8.2 PROPERTIES OF ACIDS AND BASES

Acids (from the Latin *acidus* meaning 'sour') have been known for hundreds of years. Many of the foods we eat contain acids. Acids give vinegar (containing ethanoic acid) its tang. Certain fruits such as lemons and grapefruit are sour due to acids (citric acid and ascorbic acid), and soft drinks owe their 'fizz' to an acid (carbonic acid). The stomach produces gastric juice containing hydrochloric acid, which provides an acidic environment for the breakdown of certain foods.

Bases are the chemical opposite of acids. They are used in a variety of cleaning products such as oven, drain and window cleaners. Common household and industrial bases include sodium hydroxide (caustic soda), sodium carbonate, hydrated sodium carbonate and ammonia. Bases such as magnesium hydroxide and aluminum hydroxide are also used in various antacids for the relief of upset stomachs caused by excess acid.

Common Acids

Name of acid	Chemical formula	Use or occurrence
Inorganic acids		
Hydrochloric	HCl	Concrete cleaner and stomach acid. Common laboratory acid
Nitric	HNO_3	Fertilizer manufacture, dyes and explosives. Laboratory acid
Phosphoric (Orthophosphoric acid)	H_3PO_4	Fertilizer manufacture, food additive
Sulfuric (or Sulphuric)	H_2SO_4	Car batteries and in the manufacture of fertilizers. Laboratory acid
Organic acids		
Acetyl salicylic	$C_9H_8O_4$	Aspirin
Ascorbic (vitamin C)	$C_6H_8O_6$	Citrus fruits
Benzoic	C_6H_5COOH	Food preservative
Carbonic	H_2CO_3	Soft drinks and rainwater
Citric	$C_6H_8O_7$	Lemons
Ethanoic (acetic)	CH_3COOH	Vinegar. Laboratory acid
Lactic	$C_3H_6O_3$	Milk and released by human muscles during strenuous exercise
Methanoic (formic)	$HCOOH$	Ant and Bee stings

Common Bases

Name of base	Chemical formula	Use or occurrence
Inorganic bases		

Ammonium hydroxide	NH_4OH	Window cleaner
Barium hydroxide	$Ba(OH)_2$	Used as a strong base in organic syntheses.
Calcium hydroxide (slaked lime)	$Ca(OH)_2$	Plaster and cement, and to neutralise soil acidity
Calcium oxide (quicklime)	CaO	Mortar for bricks, and to neutralise soil acidity
Hydrated sodium carbonate	$Na_2CO_3 \cdot 10H_2O$	Washing soda
Magnesium hydroxide	$Mg(OH)_2$	Antacid
Sodium carbonate	Na_2CO_3	Washing powders and in the manufacture of glass
Sodium hydrogen carbonate (sodium bicarbonate)	$NaHCO_3$	Baking soda
Sodium hydroxide (caustic soda)	$NaOH$	Drain and oven cleaners, and in soap production
Organic bases		
Ammonia	NH_3	Fish urine
Methylamine	CH_3NH_2	Agricultural chemicals

The first theory of acids and bases was hypothesized by Svante Arrhenius, a Swedish Chemist who also proposed the first explanation for activation energy. In his 1883 University doctoral dissertation he proposed that ions carried the charge in salt solutions (ionic compounds) and these ions that were present even in the absence of an electric current. His work was ground breaking but was given a low grade by the University examiners. Fortunately his work was regarded much more respectfully by scientists throughout Europe and he was able to use these contacts to further his career. In 1884 Arrhenius extended his theory of ions to acids and described acids as substances that contained hydrogen and yielded hydrogen ions in aqueous solution; bases contained the OH group and yielded hydroxide ions in aqueous solution. The theory of acids and bases chemists use today is more sophisticated than this but Arrhenius' first concepts are still relevant.

ACIDS

1. The Arrhenius theory of acids describes how acids when dissolved in water break up into their respective ions of which one will be the *hydrogen, H^+ ion*. Hydrogen ions are often referred to as *protons* because they are hydrogen atoms, which have lost an electron.

Examples (fill in the boxes)

$$HCl_{(aq)} \quad + \quad H_2O_{(l)} \quad \rightarrow \quad H^+_{(aq)} \quad + \quad Cl^-_{(aq)}$$

$HNO_{3(aq)}$	+	$H_2O_{(l)}$	$\rightarrow$		+		
$H_2SO_{4(aq)}$	+	$H_2O_{(l)}$	$\rightarrow$		+		
$CH_3COOH_{(aq)}$	+	$H_2O_{(l)}$	$\leftrightarrow$		+		
$HCN_{(aq)}$	+	$H_2O_{(l)}$	$\rightarrow$		+		
$HF_{(aq)}$	+	$H_2O_{(l)}$	$\rightarrow$		+		

2. Other substances are said to be acids because they react with water to form an acid. For example sulfur trioxide is called an acidic oxide because it reacts with water to produce sulphuric acid. Non-metal oxides are acids.

$$SO_{3(g)} + H_2O_{(l)} \rightarrow H_2SO_{4(aq)}$$

3. Most non metal oxides are also called acids because they react with bases to produce a salt and water (**neutralization** reaction)

Common reactions of acids

1. acid + metal $\rightarrow$ salt + hydrogen gas

e.g. $2HCl + Zn \rightarrow ZnCl_2 + H_2$

2. acid + carbonate $\rightarrow$ salt + water + carbon dioxide

	or hydrogen carbonate					gas

e.g. $2HCl + CaCO_3 \rightarrow CaCl_2 + H_2O + CO_2$

3.	acid	+	metal oxide or metal hydroxide	→	salt	+	water

e.g.

$2HCl + CaO \rightarrow CaCl_2 + H_2O$

$2HCl + Ca(OH)_2 \rightarrow CaCl_2 + 2H_2O$

4.	acid	+	base	→	salt	+	water

e.g. $HCl + NaOH \rightarrow NaCl + H_2O$

BASES

1. The Arrhenius theory of bases describes how bases when dissolved in water break up into their constituent ions, one of which will be the **hydroxide ion, OH^-** ion. Most metal oxides are bases because they react with acids to give a salt and water.

$$NaOH + H_2O \rightarrow Na^+_{(aq)} + OH^-_{(aq)}$$

$$NH_3 + H_2O \leftrightarrow NH_4^+{}_{(aq)} + OH^-_{(aq)}$$

2. Metal oxides are bases because they react with acids to give a salt and water.

$$CuO + 2HCl \rightarrow CuCl_2 + H_2O$$

NOTE: Some bases do not obviously contain hydroxide ions in their formula. For example ammonia (NH_3), soluble carbonates like sodium carbonate, Na_2CO_3 and hydrogen carbonates like $NaHCO_3$.

AMPHOTERIC SUBSTANCES.

Amphoteric compounds can act as both an acid and a base. For example aluminum oxide, Al_2O_3, aluminum hydroxide, $Al(OH)_3$ and the hydrogen carbonate ion, $HCO^-_{3(aq)}$

Aluminum oxide acts as an acid when it reacts with a base

$$Al_2O_3 \text{ (acid)} + 2NaOH \text{ (base)} \rightarrow Al(OH)_4^- + H_2O$$

Aluminum oxide acts as a base when it reacts with an acid

$$Al_2O_3 \text{ (base)} + 6HCl \text{ (acid)} \rightarrow 2AlCl_3 + 3H_2O$$

Hydrogen carbonate ion acts as an acid because when it reacts with water it produces hydrogen ions.

$$HCO^-_{3(aq)} + H_2O \rightarrow H^+_{(aq)} + CO_3^{2-}{}_{(aq)}$$

Hydrogen carbonate ion acts as a base because when it reacts with water it produces hydroxide ions

$$HCO^-_{3(aq)} + H_2O \rightarrow OH^-_{(aq)} + H_2CO_{3(aq)}$$

Acidic and Basic Properties of the Third Period Oxides

Oxide	Reaction of oxides with water
Sodium oxide	$Na_2O_{(s)} + H_2O_{(l)} \rightarrow 2NaOH_{(aq)}$ Sodium hydroxide
Magnesium oxide	$MgO_{(s)} + H_2O_{(l)} \rightarrow Mg(OH)_{2(aq)}$ Magnesium hydroxide
Tetraphosphorus decaoxide	$P_4O_{10(s)} + 6H_2O_{(l)} \rightarrow 4H_3PO_{4(aq)}$ Phosphoric acid
Tetraphosphorus hexaoxide	$P_4O_{6(s)} + 6H_2O_{(l)} \rightarrow 4H_3PO_{3(aq)}$ Phosphorous acid
Sulphur dioxide	$SO_{2(g)} + H_2O_{(l)} \rightarrow H_2SO_{3(aq)}$ Sulfurous acid
Sulphur trioxide	$SO_{3(l)} + H_2O_{(l)} \rightarrow H_2SO_{4(aq)}$ Sulfuric acid
Dichlorine Oxide	$Cl_2O_{(g)} + H_2O_{(l)} \rightarrow 2HOCl_{(aq)}$ Hypochlorous acid
Dichlorine heptaoxide	$Cl_2O_{7(l)} + H_2O_{(l)} \rightarrow 2HClO_{4(aq)}$ Perchloric acid

Formula of oxides	$Na_2O_{(s)}$	$MgO_{(s)}$	$Al_2O_{3(s)}$	$SiO_{2(s)}$	$P_4O_{10(s)}$, $P_4O_{6(s)}$	$SO_{2(g)}$ $SO_{3(l)}$	$Cl_2O_{(g)}$ $Cl_2O_{7(l)}$
Names of oxides	Sodium Oxide	Magnesium Oxide	Aluminum Oxide	Silicon dioxide	Tetraphosphorus decaoxide, tetraphosphorus hexaoxide	Sulphur dioxide, sulphur trioxide	Dichlorine Oxide, dichlorine heptaoxide
Types of oxides	Metal	Metal	Metal	Metal	Non metal	Non metal	Non metal
	Alkaline	Alkaline	Amphoteric	Acidic	Acidic	Acidic	Acidic
Reaction with water	React (see table below)	React (see table below)	Insoluble	Insoluble	React (see table below)	React (see table below)	React (see table below)
Structure	Ionic Lattice	Ionic Lattice	Ionic Lattice	Giant covalent lattice	Simple covalent molecule	Simple covalent molecule	Simple covalent molecule

Ionization vs. dissociation

Dissociation refers to the breaking of chemical bonds, whether the product is ions or neutral molecules.

$$HCl + H_2O \rightarrow H^+_{(aq)} + Cl^-_{(aq)}$$

HCl and H_2O dissociate because the H-Cl bond breaks and ions are formed. Ionization refers to any process that forms ions. For example sodium chloride dissolving in water, and acid or base dissolving in water, an atom losing an electron to become a positive ion in a mass spectrometer are all examples of ionization.

$$NaCl \quad + \quad H_2O \quad \rightarrow \quad Na^+_{(aq)} \quad + \quad Cl^-_{(aq)}$$

Ionic Equations

In many chemical reactions there are species (usually ions) which do not participate in the actual reaction. Like people in a crowd at a football match who watch, but do not participate in the match, these ions are called **spectator ions**.

An ionic equation focuses on that part of the reaction which is actually undergoing chemical change, those atoms, molecules or ions whose bonds are breaking and which are forming new bonds. In addition these particles are changing state. The spectator ions are omitted from an ionic equation. Ionic equations can be useful in accurately representing acid-base reactions.

Consider the reaction between hydrochloric acid and sodium hydroxide

Full equation:

$$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$$

Because the reactants HCl and NaOH are in solution they dissociate so we can list all the species present.

Species present:

$$H^+(aq) + Cl^-(aq) + Na^+(aq) + OH^-(aq) \rightarrow Na^+(aq) + Cl^-(aq) + H_2O(l)$$

The spectator ions (the ions which have not changed from the left hand side to the right hand side of the equation) are $Na^+(aq)$ and $Cl^-(aq)$. Omitting these spectator ions gives the ionic equation

Ionic equation:

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

NOTE: All full and ionic equations need to be balanced. Normally when an equation means a full ionic equation.

Ionic equations for some typical acid-base reactions

Full equation	Ionic equation
$2HCl(aq) + Mg(s) \rightarrow MgCl_2(aq) + H_2(g)$	$2H^+(aq) + Mg(s) \rightarrow Mg^{2+}(aq) + H_2(g)$
$2HCl(aq) + Mg(OH)_2(s) \rightarrow MgCl_2(aq) + 2H_2O(l)$	$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$
$2HCl(aq) + MgO(s) \rightarrow MgCl_2(aq) + H_2O(l)$	$2H^+(aq) + O^{2-}(aq) \rightarrow H_2O(l)$
$2HCl(aq) + Na_2CO_3(aq) \rightarrow 2NaCl(aq) + H_2O(l) + CO_2(g)$	$2H^+(aq) + CO_3^{2-}(aq) \rightarrow H_2O(l) + CO_2(g)$
$HCl(aq) + NaHCO_3(aq) \rightarrow NaCl(aq) + H_2O(l) + CO_2(g)$	$H^+(aq) + HCO_3^-(aq) \rightarrow H_2O(l) + CO_2(g)$

Summary of the Properties of Acids and Bases

Acids	Bases
• Taste sour	• Feel slippery
• Conduct electricity	• Conduct electricity
• Change the color of indicators. Blue litmus and universal indicator turn red in an acid	• Change the color of indicators. Red litmus paper and universal indicator turn blue in a base
• Contain H^+ ions when in solution	• Contain OH^- ions in solution
• React with bases in a neutralization reaction to produce a salt and water	• React with acids in a neutralization reaction to produce a salt and water
• React with metals and produce a salt and hydrogen gas	
• React with carbonate compounds to produce a salt, carbon dioxide and water	

Questions

1. Which one of the following substances would an acid not react with?
   - A. blue litmus paper
   - B. sodium carbonate
   - C. magnesium ribbon
   - D. silver chloride

2. Which one of the following solutions could you distinguish from the others using universal indicator paper?
   - A. Aqueous ammonia
   - B. Aqueous sodium chloride
   - C. Aqueous sodium carbonate
   - D. Aqueous calcium hydroxide

3. (M06/S) Which substance reacts with dilute hydrochloric acid to produce hydrogen gas?
   - A. Mg
   - B. MgO

C. $Mg(OH)_2$
D. $MgCO_3$

4. Which statement about hydrochloric acid is false?
A. It can react with copper to give hydrogen
B. It can react with sodium carbonate to give ammonium chloride
C. It can react with ammonia to give ammonium chloride
D. It can react with copper oxide to give water

5. (N03/H) Which one of the following is/are formed when a metal oxide reacts with a dilute acid?
I. A metal salt
II. Water
III. Hydrogen gas

a) I only
b) I and II only
c) II and III only
d) I, II and III

6. (N00/S) What mass of sodium hydroxide would you use and how would you prepare 0.500 dm^3 of a 0.500 $moldm^{-3}$ sodium hydroxide solution?

7. What total volume of water would be need to make a 0.50 mol dm^{-3} solution of sulfuric acid, H_2SO_4 if you had to dilute a 20.0 cm^3 of a concentrated 18 mol dm^{-3} of the solution?

8. Write balanced equations for the following reactions:
a) iron with dilute sulfuric acid
b) lead carbonate with nitric acid
c) zinc oxide with hydrochloric acid
d) calcium hydroxide with nitric acid
e) sodium hydrogen carbonate with sulfuric acid

9. a) Write the formulae of the oxides of sodium, phosphorus and sulfur
b) Describe their acid/base nature.
c) Write balanced chemical equations for their reactions with water.

10. Classify each of the following oxides as acidic, basic or amphoteric.
a) aluminium oxide
b) magnesium oxide
c) dichlorine oxide

11. For the following reactants write
i) full equation
ii) ionic equation

a) $HNO_3(aq) + KOH(s) \rightarrow$
b) Sulphuric acid + sodium hydrogen carbonate →
c) Ethanoic acid + sodium hydroxide →

12. (M06/S) State the name used to describe a substance that can act as an acid and a base. Using an example illustrate how it can behave as both an acid and a base. *[3]*

13. (N01/S) When sodium oxide and sulfur dioxide are added to separate test tubes containing water, the solutions will be, respectively

A. acidic and acidic
B. acidic and basic
C. basic and basic
D. basic and acidic

14. (N00/H) A household cleaner contains aqueous ammonia. A 2.447g sample of the cleaner is diluted with water to 20.0cm^3. This solution required 28.51cm^3 of 0.04040 moldm^{-3} sulfuric acid to neutralize all the alkali.

a) Write a balanced chemical equation for the reaction of sulfuric acid with ammonia to form ammonium sulfate. *[1]*

b) Calculate the amount (moles) of sulfuric acid required for this reaction, and the amount (moles), mass and percentage by mass of ammonia present in the household cleaner. *[4]*

15. HL/SL Review of 4.2.6 Lewis Structures. Complete the following table.

Formula / Name	Lewis Structure	Number of negative charge centers	Number of lone pairs of electrons	Number of bonding pairs of electrons	Overall Shape according to VSEPR	Structural formula drawn in 3d shape	Bond angle between attached atoms
OH^- Hydroxide ion							
NO_3^- Nitrate ion							
CO_3^{2-} Carbonate ion							
SO_4^{2-} Sulphate ion							

Explain the shape of any of <u>two</u> ions above using VSEPR theory

16. (N00/H) 25.0cm^3 of sulfuric acid solution reacts with 36.2cm^3 of 0.225 moldm^{-3} sodium hydroxide solution. The concentration of the acid is

A. <u>36.2 x 0.225</u>

25.0

B. $\frac{2 \times 36.2 \times 0.225}{25.0}$

C. $\frac{36.2 \times 0.225}{2 \times 25.0}$

D. $\frac{25.0}{2 \times 36.2 \times 0.225}$

HL ONLY

17. (N01) Define *delocalization* and *hybridization*. *[2]*

18. (M00) Ethanoic acid, CH_3OOH, is a weak acid.
   a) State the number of sigma bonds and the number of pi bonds in CH_3COOH and describe the difference between such bonds. *[2]*
   b) Compare the carbon – oxygen bond lengths in CH_3COOH giving your reasoning. *[2]*
   c) Deduce the shape and bond angle in CH_3COOH and give a reason. *[3]*
   d) Compare the carbon – oxygen bond length in the ethanoate ion, CH_3COO^- giving your reasoning. *[2]*
   e) Deduce the shape and bond angle with respect to each carbon atom in the ethanoate ion. *[2]*
   f) Write the two Lewis electron dot structures for the ethanoate ions and state how the bonding in the ion is related to these structures. *[2]*

19. (M06/S) Discuss the acid-base nature of the period three oxides. Write an equation to illustrate the reaction of one of these oxides to produce an acid and another equation of another of these oxides to produce a hydroxide. [5]

20. (M99/H)
   a) State the bonding in the oxides of sodium, magnesium, silicon and phosphorus. [4]
   b) What happens to the pH of pure water when these oxides are added to separate samples of the water? Give equations for any reactions that occur. [7]

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