Acids & Bases - 1. - Outcomes

1. Write ionic equations, and give observations for
   - a) acid reacting with
     - i) metal hydroxide
     - ii) metal oxide
     - iii) carbonate
     - iv) hydrogencarbonate
     - v) sulfite
     - vi) sulfide
     - vii) reactive metals
     - viii) ammonia
   - b) metal hydroxide reacting with
     - i) amphoteric metals
     - ii) amphoteric metal ions
     - iii) amphoteric oxides
     - iv) amphoteric hydroxides
     - v) ammonium ions

2. Theories of acids & bases
   - a) Use the Arrhenius acid-base model to define an acid and a base. Use equations to support definition.
   - b) Use the Bronsted-Lowry acid-base model to define an acid and a base. Use equations to support definition
   - c) Identify conjugate acid/base pairs in a reaction.
   - d) Identify in chemical equations the reactants which are acting as acids or bases.

3. Strong and weak acids & bases
   - a) Define strong and weak acids and bases, in terms of equilibrium concepts.
   - b) Identify examples of acids and bases as strong or weak.
   - c) Explain and identify concentrated and dilute acid and base solutions.
   - d) Define polyprotic acids.
   - e) Define amphoteric metals, oxides and hydroxides. Support definition with equations.

4. $[H^+]$, $[OH^-]$ and pH
   - a) Explain the existence of H^+ and OH^- in water.
   - b) Define the ionisation constant for water.
   - c) Calculate the $[H^+]$ and $[OH^-]$ in
     - i) pure water
     - ii) a solution of a strong acid or a strong base
     - iii) a mixture of a strong acid and a strong base
   - d) Define pH
   - e) Explain the pH values of neutral, acidic and basic solutions
   - d) Calculate the pH of
     - i) pure water
     - ii) a solution of a strong acid or a strong base
     - iii) a mixture of a strong acid and a strong base
   - e) Given the pH of a solution, calculate the $[H^+]$ and $[OH^-]$.

5. Salts

   a) Describe the formation of salts by neutralisation reactions between acids and bases.

   b) Distinguish between dissociation and hydrolysis processes.

   c) Predict and explain the acidic, basic or neutral nature of aqueous solutions of salts.

6. Periodic trends in acid & base properties.

   a) Describe the trend in acidic and basic properties of the oxides and the hydroxides across the third row of the Periodic table. Give equations to support description

   b) Describe the trend in acidic and basic properties of the oxides and the hydroxides down a group of the Periodic table.

Acids & Bases - 1. Class Worksheet

1. Reactions of Acids

a) Background knowledge:

i) Give the formulae of the following:

hydrochloric acid	sulfuric acid	nitric acid
acetic acid	phosphoric acid	hydroxide ion
hydrobromic acid	hydroiodic acid	oxide ion
carbonate ion	hydrogencarbonate ion	sulfide ion
sulfite ion	carbon dioxide	hydrogen sulfide
sulfur dioxide	hydrogen gas	magnesium
zinc	calcium	chloride ion
bromide ion	sulfate ion	acetate ion
nitrate ion	hydrogen ion	sodium ion
calcium ion	potassium ion	magnesium ion
ammonia	ammonium ion	

ii) Complete the following general reactions:

acid + hydroxide $\rightarrow$ …………………… + …………………………………………

acid + oxide $\rightarrow$ …………………… + ………………………………………….

acid + carbonate $\rightarrow$ ……………. + …………………….. + ………………………………….

acid + hydrogencarbonate $\rightarrow$ ……………. + ……………… + ………………………………

acid + sulfite $\rightarrow$ ……………. + …………………….. + ………………………………….

acid + sulfide $\rightarrow$ …………………… + …………………………………………….

acid + ‘active’ metal $\rightarrow$ …………………… + …………………………………………

acid + ammonia $\rightarrow$ ……………………………………………..

iii) Ionic equation ‘rules’

- …………………. acids written as separated ions
  - e.g. hydrochloric acid is written as
  - nitric acid is written as
  - sulfur acid is written as
- …………………. acids written as neutral molecules e.g. acetic acid is written as
- solid ionic compounds written as …………………… formulae
  - e.g. solid magnesium oxide is written as
  - solid sodium carbonate is written as
- …………………. of ionic compounds written as separated ions
  - e.g. solution of sodium hydroxide is written as
  - solution of potassium carbonate is written as

b) Write ionic equations and give observations for the following acid reactions:

i) dilute hydrochloric acid + solid magnesium oxide

ii) nitric acid solution + solution of calcium hydroxide

iii) solid copper carbonate + dilute sulfuric acid

iv) a solution of sodium hydrogencarbonate + dilute acetic acid

v) a solution of hydrobromic acid + a solution of potassium sulfite

vi) a solution of phosphoric acid + a solution of potassium hydroxide

vii) 2.0 mol L^{-1} hydrochloric acid is added to aluminium and the mixture heated

viii) ammonia gas is bubbled into a solution of nitric acid

2. Reactions of Bases

a) Background knowledge

i) List the amphoteric metals:

amphoteric metal hydroxides:

amphoteric metal oxides:

ii) Give the formulae of tetrahydroxoaluminate ion

tetrahydroxochromate ion

tetrahydroxozincate ion

ii) Complete the following general equations:

OH^- + most metals → ……………………………………………

OH^- + amphoteric metals + …………….. → …………… + ……………………………………..

OH^- + most metal hydroxides → ………………………………………

OH^- + amphoteric metal hydroxides → …………………………………

OH^- + most metal oxides → ……………………………………….

OH^- + amphoteric metal oxides + ………………….. → ……………………………………

b) Write ionic equations and give observations for the following metal hydroxide reactions:

i) aluminium is added to a concentrated solution of sodium hydroxide and the mixture is heated

ii) an excess of potassium hydroxide solution is added to a solution of zinc nitrate

iii) magnesium oxide is added to a solution of sodium hydroxide

iv) chromium (III) oxide is added to a solution of potassium hydroxide

v) a solution of sodium hydroxide is mixed with some aluminium hydroxide

vi) a solution of sodium hydroxide is added to some copper hydroxide

3. Describe an experiment you could carry out to distinguish between the following substances. Also, give the expected results:

a) sodium carbonate and sodium oxide

b) potassium sulfide and potassium hydrogencarbonate

c) copper carbonate and sodium carbonate

d) zinc and magnesium

e) aluminium oxide and magnesium oxide

f) a solution of sodium hydroxide and a solution of hydrochloric acid

Theories of Acids and Bases

4. Complete the following:

According to the Arrhenius theory, acids .... in aqueous solution, while bases .... In terms of the Bronsted-Lowry theory, an acid is a ...., and a base is a ....

5. What are the three different names for the species $H^+(aq)$?

6. For the following reaction, which reactant is acting as the acid?

a) $NH_3(aq) + HNO_2(aq) \rightarrow NH_4^+(aq) + NO_2^-(aq)$

b) $HF(l) + NH_3(l) \rightarrow H_2F^+ + NH_2^-$

c) $HCO_3^-(aq) + H_2O(l) \rightarrow H_2CO_3(aq) + OH^-(aq)$

d) $Cr(H_2O)_6^{3+} + H_2O(l) \rightarrow Cr(H_2O)_5(OH)^{2+}(aq) + H_3O^+(aq)$

e) $Mg(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2(g)$

7. a) Complete:

In an acid/base conjugate pair, the acid has one .... than its conjugate base.

b) Give the conjugate base of the following:

i) HNO_3 ii) $H_2PO_4^-$ iii) $Al(H_2O)_6^{3+}$

c) Give the conjugate acid of the following:

i) PH_3 ii) HSO_3^- iii) OH^-

Strong and Weak Acids and Bases

8. Complete the gaps:

According to the Arrhenius theory of acids and bases, a strong acid and a strong base undergo .... ionisation/dissociation in aqueous solution, but a weak acid and a weak base undergo only .... ionisation/dissociation.

9. What particles are present (in amounts greater than approx 10^{-7} moles L^{-1}) in the following solution?

a) 0.1 mol L^{-1} HCl b) 0.1 mol L^{-1} HF

c) 0.1 mol L^{-1} NH_3 d) 0.1 mol L^{-1} NaOH

10. Complete the gaps:

The strength of an acid is defined by the equilibrium position of its .... reaction:

$$HA(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + A^-(aq)$$

(The equilibrium constant for the hydrolysis reaction of an acid is sometimes called the acidity constant or acid dissociation constant)

A strong acid is one for which this equilibrium lies far to the.................................... This means that virtually .... the original HA is ionised at equilibrium. There is an important connection between the strength of an acid and that of its .... base. A strong acid yields a........................... .... conjugate base i.e. one that has a very low affinity for a ....

Conversely, a weak acid is one for which the equilibrium lies far to the........................... Most of the acid originally placed in the solution is still present as .... at equilibrium. That is, a weak acid hydrolyses only to a very .... extent in aqueous solution.

Because there is a greater range in acid strength amongst the weak acids (compared to the strong acids), it .... be concluded that all weak acids will have strong conjugate bases. Only the very, very weak acids have .... conjugate bases. Most weak acids have .... conjugate bases.

Acidity Constants (Equilibrium constant for hydrolysis reaction of the acid)

Common Name of acid	Formula	Acidity Constant		Common name of conjugate base	Formula	Basicity Constant
perchloric acid	$HClO_4$	*ca.* 10^{10}				
hydrogen iodide	HI	*ca.* 10^{9}		iodide ion	I^-	approx 10^{-23}
hydrogen bromide	HBr	*ca.* 10^{9}		bomide ion	Br^-	approx 10^{-23}
hydrogen chloride	HCl	*ca.* 10^{7}		chloride ion	Cl^-	approx 10^{-21}
nitric acid	HNO_3	*ca.* 200		nitrate ion	NO_3^-	approx 10^{-16}
hydronium ion	H_3O^+	55		water	H_2O	approx 10^{-15}
hydrogen fluoride	HF	6.6×10^{-4}		fluoride ion	F^-	approx 10^{-10}
nitrous acid	HNO_2	5.0×10^{-4}		nitrite ion	NO_2^-	approx 10^{-10}
acetic acid	CH_3COOH	1.8×10^{-5}		acetate ion	CH_3COO^-	approx 10^{-9}
aluminium ion	$Al(H_2O)_6^{3+}$	1.5×10^{-6}				
hydrazoic acid	HN_3	2.37×10^{-5}				
hypochlorous acid	HOCl	2.95×10^{-8}		hypochlorite ion	OCl^-	approx 10^{-6}
hypobromous acid	HOBr	2.3×10^{-9}				
hydrocyanic acid	HCN	5.8×10^{-10}		cyanide ion	CN^-	approx 10^{-4}
ammonium ion	NH_4^+	5.6×10^{-10}		ammonia	NH_3	approx 10^{-4}
water	H_2O	1.82×10^{-16}		hydroxide ion	OH^-	approx 10^{2}
ammonia	NH_3	*ca.* 10^{-34}			NH_2^-	approx 10

Common Name of acid	Formula	Acidity Constant		Common Name of conjugate base	Formula	Basicity Constant
sulfuric acid	H_2SO_4 HSO_4^-	$K_1 = 2.4 \times 10^{6}$ $K_2 = 1.0 \times 10^{-2}$		hydrogensulfate ion sulfate ion	HSO_4^- SO_4^{2-}	approx 10^{-20} approx 10^{-12}
sulfurous acid	H_2SO_3 HSO_3^-	$K_1 = 1.71 \times 10^{-2}$ $K_2 = 5.98 \times 10^{-8}$				
phosphoric acid	H_3PO_4 $H_2PO_4^-$ HPO_4^{2-}	$K_1 = 7.1 \times 10^{-3}$ $K_2 = 6.2 \times 10^{-8}$ $K_3 = 4.6 \times 10^{-13}$		dihydrogenphosphate ion hydrogenphosphate ion phosphate ion	$H_2PO_4^-$ HPO_4^{2-} PO_4^{3-}	approx 10^{-11} approx 10^{-6} approx 10^{-1}
carbonic acid	H_2CO_3 HCO_3^-	$K_1 = 4.35 \times 10^{-7}$ $K_2 = 4.69 \times 10^{-11}$		hydrogencarbonate ion carbonate ion	HCO_3^{2-} CO_3^{2-}	approx 10^{-7} approx 10^{-3}
hydrogen sulfide	H_2S HS^-	$K_1 = 9 \times 10^{-8}$ $K_2 =$ *ca.*10^{-15}				

11.

<u>Relative strengths of some monoprotic acids</u>

HCl, HNO_3
HSO_4^-
HF
HNO_2
CH_3COOH
$Al(H_2O)_6^{3+}$
HCN
NH_4^+
H_2O

Increasing acid strength

Use the data in the table above to identify the following statements as true or false.

a) 1 L of 0.1 mol L^{-1} hydrofluoric acid would contain the same number of hydrogen ions as 1 L of 0.1 mol L^{-1} hydrochloric acid

b) The equilibrium constant for the hydrolysis reaction for HCl would be larger than that for HF.

c) The fluoride ion would be a stronger base than the chloride ion

d) OH^- is a stronger base than NH_3

12. Classify each of the following as a strong acid, a weak acid, a strong base or a weak base:

hydrochloric acid	phosphoric acid	sodium hydroxide
HNO_3	K_2O	NH_3
H_2SO_4	$Ca(OH)_2$	citric acid
H_2SO_3	CO_3^{2-}	HSO_4^-
NH_4^+	F^-	HCO_3^-
CH_3COO^-	CH_3COOH	NO_2^-
aluminium ions	PO_4^{3-}	$H_2PO_4^-$

13. Summarise the acid/base properties of substances by placing the following substances/labels in the correct columns:

most acids	negative ions of strong acids
NH_4^+	HSO_4^-, $H_2PO_4^-$
NH_3	HCl, HNO_3, H_2SO_4, $HClO_4$
transition metal ions and +3 metal ions	metal hydroxides and oxides
negative ions of weak acids	positive ions of Groups 1 and 2

Strong Acids	Weak Acids	Strong Bases	Weak Bases	Neutral

14. Give the equation to represent what happens when the following species react with water i.e. when they undergo hydrolysis:

    a) NH_3

    b) HF

    c) CO_3^{2-}

    d) NH_4^+

    e) HNO_2

    f) CN^-

    g) HSO_4^-

    h) CaO

15. Give an example of

    a) a concentrated solution of a strong acid

    b) a dilute solution of a weak base

    c) a dilute solution of a weak acid

    d) a concentrated solution of a strong base

Polyprotic Acids

16. a) Give an example of a strong polyprotic acid.

    b) Write equations to show the hydrolysis reactions that occur when this acid dissolves in water.

    c) Comment on the relative size of the equilibrium constant for these reactions.

    d) List the species present in a 1.0 mol L^{-1} solution of this acid, in order of largest concentration to least.

17. Phosphoric acid is a weak triprotic acid.

    a) Write equations to show the hydrolysis reactions that occur when this acid dissolves in water.

    b) Comment on the relative size of the equilibrium constant for these reactions.

    c) List the species present in a 1.0 mol L^{-1} solution of this acid.

Amphoteric substances

18. a) Aluminium is an amphoteric metal. What does this statement mean?

    b) Give equations which show the reaction of aluminium with an acid and with a solution containing hydroxide ions.

19. Zinc oxide is an amphoteric oxide. Give two equations to support this statement.

20. a) Describe how you could prepare a sample of chromium (III) hydroxide.

    b) Describe how you would prepare a solution containing the complex ion $Cr(OH)_4^-$.

Calculation of $[H^+]$, $[OH^-]$ and pH

21. a) Give an equation for the self-ionisation reaction of water.

    b) What is the equilibrium constant, at 25ºC, for this reaction?

    c) What is this equilibrium constant called?

    d) Calculate the concentration of H^+ and OH^- in pure water at 25ºC.

22. In any aqueous solution, at 25ºC, what relationship will exist between the concentration of H^+ and OH^-?

23. If pure water is added to 0.100 mole of HCl to make 1 L of solution, what are the concentrations, in mol L^{-1}, of H^+ and OH^- in this solution?

24. If 0.200 mole of NaOH is added to pure water and the solution made up to 500 mL, what are the concentrations, in mol L^{-1}, of OH^- and H^+ in this solution?

25. If 300 mL of 0.4 mol L^{-1} HCl is mixed with 100 mL of 0.2 mol l^{-1} KOH, what are the concentrations of H^+ and OH^- in the resultant mixture?

26. What formula is used to determine the pH of a solution?

27. Calculate the pH of solutions with the following concentrations:

a) $[H^+] = 1 \times 10^{-2}$ mol L^{-1} b) $[H^+] = 1 \times 10^{-10}$ mol L^{-1}

c) $[H^+] = 0.00100$ mol L^{-1} d) $[H^+] = 1.00$ mol L^{-1}

e) $[H^+] = 0.000520$ mol L^{-1} f) $[H^+] = 4.60 \times 10^{-6}$ mol L^{-1}

g) $[OH^-] = 1 \times 10^{-3}$ mol L^{-1} h) $[OH^-] = 0.0781$ mol L^{-1}

28. a) Explain why pure water has a pH of 7 at 25ºC.

b) When an acid is dissolved in water, an acidic solution is said to have formed. Why does an acidic solution have a pH less than 7?

c) Why do basic solutions have a pH greater than 7?

29. Complete the gaps in the following:

i) As the $[H^+]$ increase, the pH ....

ii) The lower the pH the .... the $[H^+]$ in the solution

iii) The higher the pH the .... the [OH-] in the solution

iv) A .... solution is one with a pH of 7.

v) A change in .... pH unit represents a tenfold change in the $[H^+]$.

30. Calculate the pH of the following solutions:

a) 0.0200 mol L^{-1} HNO_3

b) 0.00700 mol L^{-1} $Ca(OH)_2$

c) a solution formed when 40.0 mL of 3.00 mol l^{-1} HCl is mixed with 30.0 mL of 4.10 mol l^{-1} NaOH

31. a) Calculate the concentration of a solution of HCl that has a pH of 4.3.

b) Calculate the concentration of a solution of KOH that has a pH of 14.8

c) What mass of NaOH must be dissolved in water to give a 2.00 L of a solution with a pH of 13.2?

Salts

32. Name and give the formula of the salt formed when the following acids and bases react:

a) hydrochloric acid + calcium hydroxide

b) acetic acid + sodium hydroxide

c) ammonia + sulfuric acid

d) HCN + potassium hydroxide

33. Define the following words. Give an example to support your definition.

a) Dissociation

b) Hydrolysis

c) Ionisation

34. a) i) Define the term “acidic solution”.

ii) Define the term “basic solution”.

b) Will the following salts form acidic, basic or neutral solutions? Give equations to support your answers.

i) potassium fluoride

ii) ammonium chloride

iii) sodium acetate

iv) sodium hydrogencarbonate

v) magnesium hydrogensulfate

35. Which would be the stronger acid a) HNO_3 or H_3PO_3?

b) $HBrO_4$ or H_3AsO_4?

36. Give an example of a) an acidic oxide

b) an amphoteric hydroxide

c) a basic oxide

d) an acidic hydroxide

e) a basic hydroxide

37. Write an equation to show what happens when each of the following are added to water:

a) Na_2O

b) SO_3

c) CO_2

ANSWERS

1. a) i)

hydrochloric acid	HCl	sulfuric acid	H_2SO_4	nitric acid	HNO_3
acetic acid	CH_3COOH	phosphoric acid	H_3PO_4	hydroxide ion	OH^-
hydrobromic acid	HBr	hydroiodic acid	HI	oxide ion	O^{2-}
carbonate ion	CO_3^{2-}	hydrogencarbonate ion	HCO_3^-	sulfide ion	S^{2-}
sulfite ion	SO_3^{2-}	carbon dioxide	CO_2	hydrogen sulfide	H_2S
sulfur dioxide	SO_2	hydrogen gas	H_2	magnesium	Mg
zinc	Zn	calcium	Ca	chloride ion	Cl^-
bromide ion	Br^-	sulfate ion	SO_4^{2-}	acetate ion	CH_3COO^-
nitrate ion	NO_3^-	hydrogen ion	H^+	sodium ion	Na^+
calcium ion	Ca^{2+}	potassium ion	K^+	magnesium ion	Mg^{2+}
ammonia	NH_3	ammonium ion	NH_4^+		

ii) acid + hydroxide → water + salt solution
acid + oxide → water + salt solution
acid + carbonate → carbon dioxide + water + salt solution
acid + hydrogencarbonate → carbon dioxide + water + salt solution
acid + sulfite → sulfur dioxide + water + salt solution
acid + sulfide → hydrogen sulfide + salt solution
acid + ‘active’ metal → hydrogen + salt solution
acid + ammonia → ammonium salt

iii) Ionic equation ‘rules’
- strong acids written as separated ions
  e.g. hydrochloric acid is written as $H^+ + Cl^-$
  nitric acid is written as $H^+ + NO_3^-$
  sulfur acid is written as $H^+ + SO_4^{2-}$
- weak acids written as neutral molecules e.g. acetic acid is written as $H^+ + CH_3COO^-$
- solid ionic compounds written as neutral formulae
  e.g. solid magnesium oxide is written as MgO
  solid sodium carbonate is written as Na_2CO_3
- solutions of ionic compounds written as separated ions
  e.g. solution of sodium hydroxide is written as $Na^+ + OH^-$
  solution of potassium carbonate is written as $K^+ + CO_3^{2-}$

b) i) $2H^+(aq) + MgO(s) \rightarrow Mg^{2+}(aq) + H_2O(l)$ white solid dissolves to form colourless solution
ii) $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$ no observable change - colourless solution remains
iii) $2H^+(aq) + CuCO_3(s) \rightarrow CO_2(g) + H_2O(l) + Cu^{2+}(aq)$ solid dissolves to form colourless, odourless gas and blue solution
iv) $CH_3COOH(aq) + HCO_3^-(aq) \rightarrow CO_2(g) + H_2O(l) + CH_3COO^-(aq)$ - colourless, odourless gas forms, solution remains colourless
v) $2H^+(aq) + SO_3^{2-}(aq) \rightarrow SO_2(g) + H_2O(l)$ colourless gas with pungent odour forms, solution remains colourless
vi) $H_3PO_4(aq) + 3OH^-(aq) \rightarrow 3H_2O(l) + PO_4^{3-}(aq)$ no observable change, solution remains colourless
vii) $6H^+(aq) + 2Al(s) \rightarrow 3H_2(g) + 2Al^{3+}(aq)$ colourless, odourless gas and colourless solution formed
viii) $NH_3(g) + H^+(aq) \rightarrow NH_4^+(aq)$ colourless solution forms, pungent odour disappears

2. a) i) amphoteric metals: Al, Cr, Zn
amphoteric metal hydroxides: $Al(OH)_3$, $Cr(OH)_3$, $Zn(OH)_2$
amphoteric metal oxides: Al_2O_3, Cr_2O_3, ZnO

ii) tetrahydroxoaluminate ion $[Al(OH)_4]^-$
tetrahydroxochromate ion $[Cr(OH)_4]^-$
tetrahydroxozincate ion $[Zn(OH)_4]^{2-}$

iii) OH^- + most metals $\rightarrow$ no reaction
OH^- + amphoteric metals + H_2O $\rightarrow$ H_2 + complex ion
OH^- + most metal hydroxides $\rightarrow$ no reaction
OH^- + amphoteric metal hydroxides $\rightarrow$ complex ion
OH^- + most metal oxides $\rightarrow$ no reaction
OH^- + amphoteric metal oxides + H_2O $\rightarrow$ complexion

b) i) $2Al(s) + 2\ OH^-(aq) + 6\ H_2O(l) \rightarrow 3\ H_2(g) + 2Al(OH)_4^-(aq)$ colourless, odourless gas and colourless solution form
ii) $Zn^{2+}(aq) + 4\ OH^-(aq) \rightarrow Zn(OH)_4^{2-}(aq)$ no observable change, solution remains colourless
iii) no reaction
iv) $Cr_2O_3(aq) + 2\ OH^-(aq) + 3\ H_2O(l) \rightarrow 2\ Cr(OH)_4^-(aq)$ solid dissolves to form a dark green solution
v) $Al(OH)_3(s) + OH^-(aq) \rightarrow Al(OH)_4^-(aq)$ solid dissolves to form colourless solution
vi) no reaction

3. a) Add hydrochloric acid - carbonate will form colourless gas, oxide will not
b) Add hydrochloric acid - sulfide will form gas with putrid odour, hydrogencarbonate will form odourless gas
c) Copper carbonate is green, sodium carbonate is white
d) Add a solution of sodium hydroxide - zinc will react to form colourless gas, magnesium will not react
e) Add a solution of sodium hydroxide - aluminium oxide will react and dissolve, magnesium oxide will not
f) Add litmus - sodium hydroxide will turn blue, hydrochloric acid will turn red

4. According to the Arrhenius theory, acids **form hydrogen ions** in aqueous solution, while bases **form hydroxide ions**. In terms of the Bronsted-Lowry theory, an acid is a **hydrogen ion donor**, and a base is a **hydrogen ion acceptor**.

5. hydrogen ion, hydronium ion, proton

6. a) HNO_2 b) NH_3 c) H_2O d) $Cr(H_2O)_6^{3+}$ e) neither reactant

7. a) more hydrogen ion b) i) NO_3^- ii) HPO_4^{2-} iii) $Al(H_2O)_5(OH)^{2+}$
c) i) PH_4^+ ii) H_2SO_3 iii) H_2O

8. complete, partial

9. a) H_2O, H^+, Cl^- b) H_2O, HF, H^+, F^- c) H_2O, NH_3, NH_4^+, OH^- d) H_2O, Na^+, OH^-

10. The strength of an acid is defined by the equilibrium position of its **hydrolysis** reaction:

$$HA(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + A^-(aq)$$

A <u>strong acid</u> is one for which this equilibrium lies far to the **right** . This means that virtually **all** the original HA is ionised at equilibrium. There is an important connection between the strength of an acid and that of its **conjugate** base. A strong acid yields a **very weak** conjugate base - one that has a very low affinity for a **hydrogen ion**.
Conversely, a <u>weak acid</u> is one for which the equilibrium lies far to the **left** . Most of the acid originally placed in the solution is still present as **HA** at equilibrium. That is, a weak acid hydrolyses only to a very **slight** extent in aqueous solution.
Because there is a greater range in acid strength amongst the weak acids (compared to the strong acids), it **can not** be concluded that all weak acids will have strong conjugate bases. Only the very very weak acids have **strong** conjugate bases. Most weak acids have **weak** conjugate bases.

11. a) False b) True c) True d) True

12. hydrochloric acid - strong acid
HNO_3 - strong acid
H_2SO_4 - strong acid
H_2SO_3 - weak acid
NH_4^+ - weak acid
CH_3COO^- - weak base
aluminium ions - weak acid
phosphoric acid - weak acid
K_2O - strong base
$Ca(OH)_2$ - strong base
CO_3^{2-} - weak base
F^- - weak base
CH_3COOH - weak acid
PO_4^{3-} - weak base
sodium hydroxide - strong base
NH_3 - weak base
citric acid - weak acid
HSO_4^- - weak acid
HCO_3^- - weak base
NO_2^- - weak base
$H_2PO_4^-$ - weak acid

13.

Strong Acids	Weak Acids	Strong Bases	Weak Bases	Neutral
- HCl, HNO_3, H_2SO_4, $HClO_4$	- most acids - NH_4^+ - HSO_4^-, $H_2PO_4^-$ - transition metal ions and +3 metal ions	- metal hydroxides and oxides	- NH_3 - negative ions of weak acids	- negative ions of strong acids - positive ions of Groups 1 and 2

14. a) $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$
b) $HF + H_2O \rightleftharpoons F^- + H_3O^+$
c) $CO_3^{2-} + H_2O \rightleftharpoons H_2CO_3 + OH^-$
d) $NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+$
e) $HNO_2 + H_2O \rightleftharpoons NO_2^- + H_3O^+$
f) $CN^- + H_2O \rightleftharpoons HCN + OH^-$
g) $HSO_4^- + H_2O \rightleftharpoons SO_4^{2-} + H_3O^+$
h) $CaO + H_2O \rightarrow Ca^{2+} + 2OH^-$

15. a) 10 mol L^{-1} HCl b) 0.01 mol L^{-1} NH_3 c) 0.05 mol L^{-1} CH_3COOH d) 12 mol L^{-1} NaOH

16. a) H_2SO_4
b) $H_2SO_4 + H_2O \rightarrow HSO_4^- + H_3O^+$
$HSO_4^- + H_2O \rightleftharpoons SO_4^{2-} + H_3O^+$

c) First reaction has a very large equilibrium constant, second one has a small equilibrium constant (approx 0.01)

d) H_2O, H_3O^+, HSO_4^-, SO_4^{2-}, H_2SO_4

17. a) $H_3PO_4 + H_2O \rightleftharpoons H_2PO_4^- + H_3O^+$
$H_2PO_4^- + H_2O \rightleftharpoons HPO_4^{2-} + H_3O^+$
$HPO_4^{2-} + H_2O \rightleftharpoons PO_4^{3-} + H_3O^+$

b) the first reaction has a small equilibrium constant (approx 10^{-3}), the second one a smaller K and the third one an even smaller K
c) H_2O, H_3PO_4, H_3O^+, $H_2PO_4^-$, HPO_4^{2-}, PO_4^{3-} (given in order of decreasing amounts)

18. a) It reacts with both acids and bases

b) $6H^+(aq) + 2Al(s) \rightarrow 3H_2(g) + 2Al^{3+}(aq)$
$2Al(s) + 2\ OH^-(aq) + 6\ H_2O(l) \rightarrow 3\ H_2(g) + 2Al(OH)_4^-(aq)$

19. $ZnO(s) + 2H^+(aq) \rightarrow H_2O(l) + Zn^{2+}(aq)$

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

20. a) Add a small amount of a dilute solution of sodium hydroxide to a solution of chromium (III) nitrate
b) Add an excess of a solution of sodium hydroxide to a solution of chromium (III) nitrate

21. a) $2H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$

b) 1×10^{-14}

c) ionisation constant of water

d) conc of H^+ = conc of OH^- = 1×10^{-7} mol L^{-1}

22. conc of H^+ x conc of OH^- = 1×10^{-14}

23. $[H^+] = 0.100$ mol L^{-1} $[OH^-] = 1.00 \times 10^{-13}$ mol L^{-1}

24. moles of OH^- = 0.200
$[OH^-] = 0.200/0.500 = 0.400$ mol L^{-1} $[H^+] = 1 \times 10^{-14}/0.400 = 2.5 \times 10^{-14}$ mol L^{-1}

25. moles of HCl = 0.300 x 0.400 = 0.120 = moles of H^+
moles of KOH = 0.100 x 0.200 = 0.0200 = moles of OH^-
$H^+ + OH^- \rightarrow H_2O$ 0.0200 moles of OH^- will react with 0.0200 moles of H^+
i.e. will have 0.120 - 0.0200 = 0.100 moles of H^+ remaining after reaction
conc of H^+ = 0.100/0.400 = **0.250 mol L^{-1}** conc of OH^- = 1 x 10^{-14}/0.250 = **4.00 x 10^{-14} mol L^{-1}**

26. pH = - $\log_{10}[H^+]$

27. a) 2 b) 10 c) 3 d) 0
e) 3.28 f) 5.34 g) 11 h) 12.9

28. a) in pure water $[H^+]$ = $[OH^-]$ and $[H^+]$ x $[OH^-]$ = 1 x 10^{-14}
i.e. $[H^+]$ = 1 x 10^{-7} mol L^{-1}, so pH = 7
b) When an acid dissolves in water, more H^+ ions are formed i.e. the $[H^+]$ will now be greater than 10^{-7} mol L^{-1},
e.g. 10^{-3} mol L^{-1}, so pH will be less than 7 in an acidic solution.

c) When a base dissolves in water, more OH^- ions are formed. Because in this solution $[H^+]$ x $[OH^-]$ = 1 x 10^{-14},
if the $[OH^-]$ becomes greater than 10^{-7} mol L^{-1}, then $[H^+]$ must become less than 10^{-7} mol L^{-1}, e.g. 10^{-9} mol L^{-1}.
So pH will be greater than 7 in a basic solution.

29. i) As the $[H^+]$ increase, the pH **decreases**
ii) The lower the pH the **greater** the $[H^+]$ in the solution
iii) The higher the pH the **greater** the $[OH^-]$ in the solution
iv) A **neutral** solution is one with a pH of 7.
v) A change in **one** pH unit represents a tenfold change in the $[H^+]$.

30. a) 1.70 b) 12.1
c) moles of H^+ before reaction = 0.12
moles of OH^- remaining after reaction = 0.003
conc of H^+ = 1 x 10^{-14}/0.0429 = 2.33 x 10^{-13}
moles of OH^- before reaction = 0.123
conc of OH^- = 0.003/0.070 = 0.0429
pH = **12.6**

31. a) 5.01 x 10^{-5} mol L^{-1} b) 6.31 mol L^{-1} c) 12.7 g

32. a) calcium chloride, $CaCl_2$ b) sodium acetate, $NaCH_3COO$ c) ammonium sulfate, $(NH_4)_2SO_4$
d) potassium cyanide, KCN

33. a) The process whereby a soluble ionic solid, when placed in water dissolves to form a solution of its ions.
$NaCl + aq \rightarrow Na^+ + Cl^-$

b) The reaction of a substance with water. $CO_3^{2-} + H_2O \rightleftharpoons HCO_3^- + OH^-$

c) The process whereby a covalent molecular substance reacts with water to produce a solution containing ions.
$HCl + H_2O \rightarrow H_3O^+ + Cl^-$

34. a) i) a solution in which the $[H^+]$ is greater than the $[OH^-]$
ii) a solution in which the $[OH^-]$ is greater than the $[H^+]$

b) i) basic $F^- + H_2O \rightleftharpoons HF + OH^-$ ii) acidic $NH_4^+ + H_2O \rightleftharpoons H_3O^+ + NH_3$
iii) basic $CH_3COO^- + H_2O \rightleftharpoons CH_3COOH + OH^-$ iv) basic $HCO_3^- + H_2O \rightleftharpoons H_2CO_3 + OH^-$
v) acidic $HSO_4^- + H_2O \rightleftharpoons H_3O^+ + SO_4^{2-}$

35. a) HNO_3 b) $HBrO_4$

36. a) CO_2; SO_3; P_4O_{10}... b) $Al(OH)_3$; $Zn(OH)_2$; $Cr(OH)_3$ c) Na_2O; MgO; CaO ...
d) H_2SO_4; H_3PO_4; HNO_3 e) NaOH; KOH; $Ba(OH)_2$ ....

37. a) $O^{2-} + H_2O \rightarrow 2OH^-$ b) $SO_3 + H_2O \rightarrow H_2SO_4$; then $H_2SO_4 + H_2O \rightarrow H_3O^+ + HSO_4^-$
c) $CO_2 + 2H_2O \rightleftharpoons H_3O^+ + HCO_3^-$