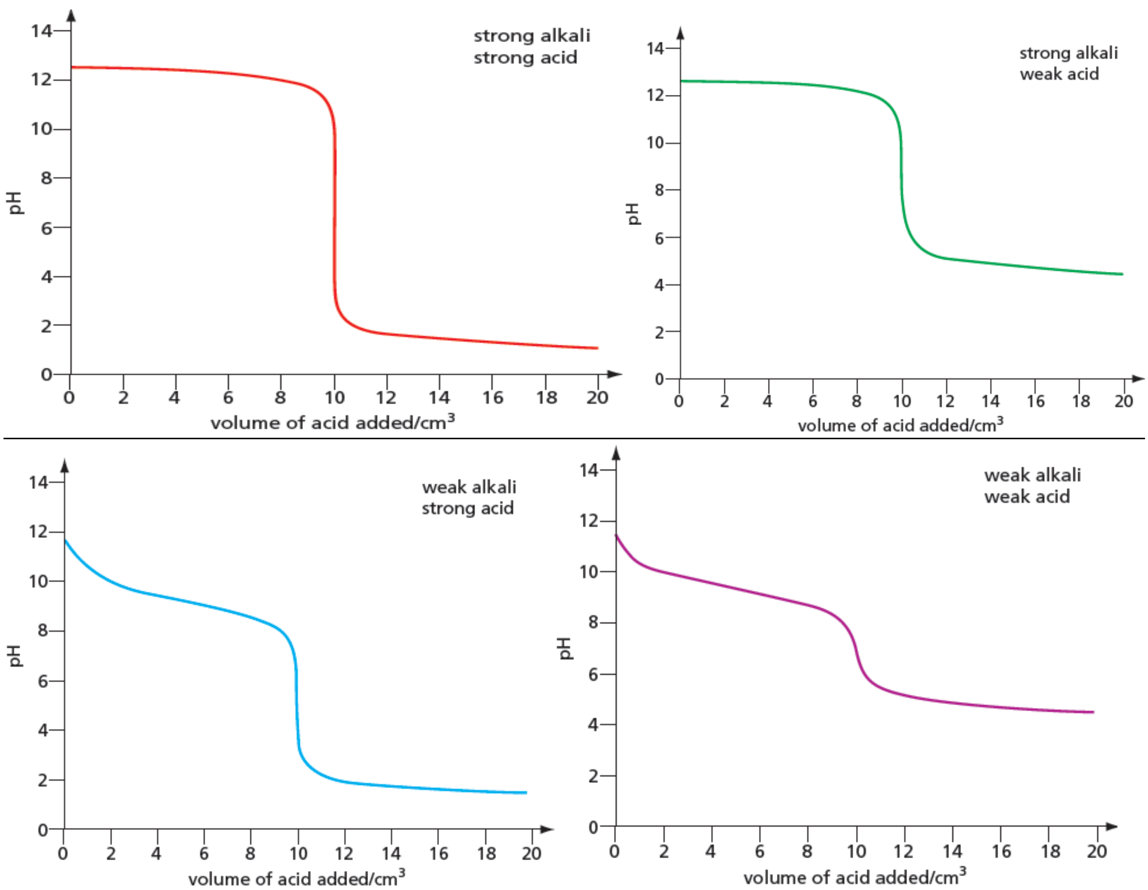
8. A farmer requires a solid compound to raise the pH of the soil in a field from 5.5 to above 6.0.
Which compound could the farmer use?

A $(NH_4)_2SO_4$ **B** NH_4NO_3 **C** $Ca(OH)_2$ **D** $Ca(NO_3)_2$

9. Which solution has the lowest pH value?

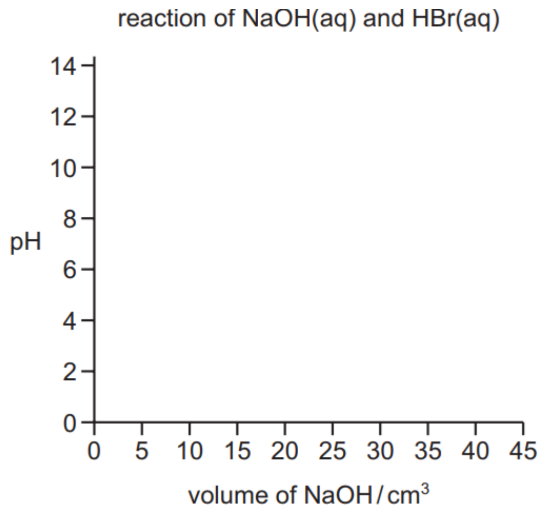
A 0.01 mol dm^{-3} butanoic acid
B 0.01 mol dm^{-3} ethanoic acid
C 0.01 mol dm^{-3} hydrochloric acid
D 0.01 mol dm^{-3} sulfuric acid

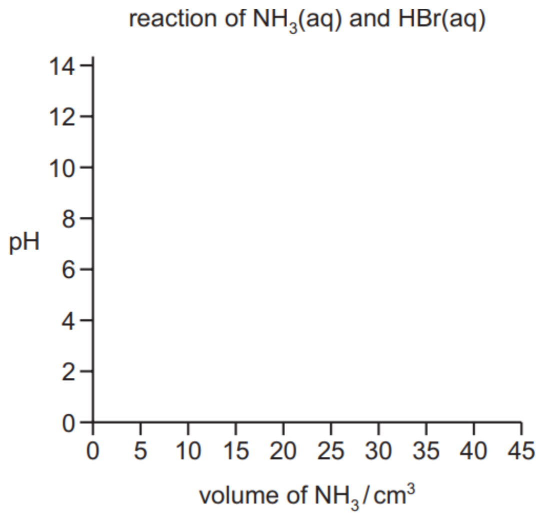
Plotting titration curves



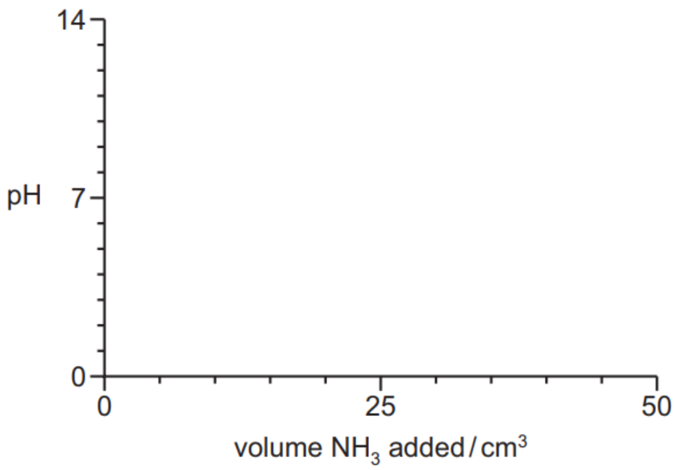
19. On the following figure, sketch the pH titration curves produced when:

- 0.1moldm^{-3} NaOH(aq) is added to 25cm^3 of 0.1moldm^{-3} HBr(aq), to excess
- 0.1moldm^{-3} NH_3(aq) is added to 25cm^3 of 0.1moldm^{-3} HBr(aq), to excess.

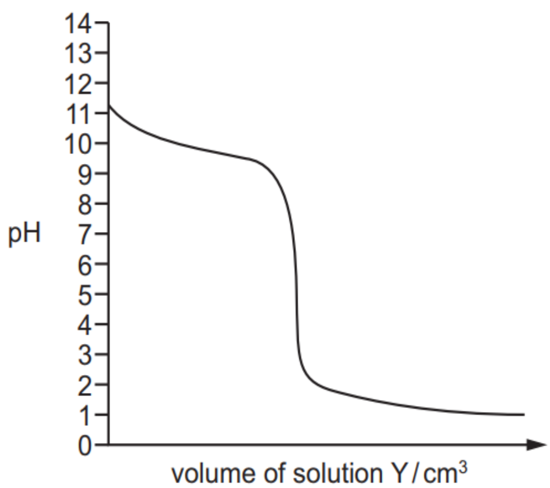




20. 25cm^3 of 0.10moldm^{-3} HC*l*(aq) is added to a beaker and its pH is recorded.
50cm^3 of 0.10moldm^{-3} NH_3(aq) is added to the HC*l*(aq) in 5cm^3 portions.
The pH of the mixture is monitored until all the NH_3(aq) is added. On the following figure sketch a graph to show the change in pH which occurs when HC**l**(aq) is titrated with NH_3(aq) as described in (d).



10. Solutions X and Y both have a concentration of 0.10 mol dm^{-3}. A fixed volume of solution X is added to a conical flask, and solution Y is added from a burette to the conical flask. A titration is performed. The diagram shows the pH titration curve for the acid–base reaction between the solutions.



What are solutions X and Y?

	solution X	solution Y
A	ammonia	nitric acid
B	ammonia	ethanoic acid
C	potassium hydroxide	nitric acid
D	potassium hydroxide	ethanoic acid

Selection for indicators

Acid -base indicator: a compound that has two different ranges of colours depending on the pH of the solution in which it is placed. It changes colour over a narrow range of pH values.

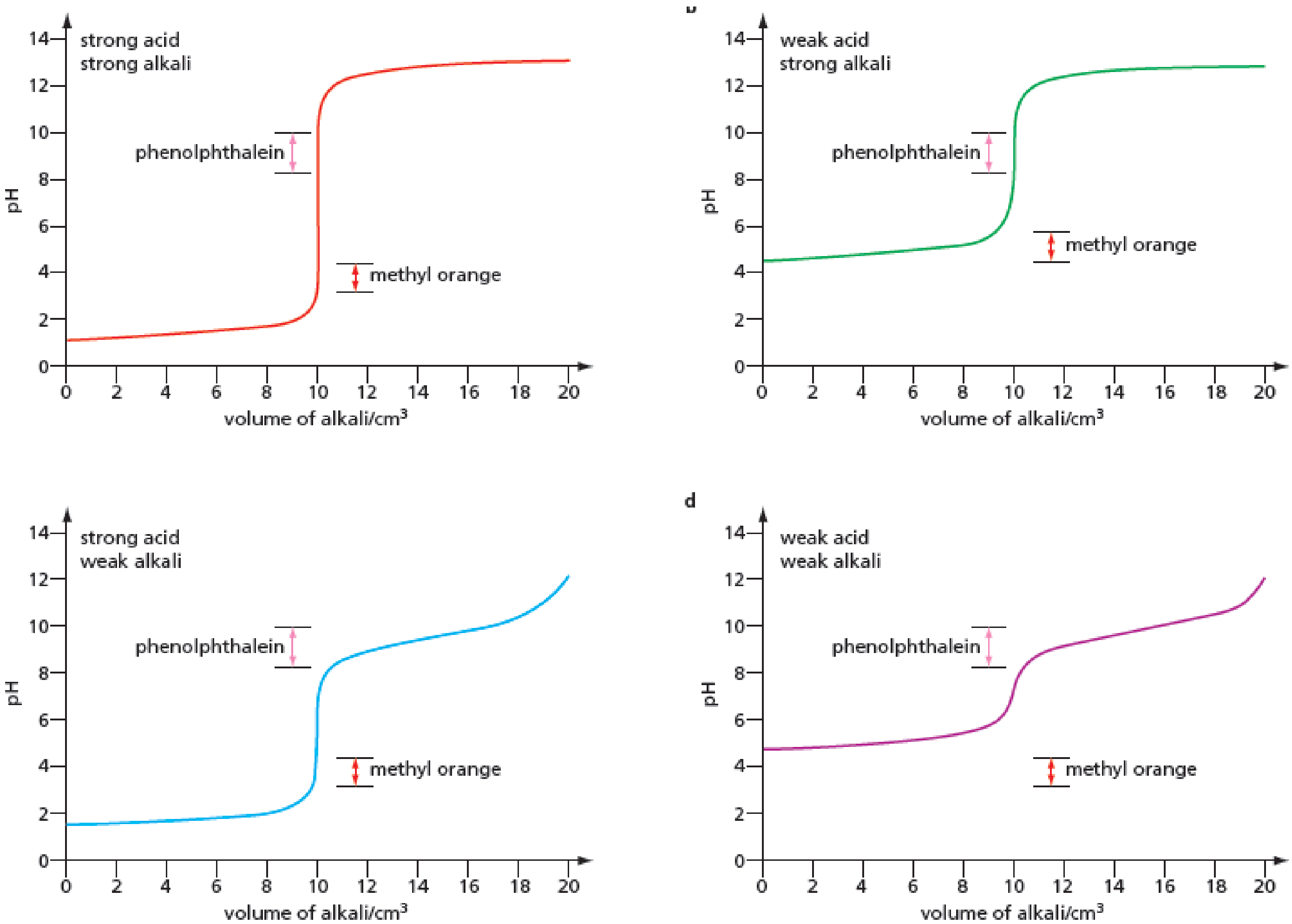
When carrying out a titration, it is the pH of the solution at the end point that is critical when choosing a suitable indicator. Two main factors need to be considered:

• The colour change should be sharp – no more than one drop of acid or alkali should give a distinct colour change.
• The end point should occur when the solution contains the same number of hydrogen ions as hydroxide ions.

Plotting graphs of the change in pH with the addition of the titrating solution produces different curves for combinations of weak and strong acids with weak and strong bases,

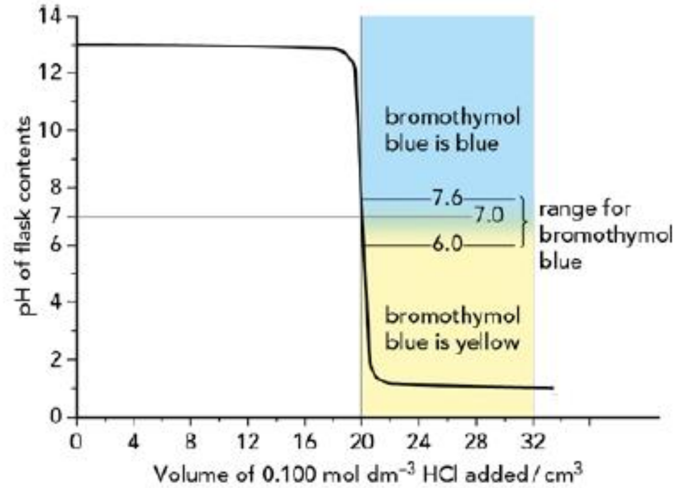
Indicator	**Colour change when acid is run from the burette**	**Colour change when alkali is run from the burette**
methyl orange	yellow to first tinge of orange	red to first tinge of orange
phenolphthalein	pink to just colourless	colourless to just pink

The vertical portion of the pH versus volume graph has to be in the pH range of the indicator to give a colour change.



Acid/base combination	Indicator used
Strong acid/strong base	Either would do
Weak acid/strong base	Phenolphthalein
Strong acid/weak base	Methyl orange
Weak acid/weak base	Neither is suitable; a different method is needed

Figure 8.18 shows how the pH changes when 0.100 mol dm^{-3} sodium hydroxide (a strong base) is titrated with 0.100 mol dm^{-3} hydrochloric acid (a strong acid) in the presence of bromothymol blue indicator.



These results show:

- a sharp fall in the graph line between pH 10.5 and pH 3.5; in this region tiny additions of H^+ ions result in a rapid change in pH a midpoint of the steep slope at pH 7
- the midpoint of the sharp fall corresponds to the point at which the H^+ ions in the acid have exactly reacted with the OH^- ions in the alkali; this is the end-point of the titration
- bromothymol blue indicator changed from blue to yellow over the range 7.6 to 6.0, where the slope is steepest.

Because there is a sharp change in pH over the region pH 3.5 to 10.5, we can use other indicators that change colour within this region. For example, phenolphthalein changes colour in the pH range 8.2 to 10.0.

*****This is not a complete note. It is just to guide you. It is recommended to study the prescribed textbooks along with this material. *****