Manitoba

Education, Citizenship and Youth

Chemistry – Grade 12

Unit 5 - Acids and Bases

DRAFT / Unedited Version

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Manitoba

Specific Learning Outcome

C12-5-01: Outline the historical development of acid base theories. (1 hour)
Include: Arrhenius, Bronsted-Lowry, Lewis
GLO: A1, A2, A4, D3

C12-5-02: Write balanced acid/base chemical equations. (1 hour)
Include: conjugate acid/base pairs, amphoteric behaviour
GLO: D3

Skills and Attitudes Outcomes

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

Entry-Level Knowledge

In Grade 10 Science, students experimented to classify acids and bases according to their characteristics (outcome S2-2-08). Students were introduced to hydrochloric, sulphuric, and nitric acids as well as some bases such as sodium hydroxide, and calcium hydroxide. In Grade 11, the only experience with acids was in the Organic Chemistry Unit where students studied organic acids such as formic and acetic acids.

Assessing Prior Knowledge

Check for understanding of prior knowledge and review as necessary. Prior knowledge can be reviewed and / or assessed by using any of the KWL strategies (e.g., Concept Map, Knowledge Chart, Think-Pair-Share – see SYSTH, Chapter 9).

Teacher Notes

As teachers review common acids, they should include other acids and bases with which students are familiar. Brainstorming or a KWL would provide students with an opportunity to describe their prior knowledge. Common examples of acids and bases might include: lactic acid in sour milk, butyric acid found in rancid butter, citric acid in citric fruit, ascorbic acid as vitamin C, acetylsalicylic acid or A.S.A. tablets, etc. Example of bases might include: Ammonia as a household cleaner, or sodium hydroxide as an oven cleaner.

Each successive definition for an acid becomes less restrictive until finally the last definition by Lewis (aka Lewis Dot Diagrams) becomes so general that any reaction in which a pair of electrons is transferred becomes an acid base reaction.

A. Svante Arrhenius (1859-1927) was the first to contribute to chemists' understanding of acids and bases. He proposed that

<u>Acids:</u> Acids are any substances that dissociate to produce <u>hydrogen ions (H^+)</u> when dissolved in water.

e.g. hydrochloric acid

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

e.g. nitric acid

$$HNO_{3(aq)} \rightarrow H^+_{(aq)} + NO_3^-{}_{(aq)}$$

<u>Base:</u> Bases are any substances that dissociate to produce <u>hydroxide ions (OH^-)</u> when dissolved in water.

e.g. sodium hydroxide

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

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e.g. barium hydroxide
$Ba(OH)_{2(aq)} \rightarrow Ba^{2+}_{(aq)} + 2OH^-_{(aq)}$

A few troublesome species such as carbon dioxide (which lacks the hydrogen) and ammonia (which lacks the hydroxide ion) were explained by Arrhenius as first reacting with water:

e.g. $CO_{2(g)} + H_2O_{(l)} \rightarrow H_2CO_{3(aq)} \rightarrow H^+_{(aq)} + HCO^-_{(aq)}$

e.g. $NH_{3(g)} + H_2O_{(l)} \rightarrow NH_4OH_{(aq)} \rightarrow NH_4^+{}_{(aq)} + OH^-_{(aq)}$

B. Johannes Brønsted (1879-1947) and Thomas Lowry (1874-1936) simultaneously proposed a new theory. Usually called the Brønsted Theory, or the Brønsted - Lowry Theory. This theory relates acid-base characteristics to proton transfer, a process that includes more reactions than the previous definition of acids and bases by Arrhenius.
According to this definition, a substances like $CO_{2(g)}$ can now be clearly seen as a base by picking up a proton when bubbled through water according to the following reaction.

e.g. $CO_{2(g)} + H_2O_{(l)} \rightarrow H_2CO_{3(aq)} \rightarrow H^+_{(aq)} + HCO^-_{(aq)}$

Acids: Acids are substances that increase the hydronium (H_3O^+) ion concentration. Thus acids are proton donors.

e.g. hydrochloric acid
$HCl_{(aq)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$

e.g. nitric acid
$HNO_{3(aq)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + NO_3^-{}_{(aq)}$

When any one of HCl, HNO_3, CH_3COOH, CO_2, or H_2SO_4 is added to water, the hydronium ion concentration is increased. Hence, they are acids.

Bases: Bases are substances that increase the hydroxide (OH^-) ion concentration. Thus bases are proton acceptors.

e.g. sodium hydroxide
$NaOH_{(aq)} + \rightarrow Na^+_{(aq)} + OH^-_{(aq)}$

e.g. ammonia
$NH_{3(aq)} + H_2O_{(l)} \rightarrow NH_4^+{}_{(aq)} + OH^-_{(aq)}$

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When any one of NaOH, $Ca(OH)_2$, CaO, MgO, or NH_3 is added to water, the hydroxide ion concentration is increased. Hence, they are considered the bases.

In any acid-base reaction, a conjugate acid and base pair are established.

$$HX_{(aq)} + H_2O_{(l)} \leftrightarrows H_3O^+_{(aq)} + X^-_{(aq)}$$

Acid	Base	Conjugate Acid	Conjugate Base

Substances, such as water, which can act as both acids and bases are said to be <u>amphoteric</u>.

Acids are classified by the number of hydrogen ions available to be donated. Monoprotic acids have one hydrogen ion to donate. Polyprotic acids have two or more hydrogen ions to donate. All polyprotic acids donate one hydrogen ion at a time. An inspection of an acid Ka table will show that a diprotic acid like sulphuric acid will have 2 Ka values for each successive dissociation.

$$H_2SO_{4(aq)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + HSO_4^-{}_{(aq)} \qquad Ka = \text{very large}$$

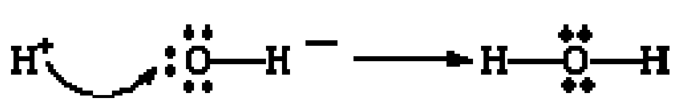
$$HSO_4^-{}_{(aq)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + SO_4^{2-}{}_{(aq)} \qquad Ka = 1.3 \times 10^{-2}$$

The above definition of BrØnsted is the most useful to grade 12 chemistry and should be the definition that is stressed. The next definition involves the transfer of electrons and can become quite complex.

C. G.N. Lewis proposed a definition of acids and bases in 1932. A Lewis base is a substance that can donate a pair of electrons. A Lewis acid is a substance that can accept a pair of electrons.

The significance of the Lewis concept is that it is more general than any of the other definitions. Lewis acid base reactions include many reactions that would not be included with the Bronsted-Lowry definition.

Lewis argued that the H^+ ion picks up (accepts) a pair of electrons from the OH^- ion to form a new covalent bond. As a result, any substance that can act as an electron pair acceptor is a Lewis acid.



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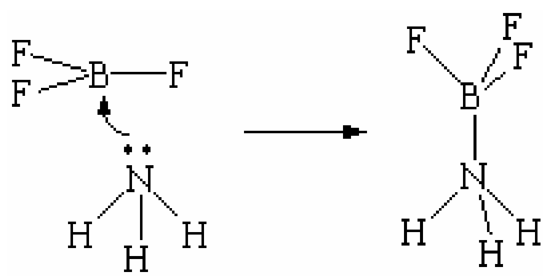
The pair of electrons that went into the new covalent bond were donated by the OH^-. Lewis therefore argued that any substance that can act as an electron pair donor is a Lewis base.

The Lewis acid-base theory does not affect the substances we have previously called Bronsted bases because any Bronsted base must have a pair of non-bonding electrons in order to accept a proton.

However, this theory vastly expands the category we have previously called Bronsted acids. Any compound that has one or more valence shell orbitals can now act as an acid! This theory explains why BF_3 reacts instantly with NH_3. The non-bonding electrons on the N in ammonia are donated into an empty orbital on the boron atom to form a covalent bond as shown below.



Teacher Background

Amino acids and proteins are amphoteric, as they both contain a basic amino group ($-NH_2$), and an acid carboxyl group (-COOH).
The following information is taken from *Chemistry, The Molecular Nature of Matter and Change*: Martin S. Silberberg, Published by McGraw Hill, Boston, Third Edition, p313.

It should not come as a surprise that there are trends in the amphoteric properties of oxides of metals and non-metals on the periodic table. Silberberg has a detailed clear description indicating how the oxides change in acid/base properties.

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Group 5A (15)
As the elements become **more** metallic down a group, their oxides become **more** basic.
e.g. least basic (most acidic) N_2O_5 to most basic Bi_2O_3

Period 3
As elements become **less** metallic across a period, their oxides become **less** basic.
e.g. most basic (least acidic) Na_2O to least basic Cl_2O_7

<u>Demonstration</u>
Ask students how soap feels then they wash their hands (slippery). Then, show them that when red litmus paper touches a wet bar of soap, the litmus paper turns blue. (p.596 Teachers Edition of Chemistry: Matter and Change)

<u>Student Activity</u>
Students can make paper cutouts to represent the atoms of hydrogen, oxygen, and chlorine in the reaction between hydrogen chloride and water. They can use thumbtacks to attach the cutouts to a poster board or bulletin board, then physically transfer the H^+ from HCl to H_2O to create H_3O^+ and Cl^-. (p.598 Teachers Edition of Chemistry: Matter and Change)

<u>EAL Strategy</u>
Have English language learners look up and then explain the meanings of several key English prefixes and words used in this outcome: mono-, di-, tri-, poly-, conjugate, polyprotic. (p.597 Teachers Edition of Chemistry: Matter and Change)

Suggestions for Assessment
<u>Paper and Pencil Tasks</u>
Students should be able to identify conjugate acid-base pairings from a given reaction. They should also be able to write equations for the ionization of hydrogen ions for polyprotic acids.

Students can complete a Three-Point Approach from the SYSTH for each of the different acid-base theories.

<u>Debate</u>
Students can perform a debate involving the Arrhenius and Bronsted-Lowry theories of acids and bases. One student would defend the Arrhenius theory white the other student defends the Bronsted-Lowry theory.

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Visual Displays
Students can develop a concept map using the terms acidic solutions, acids, bases, Arrhenius theory, pH < 7, pH > 7, Bronsted-Lowry theory, Lewis theory, pair of electrons, accept, donate

Learning Resources Links
Chemistry: Matter and Change, Dingrando *et al*., Glencoe-McGraw-Hill, 2005
Ch. 19.1 Acids and Bases (doesn't include Lewis definition of acids and bases)

Prentice Hall Chemistry, Wilbraham *et al*., Pearson Education / Prentice-Hall, 2005
Ch. 19.1 Acids and Bases

Chemistry Experiment Simulations, Tutorials and Conceptual Computer Animations for Introduction to College Chemistry (aka General Chemistry)
http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/animationsindex.htm
$NH_{3(aq)}$ (equilibrium system) This animation shows NH_3 and H_2O combining to form NH_4^+ and OH^-. It also illustrates the Lewis structures for this equilibrium. The reverse reaction is also shown.

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Include: the ion product constant for water, $K_{w.}$ (0.5 hour)
GLO: D3

C12-5-04: Perform an activity to formulate an operational definition of pH. (1 hour)
GLO: C2

C12-5-05: Describe how an acid-base indicator works in terms of colour shifts and Le Chatelier's Principle. (0.5 hour)
GLO: D3

C12-5-06: Solve problems involving pH.
GLO: D3

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C12-0-S7 Interpret patterns and trends in data, and infer and explain relationships.
GLO: C2, C5

C12-0-S9 Draw a conclusion based on the analysis and interpretation of data.
Include: cause and effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction.
GLO: C2, C5, C8

Entry-Level Knowledge

In Grade 10 Science students experimented to classify acids and bases according to their characteristic properties. This included a discussion of the definition of pH, the significance of the pH table, and the use of indicators to differentiate between acidic and basic solutions (outcome S2-2-08). In Grade 11, the only experience with acids was in the Organic Chemistry Unit where students studied organic acids like formic and acetic acids.

Assessing Prior Knowledge

Check for understanding of prior knowledge and review as necessary. Prior knowledge can be reviewed and / or assessed by using any of the KWL forms in SYSTH, chapter 9, e.g. Concept maps; Knowledge Charts; Think, Pair, Share, Word Cycle, Three Point Approach or Compare Contrast to review terms:

Teacher Notes

Kw

Pure water undergoes a small degree of ionization. In fact, only two molecules out of one billion will ionize.

$$2H_2O_{(l)} \leftrightarrows H_3O^+_{(aq)} + OH^-_{(aq)}$$

The equilibrium expression for this reaction is:

$$K_{eq} = K_w = \frac{[H_3O^+][OH^-]}{1} = [H_3O^+][OH^-]$$

Note: The concentration of H_2O, $[H_2O]$, is equal to 1 because all pure liquids or solids have a constant concentration.

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K_w is the dissociation constant for water.

In pure water the $[H_3O^+]$ and $[OH^-]$ at 25°C are experimentally measured as 1×10^{-7} mol/L. By substituting these values into the expression

$$K_w = [H_3O^+][OH^-]$$

we get

$$K_w = [1 \times 10^{-7}][1 \times 10^{-7}] = 1 \times 10^{-14}$$

pH

Every water solution is neutral, acidic, or basic:

a. A neutral solution occurs when the hydronium ion concentration is equal to the hydroxide ion concentration. $[H_3O^+] = [OH^-]$

b. An acidic solution occurs when the hydronium ion concentration is greater than the hydroxide ion concentration. $[H_3O^+] > [OH^-]$

c. A basic solution occurs when the hydronium ion concentration is less than the hydroxide ion concentration. $[H_3O^+] < [OH^-]$

Most concentrations of hydronium ions are very small (i.e.. 4×10^{-8} mol/L or 0.00000004 mol/L), so Soren P. Sorenson of Denmark proposed the potency of hydrogen, or the pH scale.

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Actual pH and concentration is calculated by:

$pH = -\log [H_3O^+]$ (all in base 10)

similarly:

$pOH = -\log [H_3O^+]$ (all in base 10)

which together:

$pH + pOH = 14$

Indicators

Students in Grade 10 used litmus, bromothymol blue and phenolphthalein to test a number of solutions for pH. Depending on what reference text is used, there are great number of substances that can be used as indicators. A table has been provided in **Appendix 1** from *Quantitative Chemical Analysis*: Robert B. Fischer, Published by W.B. Saunders Company, Philadelphia and London, 1965, p 265. This text also provides a detailed explanation of how indicators work and how to choose the right one for a particular test of pH. A brief summary of this information has been provided.

Indicators are weak organic acids that change color when the hydronium or hydroxide ion concentration is changed. Indicators change colour over a given pH range. Le Chatelier's Principle can be used to explain the colour change.

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Colour 1 (→ HIn) Colour 2 (→ In^-)

$$HIn_{(aq)} \rightleftharpoons H^+_{(aq)} + In^-_{(aq)}$$

(acid form) (basic form)

The presence of an acid increases hydrogen ion concentration causing a shift from colour 2 toward colour 1. The presence of a base decreases hydrogen ion concentration causing a shift from colour 1 toward colour 2.

Change ranges are often about 2 pH units, although quite a few are less. The human eye responds more readily to some shades of color than to others, and some substances are naturally more intensely colored than others are, even at the same concentration.

Extension Activity

An extension to this discussion would be to show students how to select an indicator from a titration curve.

Teacher Background

It is important to realize that a pH change of 2 units is usually required to produce a visible colour change of a neutralization indicator. Also the pH range necessary to produce a visible end point indication in the on color type of indicator (the colour goes either **to** colourless or **from** colourless) is governed to some extent by the concentration of the indicator, while such is not case for an indicator that posses two distinct colours (*Quantitative Chemical Analysis*: Robert B. Fischer, Published by W.B. Saunders Company, Philadelphia and London, 1965, p 265).

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Laboratory Activity
Have students perform an activity to develop an operational definition of pH (see **Appendix 2**). Teacher notes can be found in **Appendix 3**. A summary of this activity has been included here.

- Make solutions of 0.1 mol/L of a strong acid (HCL or HNO_3)
- Prepare serial dilutions (see appendix for instructions)
- Determine the pH of these solutions using indicators, or a pH meter and compare with the dilution concentrations.
- Find the pH of common household products and compare to the pH of the known dilution solutions.

Another option would be for students to perform the Quick Lab, *Indicators from Natural Sources* (p.604 Prentice Hall Chemistry).

Teachers can also check the approved texts or teacher reference texts for additional lab activities.

Journal Writing
- Have students write an operational definition of pH in their Journals.
- Students can compare the acidity of a solution with pH = 1 with the acidity of a solution with pH = 3. They should be able to explain the exponential nature of the pH scale using this comparison. (p.612 Teachers Edition of Chemistry: Matter and Change)

Research Projects
Have students research and report on:
- Acid containing and acid-free paper
- Acids in cooking

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- Biographical sketches of Soren Sorensen (pH scale) or Arnold Beckman (pH meter)
- Products of a specific Ph such as shampoos and antacids.

Demonstrations

There are literally hundreds of demonstrations that will show colour changes. A series of 4 excellent books by Bassam Z. Shakhashiri can be purchased by any school where the chemistry teacher enjoys performing in front of the class. One complete volume of this set has been devoted to colour changes in chemistry. A few procedures for demonstrations have been included for reference. It should be cautioned that in many cases the chemicals required for some of these demonstrations are very expensive. Schools in a school division could collaborate. Each school could purchase one or more of the chemicals required in order to share the cost.

<u>The pH Rainbow Tube</u>

Fill a glass tube with universal indicator solution. Stopper each end. Add two drops of HCl to one end of the tube and two drops of NaOH to the other end. Use HCl and NaOH of equal concentrations. Invert the tube several times and note the colour spectrum in the tube.

<u>Dry Ice Tube</u>

Similar to the previous demonstration only dry ice is placed into a 1000 mL graduated cylinder of universal indicator made slightly basic. As the CO_2 bubbles though the solution, it forms carbonic acid and the pH gradually changes from basic to acidic.

<u>The MOM Demonstration</u>

Add 50 mL of milk of magnesia to a beaker and a few drops of universal indicator. Use a magnetic stirrer to mix the solution. Add 50 mL of 0.5M hydrochloric acid. The colour will change as the basic solution

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becomes acidified. The colour will change back as the buffering salts in the milk of magnesia raise the pH once again.

The Rainbow Connection
A series of 7 combinations of indicators are secretly placed into 7 empty glasses. As a clear acid solution is added to each of the glasses, the following colours appear red, orange, yellow, green, blue, indigo and finally violet. This demonstration can be found in Bassam Shakhashiri's books.

Wearable Indicators
By carefully soaking 100% cotton t-shirts or shoes with a 1% solution of congo red indicator, the article of clothing becomes a great way to demonstrate lab spills or simply have some fun in the lab. Once the excess indicator is washed off, it can be used to demonstrate a pH change. When the clothes are sprayed with a weak acid solution, the clothing will turn blue. When sprayed with a weak sodium carbonate solution the clothing will change blue etc. Vinegar of course will change the blue back to red.

Animations
Chemistry Experiment Simulations, Tutorials and Conceptual Computer Animations for Introduction to College Chemistry (aka General Chemistry)
http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/animationsindex.htm
Simulation for Chem 178L Experiment Acids & Bases pH meter "pH Measurements of Acids & Bases" Students can determine the pH of various acidic and basic solutions by inserting probes into the solutions and reading the pH values given on the pH meter.

NCSSM Distance Learning Technologies
http://www.dlt.ncssm.edu/TIGER/chem6.htm

Specific Learning Outcomes

C12-5-03 Describe the relationship between the hydronium and hydroxide ion concentrations in water.
Include: the ion product constant for water, $K_{w.}$ (0.5 hour)
GLO: D3

C12-5-04: Perform an activity to formulate an operational definition of pH. (1 hour)
GLO: C2

C12-5-05: Describe how an acid-base indicator works in terms of colour shifts and Le Chatelier's Principle. (0.5 hour)
GLO: D3

C12-5-06: Solve problems involving pH.
GLO: D3

Skills and Attitudes Outcomes

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-S7 Interpret patterns and trends in data, and infer and explain relationships.
GLO: C2, C5

C12-0-S9 Draw a conclusion based on the analysis and interpretation of data.
Include: cause and effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction.
GLO: C2, C5, C8

Acid-Base. This chart shows the pH color range for several acid-base indicators.
pH_RangeForColorChange.gif

Suggestions for Assessment

Paper and Pencil Task
Students can solve problems given pH, $[H_3O^+]$, or $[OH^-]$ to calculate the concentration of the opposing acid or base.

Laboratory Skills
Students should be able to set up properly the range of indicators showing the pH ranges of indicators. Teachers can use the Lab Skills Checklist available in the Appendix.

Laboratory Report
Students use Lab Report Format (see SYSTH). Word processing and spreadsheet software could be used to prepare reports.

Research Report
Students can research plants that grow best in acidic soil and those that grow best in basic soil. They can investigate how soils can be made more acidic or more basic. (p. 609 Teachers Edition of Chemistry: Matter and Change)

Students can research the pH of skin and how various products, particularly basic soaps, can interact with substances that protect the skin. (p. 611 Teachers Edition of Chemistry: Matter and Change)

Learning Resources Links

Chemistry: Matter and Change, Dingrando *et al*., Glencoe-McGraw-Hill, 2005

Specific Learning Outcomes

C12-5-03 Describe the relationship between the hydronium and hydroxide ion concentrations in water.
Include: the ion product constant for water, $K_{w.}$ (0.5 hour)
GLO: D3

C12-5-04: Perform an activity to formulate an operational definition of pH. (1 hour)
GLO: C2

C12-5-05: Describe how an acid-base indicator works in terms of colour shifts and Le Chatelier's Principle. (0.5 hour)
GLO: D3

C12-5-06: Solve problems involving pH.
GLO: D3

Skills and Attitudes Outcomes

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

C12-0-S7 Interpret patterns and trends in data, and infer and explain relationships.
GLO: C2, C5

C12-0-S9 Draw a conclusion based on the analysis and interpretation of data.
Include: cause and effect relationships, alternative explanations, supporting or rejecting a hypothesis or prediction.
GLO: C2, C5, C8

Ch. 19.3 Acids and Bases

Prentice Hall Chemistry, Wilbraham *et al*., Pearson Education / Prentice-Hall, 2005
Ch. 19.2 Acids and Bases
Quick Lab, Indicators from Natural Sources. (p.604 Prentice Hall Chemistry)

Laboratory Manual - Teacher's Edition, Glencoe Chemistry, Dingrando *et al*., McGraw-Hill, 2002
40 Estimation of pH p.247-250

Small-Scale Chemistry Laboratory Manual, Teacher's Edition, Glencoe Chemistry, Dingrando *et al*., McGraw-Hill, 2002.
30 A Small-Scale Colorimetric pH Meter p.213-215

Chemical Demonstrations: A Handbook for Teachers of Chemistry: Bassam Z. Shakhashiri
Published by The University of Wisconsin Press, Copyright 1983 (vol.1)
1985 (vol. 2)
1989 (vol. 3)
1992 (vol. 4)

Specific Learning Outcome

C12-5-07: Distinguish between weak and strong aqueous solutions of acids and bases. (0.25 hours)
Include: electrolytes and non-electrolytes
GLO: D3

C12-5-08: Write the equilibrium expression (K_a or K_b) from a balanced chemical equation. (0.25 hours)
GLO: D3

C12-5-09: Use K_a or K_b to solve problems for pH, percent dissociation and concentration. (4 hours)
GLO: D3

Skills and Attitudes Outcomes

12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

Entry-Level Knowledge

In the Aqueous Reactions Unit, specific student learning outcome C12-1-03, students were introduced to acid / base nomenclature and strong acids and bases.

Students should also be reminded that equilibrium constants were discussed in unit 4 as indicators of whether a reaction went more or less to completion, C12-4-03. This knowledge will be used in this outcome to explain the difference between strong and weak acids and bases.

Teacher Notes

Demonstration

The teacher can demonstrate the difference between electrolytes and non-electrolytes using an electrical conductivity tester with distilled water, salt water solution, sugar water solution, and ordinary tap water.

Beginning with distilled water the bulb does not light. After dissolving a small number of salt crystals the bulb will light dimly. With the dissolving of more and more salt crystals the bulb will glow brighter.

Test the electrical conductivities of 0.1 mol / L aqueous solutions of hydrochloric acid and acetic acid using a conductivity apparatus. Students will recognize that they both will result in a glowing filament but the hydrochloric acid sample will glow brighter - due to its virtual 100% dissociation (strong acid) and the greater number of free ions formed.

Strengths of Acids and Bases

In Grade 11 chemistry, students understood the difference between a dilute solution e.g. 0.0010 mol /L and concentrated solution e.g. 11.2 mol/L. Now students will be shown how to differentiate between strong and weak terms. Obviously, a dilute solution of a strong acid is possible (0.0010 mol/L of sulphuric acid) as is a concentrated solution of a weak acid. (17.4 mol/L acetic acid).

Aids and bases differ greatly in their strength.

<u>Strong Acid</u>

In general, a strong acid, HA, will dissociate essentially 100% and have a very large K_{eq}. This means that the reaction goes to completion to products with very little if any of the reactant HA left.

Specific Learning Outcome

C12-5-07: Distinguish between weak and strong aqueous solutions of acids and bases. (0.25 hours)
Include: electrolytes and non-electrolytes
GLO: D3

C12-5-08: Write the equilibrium expression (K_a or K_b) from a balanced chemical equation. (0.25 hours)
GLO: D3

C12-5-09: Use K_a or K_b to solve problems for pH, percent dissociation and concentration. (4 hours)
GLO: D3

Skills and Attitudes Outcomes

12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

$HA + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + A^-_{(aq)}$ A single arrow is used.

Chemists do not usually write equilibrium expressions for strong acids and bases because there is essentially no equilibrium. If we did, the equilibrium expression would look like:

$$K_{eq} = \frac{[H_3O^+][A^-]}{[HA][H_2O]}$$ and at equilibrium K_{eq} is very large, K_{eq} >>>> 1

In the example of a strong acid like hydrochloric, there are virtually no HCl molecules present in the aqueous solution of acid. K_{eq} = very large for HCl

Other examples of strong acids are $HClO_4$ (perchloric acid), HI (hydroiodic acid), HBr (hydrobromic acid), and H_2SO_4 (sulfuric acid).

Strong Base
A strong base is one that also completely dissociates into ions.

Examples of strong bases are NaOH (sodium hydroxide), KOH (potassium hydroxide), LiOH (lithium hydroxide), $Ca(OH)_2$ (calcium hydroxide), RbOH (rubidium hydroxide), and $Ba(OH)_2$ (barium hydroxide).

NOTE
In both strong acids and strong bases, the reaction is so far to the right that there is essentially no reactant left and so there is no equilibrium.

For strong acids and bases, the reactions use only a forward arrow denoting no reverse reaction.

0.50 mol/L of HCl will produce $[H^+] = [Cl^-]$ = 0.50 mol/L

0.50 mol/L of NaOH will produce $[Na^+] = [OH^-]$ = 0.50 mol/L

Weak Acids dissociate only slightly into ions.

$HAc_{(aq)} + H_2O \rightleftharpoons H_3O^+_{(aq)} + Ac^-_{(aq)}$ A reversible arrow is used.

Specific Learning Outcome

C12-5-07: Distinguish between weak and strong aqueous solutions of acids and bases. (0.25 hours)
Include: electrolytes and non-electrolytes
GLO: D3

C12-5-08: Write the equilibrium expression (K_a or K_b) from a balanced chemical equation. (0.25 hours)
GLO: D3

C12-5-09: Use K_a or K_b to solve problems for pH, percent dissociation and concentration. (4 hours)
GLO: D3

Skills and Attitudes Outcomes

12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

In this case, very little product is formed, i.e. the reverse reaction is preferred, and K_{eq} is very small, $K_{eq} <<<< 1$

In the example of HCN, $HCN_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + CN^-_{(aq)}$ $K_{eq} = 6.2 \times 10^{-10}$

These equilibrium expressions can be simplified since the concentration of water is very large compared to the concentration of the acid. As a result, we can write:

$$HA_{(aq)} + H_2O \rightleftharpoons H_3O^+_{(aq)} + A^-_{(aq)}$$

$$K_{eq}\left(\left[H_2O\right]\right) = K_a = \frac{\left[H_3O^+\right]\left[A^-\right]}{HA}$$

Where K_a is called the acid dissociation constant

The value of K_a or K_b in the case of a base provided the chemist with a measure of the relative strength of an acid or a base.

<u>Weak bases</u> dissociate only slightly into ions.

An important weak base is ammonia.

$$NH_{3(aq)} + H_2O_{(l)} \rightleftharpoons NH^+_{4(aq)} + OH^-_{(aq)}$$

Writing the equilibrium expression:

$$K_{eq} = \frac{\left[NH_4^+\right]\left[OH^-\right]}{\left[NH_3\right]\left[H_2O\right]}$$

Similarly to a weak acid, this equilibrium expression can be simplified since the concentration of water is very large compared to the concentration of the base. As a result, we can write:

Specific Learning Outcome

C12-5-07: Distinguish between weak and strong aqueous solutions of acids and bases. (0.25 hours)
Include: electrolytes and non-electrolytes
GLO: D3

C12-5-08: Write the equilibrium expression (K_a or K_b) from a balanced chemical equation. (0.25 hours)
GLO: D3

C12-5-09: Use K_a or K_b to solve problems for pH, percent dissociation and concentration. (4 hours)
GLO: D3

Skills and Attitudes Outcomes

12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

$$K_{eq}\left[H_2O\right] = K_b = \frac{\left[NH_4^+\right]\left[OH^-\right]}{\left[NH_3\right]} = 1.8 \times 10^{-5}$$

Other examples of weak bases are $C_6H_5NH_2$ (aniline), CH_3NH_2 (methylamine), and C_5H_5N (pyridine).

NOTE
In **Appendix 4**, there is a Ka chart for acids. The larger the K_a, the stronger the acid and the greater the tendency to release H^+ (H_3O^+) ions into solution. If we follow this argument, the species on the other side of the arrow are bases. They have a tendency to pick up H^+ (H_3O^+). If the strongest acids are on the top left, then the strongest bases must be towards the bottom of the right. The amide ion (NH_2^-) is therefore the strongest base species closely followed by the oxide ion (O^{2-}).

To review :

Stronger acid ⇒ higher % dissociation ⇒ higher [H_3O^+] ⇒ larger K_a
conversely
Smaller K_a ⇒ lower [H_3O^+] ⇒ lower % dissociation ⇒ weaker acid

The same argument can be applied to bases such that

Stronger base ⇒ higher % dissociation ⇒ higher [OH^-] ⇒ larger K_b
conversely
Smaller K_b ⇒ lower [OH^-] ⇒ lower % dissociation ⇒ weaker base

Demonstration
Equal amounts and concentrations of HCl and CH_3COOH are added to magnesium metal. HCl will react vigorously while acetic acid does not. This is because of the number of hydronium ions produced by each acid. (This demonstration can be also used to reinforce the concepts of reaction rates and concentrations of reactants.)

Specific Learning Outcome

C12-5-07: Distinguish between weak and strong aqueous solutions of acids and bases. (0.25 hours)
Include: electrolytes and non-electrolytes
GLO: D3

C12-5-08: Write the equilibrium expression (K_a or K_b) from a balanced chemical equation. (0.25 hours)
GLO: D3

C12-5-09: Use K_a or K_b to solve problems for pH, percent dissociation and concentration. (4 hours)
GLO: D3

Skills and Attitudes Outcomes

12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

Animations/Simulations

NCSSM Distance Learning Technologies
http://www.dlt.ncssm.edu/TIGER/chem6.htm
The following two animations show the difference in ionization between a strong acid solution and a weak acid solution.
StrongAcidIonization.html
This animation shows the 100% percent ionization of a strong acid in water.
WeakAcidEquilibrium.html
This animation shows the low percent ionization of a weak acid in water.

Suggestions for Assessment

Sample Problem Types

There are numerous ways that questions that can be asked of students. The following variables are those that can be added to the mix:
Initial concentration, $[H_3O^+]$, $[OH^-]$, Ka, Kb, % dissociation, pH, pOH

Teachers should be cautious of presenting too many different types of questions before the basic questions have been understood and mastered e.g. Assign questions with reverse calculations only after students understand the forward calculations. Add pH and pOH later to the mix.

There are basically two types of questions for a weak acid / weak base:

A. Given the initial concentration of the acid/base and % dissociation, pH, pOH, $[H_3O^+]$ or $[OH^-]$, find K_a or K_b
B. Given the initial concentration of the acid/base and K_a or K_b, find $[H_3O^+]$, $[OH^-]$, % dissociation, pH, pOH.

A. Using a 0.75 mol/L solution of a weak base NH_3 and $[OH^-]$= 1.0 x 10^{-4} mol/L find Ka

$$NH_{3(aq)} + H_2O_{(l)} \rightarrow NH^+_{4(aq)} + OH^-_{(aq)}$$

Write the equilibrium expression:

Specific Learning Outcome

C12-5-07: Distinguish between weak and strong aqueous solutions of acids and bases. (0.25 hours)
Include: electrolytes and non-electrolytes
GLO: D3

C12-5-08: Write the equilibrium expression (K_a or K_b) from a balanced chemical equation. (0.25 hours)
GLO: D3

C12-5-09: Use K_a or K_b to solve problems for pH, percent dissociation and concentration. (4 hours)
GLO: D3

Skills and Attitudes Outcomes

12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

$K_b = \frac{[NH_4^+][OH^-]}{[NH_3]}$ and substitute the given values

$K_b = \frac{[1.0 \times 10^{-4}][1.0 \times 10^{-4}]}{[0.75]}$ $\quad [NH_4^+] = [OH^-] = 1.0 \times 10^{-4}$ mol/L since the stoichiometry is 1:1

$K_b = 1.3 \times 10^{-8}$

B. Using 0.75 mol/L solution of a weak acid H_2O_2, find $[H_3O^+]$ and the % dissociation.

The K_a is taken from a K_a table that can be found in **Appendix 4**.

$$H_2O_{2\,(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + HO^-_{2\,(aq)}$$

$K_a = \frac{[H_3O^+][HO_2^-]}{[H_2O_2]} = 2.4 \times 10^{-12}$ [

Recall that in the unit on equilibrium, students were introduced to the ICE box, IUPE chart and the BIR/PEC methods of accounting

Let x = amount that dissociates, therefore at equilibrium:

$[H_2O_2] = 0.75 - x$
$[H_3O] = 0 + x$
$[HO_2^-] = 0 + x$

Substituting into the equilibrium expression

$2.4 \times 10^{-12} = \frac{(0 + x)(0 + x)}{(0.75\text{mol/L} - x)}$

Specific Learning Outcome

C12-5-07: Distinguish between weak and strong aqueous solutions of acids and bases. (0.25 hours)
Include: electrolytes and non-electrolytes
GLO: D3

C12-5-08: Write the equilibrium expression (K_a or K_b) from a balanced chemical equation. (0.25 hours)
GLO: D3

C12-5-09: Use K_a or K_b to solve problems for pH, percent dissociation and concentration. (4 hours)
GLO: D3

Skills and Attitudes Outcomes

12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

If we solve this according to mathematical procedures, the quadratic formula would be used…(see note below))

NOTE: It is recommended to avoid the use of the quadratic formula to solve dissociation problems, unless conditions exist for student success with this level of treatment.

Chemists use the following assumption to simplify the calculation and avoid using the quadratic.
If x is so very much less than the initial concentration of the weak acid or weak base, x can be neglected when compared to 0.75 etc. Hence (0.75mol/L - x) becomes 0.75 to 2 significant figures.

This is only possible when 'x' is negligible compared to the initial concentration.

If K_a or K_b is quite large, and/or the initial concentration is given as more significant figures, the assumption may not work, and the quadratic formula would have to be used.

With this assumption, the equilibrium expression becomes

$$2.4 \times 10^{-12} = \frac{(0 + x)(0 + x)}{(0.75\text{mol/L})}$$

simplified to $$2.4 \times 10^{-12} = \frac{x^2}{(0.75\text{mol/L})}$$

and $$x = 1.3 \times 10^{-5}$$

Teachers may want to show students how this is possible, by checking the final answer to 2 significant figures 0.75mol/L – 0.000013 mol/L = 0.75 mol/L to 2 significant figures.

Hence $x = [H_3O^+] = [HO_2^-] = 1.3 \times 10^{-5}$ mol/L

$$\%\ \text{dissociation} = \frac{[H_3O^+]\ \text{or}\ [HO_2^-]}{\text{initial concentration}} \times 100$$

$$= \frac{1.3 \times 10^{-5}}{0.75} \times 100$$

$$= 1.7 \times 10^{-3}\ \%\quad \text{or}\quad 0.0017\%$$

Specific Learning Outcome

C12-5-07: Distinguish between weak and strong aqueous solutions of acids and bases. (0.25 hours)
Include: electrolytes and non-electrolytes
GLO: D3

C12-5-08: Write the equilibrium expression (K_a or K_b) from a balanced chemical equation. (0.25 hours)
GLO: D3

C12-5-09: Use K_a or K_b to solve problems for pH, percent dissociation and concentration. (4 hours)
GLO: D3

Skills and Attitudes Outcomes

12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

Once students have mastered these types of questions then pH and pOH could be used instead of $[H_3O^+]$ and $[OH^-]$

There is another type of question that can be asked that involves Ka and Kb constants and Le Chatelier's Principle

The following examples have been provided:

A In each case:

1. complete the acid-base reaction with the help of tables
2. specify the two acids and bases involved
3. specify the stronger and weaker of the acids
4. indicate in your answer whether reactants or products are favoured at equilibrium.

a) $H_3PO_4 + CH_3COO^- \rightleftharpoons$

$H_3PO_4 + CH_3COO^- \rightleftharpoons H_2PO_4 + CH_3COOH$

acid1 base1 CB CA

Ka = 7.5×10^{-3} Ka = 1.8×10^{-5}

Stronger acid Weaker acid

Products favoured → → →

b) $SO_3^{2-} + NH_4^+ \rightleftharpoons$

$SO_3^{2-} + NH_4^+ \rightleftharpoons HSO_3^{1-} + HN_3$

base 1 acid 1 CA CB

Ka = 5.7×10^{-10} Ka = 6.2×10^{-8}

Weaker acid Stronger acid

← ← ← Reactants favoured

c) $HPO_4^{2-} + S^{2-} \rightleftharpoons$

$HPO_4^{2-} + S^{2-} \rightleftharpoons PO_4^{3-} + HS^{1-}$

Specific Learning Outcome

C12-5-07: Distinguish between weak and strong aqueous solutions of acids and bases. (0.25 hours)
Include: electrolytes and non-electrolytes
GLO: D3

C12-5-08: Write the equilibrium expression (K_a or K_b) from a balanced chemical equation. (0.25 hours)
GLO: D3

C12-5-09: Use K_a or K_b to solve problems for pH, percent dissociation and concentration. (4 hours)
GLO: D3

Skills and Attitudes Outcomes

12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

Acid 1	base 1	CB	CA
$Ka = 4.4 \times 10^{-14}$			$Ka = 1.2 \times 10^{-15}$
Stronger acid			weaker acid
Products favoured → → →			

B Challenge question
One mL of 0.10 mol/L HCl is added to each of 5 test tubes containing 10 mL of 1.0 mol/L solutions of the following 5 ions. In each case, write the acid-base reaction according to Bronsted, and identify the acids and bases on both sides of the reaction. In which case is the hydronium ion concentration lowered the most by the reaction with HCl?

a) CO_3^{2-} b) HCO_3^- c) HPO_4^{2-} d) CH_3COO^- e) HSO_3^-

a) $CO_3^{2-} + HCl \rightleftharpoons HCO_3^{1-} + Cl^{1-}$
HCl: Ka very large; HCO_3^{1-}: $Ka = 4.7 \times 10^{-11}$

b) $HCO_3^{1-} + HCl \rightleftharpoons H_2CO_3 + Cl^{1-}$
HCl: Ka very large; H_2CO_3: $Ka = 4.4 \times 10^{-7}$

c) $HPO_4^{2-} + HCl \rightleftharpoons H_2PO_4^{1-} + Cl^{1-}$
HCl: Ka very large; $H_2PO_4^{1-}$: $Ka = 6.3 \times 10^{-8}$

d) $CH_3COO^{1-} + HCl \rightleftharpoons CH_3COOH + Cl^{1-}$
HCl: Ka very large; CH_3COOH: $Ka = 1.8 \times 10^{-5}$

e) $HSO_3^{1-} + HCl \rightleftharpoons H_2SO_3 + Cl^{1-}$
HCl: Ka very large; H_2SO_3: $Ka = 6.2 \times 10^{-8}$

As the Ka for HCl is constant in each reaction, we are comparing the Ka values for the conjugate acids. Since the Ka for CH_3COOH is the largest compared to the others, that reaction with go the least to the right, whereas with HCO_3^{1-} its Ka is the smallest, having the least effect on the Ka for HCl, therefore, that reaction will go the furthest to the right , thus causing the hydronium concentration to be lowered the most.

<u>Paper and Pencil Tasks</u>
Students should be able to write the equilibrium expression (K_a or K_b) from a balanced chemical equation.

Specific Learning Outcome

C12-5-07: Distinguish between weak and strong aqueous solutions of acids and bases. (0.25 hours)
Include: electrolytes and non-electrolytes
GLO: D3

C12-5-08: Write the equilibrium expression (K_a or K_b) from a balanced chemical equation. (0.25 hours)
GLO: D3

C12-5-09: Use K_a or K_b to solve problems for pH, percent dissociation and concentration. (4 hours)
GLO: D3

Skills and Attitudes Outcomes

12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

Students should be able to solve problems for pH, percent dissociation and concentration given the K_a or K_b.

<u>Compare and Contrast</u>
Students can do a compare/contrast frame for weak and strong acids and for weak and strong bases.

Learning Resources Links
Chemistry: Matter and Change, Dingrando *et al*., Glencoe-McGraw-Hill, 2005
Ch. 19 Acids and Bases

Prentice Hall Chemistry, Wilbraham *et al*., Pearson Education / Prentice-Hall, 2005
Ch. 19 Acids and Bases

Specific Learning Outcome

C12-5-10: Using a standardized acid or base, experimentally determine the concentration of an unknown base or acid. (3 hours)
GLO: C2

Skills and Attitudes Outcomes

C12-0-S1 Demonstrate work habits that ensure personal safety and the safety of others, as well as consideration for the environment
Include: knowledge and use of relevant safety precautions, Workplace Hazardous Materials Information System (WHMIS), emergency equipment.
GLO: B3, B5, C1, C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-S6 Estimate and measure accurately using Système International (SI) and other standard units.
Include: SI conversions, significant figures.
GLO : C2

Entry-Level Knowledge
In Grade 10 Science students were able to explain how acids and bases interact to form a salt and water in the process of neutralization (S2-2-10).
In the Aqueous Reactions unit, C12-1-04, students performed a lab to demonstrate the stoichiometry of a neutralization reaction between a strong base and a strong acid.

Assessing prior Knowledge
The experiment that students will perform for this outcome requires a complete understanding of the process and theory of neutralization from the first unit. To reduce the possibility of poor quantitative results in the lab experiment, a thorough review should be done before assigning the lab experiment. Check for understanding of prior knowledge and review as necessary. Prior knowledge can be reviewed and / or assessed by using any of the KWL forms in SYSTH, chapter 9, e.g. Concept maps; Knowledge Charts; Think, Pair, Share.

Lab Activity
Have students complete an acid-base titration lab (see **Appendix 5**).

Teacher Notes for the Laboratory Activity
Burets found in schools will differ greatly in quality. There are many schools that still have burets with rubber hose, a glass tip, part of an eye dropper and a pinch clamp to regulate the stream of liquid. The number of drops and the size of drop with this crude buret is not easy to control and so the possible accuracy and reliability would be less than using a buret with a Teflon spigot and a 120 sec tip.

As the document suggests in Unit 1, teachers may have given students microscale well-plates with which to conduct their neutralization investigation. If this was the case, then students may not have seen a buret and must be first introduced to the care and correct use of this delicate piece of equipment.

The lab that has been provided in Appendix 5 assumes that there are enough burets such that each student in the class can have one for acid and another for base. If this is not possible, then a common buret for the standard solution can be used by two students but each having their own unknown solution in a separate buret.

Specific Learning Outcome

C12-5-10: Using a standardized acid or base, experimentally determine the concentration of an unknown base or acid. (3 hours)
GLO: C2

Skills and Attitudes Outcomes

C12-0-S1 Demonstrate work habits that ensure personal safety and the safety of others, as well as consideration for the environment
Include: knowledge and use of relevant safety precautions, Workplace Hazardous Materials Information System (WHMIS), emergency equipment.
GLO: B3, B5, C1, C2

C12-0-S5 Collect, record, organize and display data using an appropriate format.
Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-S6 Estimate and measure accurately using Système International (SI) and other standard units.
Include: SI conversions, significant figures.
GLO : C2

If teachers wish to have their students do the B part of the lab that involves the titration of a solid acid, students will need an accurate quantitative method of dissolving the sample of acid given to them by the teacher. This is best done with a volumetric flask as is indicated in the lab. Teachers should also note that having an electronic balance that reads to 0.001 g would help to increase the accuracy of the results.

If teachers decide to have their students do both parts of the lab, an important suggestion would be that teachers should review the procedure after students have first read the lab over as an assignment (prior knowledge). The teachers would then initiate a discussion of lab skills and errors. It would be at this time that teachers differentiate for students what accuracy and reliability are with respect to this experiment.

If teachers wish to expose their students to other types of titration curves other than the strong acid –strong base pairing (the suggested lab in Appendix 5 does not ask students to draw a titration curve). It is left to local teacher discretion whether students are expected to prepare or interpret titration curves. Samples can be found in the Appendix 9 (i.e strong acid-weak base, weak acid –strong base, weak acid-weak base).

If teachers wish to expose their students to other types of titration curves other than strong acid-strong base, sample titration curves with along with activity questions can be found in the appendix #??? for strong acid with weak base, strong base with weak acid, weak acid with weak base. (Transitional document pages 180 to 186

Additional Lab Activities

There are several lab activities that involve the titration process that teachers may wish to use either as an alternative lab or an additional lab depending on available time.

1. The percent acetic acid in household vinegar (see **Appendix 6**).
2. The analysis of Aspirin™ (see **Appendix 7**)
3. Titration of sodium hypochlorite in bleach with sodium thiosulphate (Pearson Prentice Hall, see reference in Resource Links.

4. Merlan Scientific Limited has published a lab manual that provides two additional labs:
   - Time-released Vitamin C Tablets
   - Phosphoric acid content in Soft Drinks

   See Resource Links for reference.

Specific Learning Outcome

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Skills and Attitudes Outcomes

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GLO: B3, B5, C1, C2

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Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-S6 Estimate and measure accurately using Système International (SI) and other standard units.
Include: SI conversions, significant figures.
GLO : C2

Suggestions for Assessment

Pencil and paper tasks
Ask students to:

- Compare and contrast, or define: titrate, titrant, end point, equivalence point, indicator, aliquot, standard solution, dilute. 'Compare/Contrast Frames' Word Cycles or other vocabulary strategies could be used by students to demonstrate their understanding of the indicated terms
- Explain why adding additional solvent water to the sample being titrated has no effect on the end point.
- Discuss their results with a discussion of experimental errors.

<u>Lab Skills</u>
Students should be able to titrate a strong acid with a strong base.
Lab skills might include:

- Massing of solid acid
- Quantitative transfer of solids
- Use of a volumetric flask
- Reading a buret to ± 0.01
- Process of titration

See Appendix for lab skills checklist

<u>Research Skills</u>
There are many research and industrial applications of the titration process. Teachers may wish to have their students do a search on the Internet for other examples than those provided.

- Testing of acid rain,
- pH soil testing,
- Efficacy of antacid tablets or aspirin,
- Concentration of oxygen in surface waters (sodium thiocyanate titrant and starch solution indicator).
- Maintenance of a required pH during the growth of bacteria
- Identification of food additives

Specific Learning Outcome

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GLO: C2

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Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware…
GLO: C2, C5

C12-0-S6 Estimate and measure accurately using Système International (SI) and other standard units.
Include: SI conversions, significant figures.
GLO : C2

- Determination of the surface area of marine alga
- Used by marine biologists to determine the condition of marine coral reefs
- Testing the phosphoric acid content in soft drinks

Web Links
The following web link provided good definitions and explanations of tittration and the related terms involved.
http://www.sparknotes.com/chemistry/acidsbases/titrations/section1.html

The next link provided a reasonable procedure for the determination of Vitamin C in any commercial product.
http://www.chemistry.ucsc.edu/teaching/roland/Chem1N/procedures/Procedure_03.pdf

This link provided students with an idea how marine scientists monitor the environment of coral reefs.
http://www.seasky.org/aquarium/aquarium_faq_page01.html

Learning Resources Links
Chemistry: Matter and Change, Dingrando *et al*., Glencoe-McGraw-Hill, 2005
Salt Hydrolysis (621)

ChemLab 19 Standardizing a Base Solution by Titration (626)
Antacids (628)

Prentice Hall Chemistry, Wilbraham *et al*., Pearson Education / Prentice-Hall, 2005
Salts in Solution (618)

Chemistry: The Molecular Nature of Matter and Change, Martin S. Silberberg, McGraw-Hill Higher Education, 2006. (796)

Chemistry, Raymond Change (8th ed), McGraw-Hill Higher Education, 2005. (656)

Specific Learning Outcome

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C12-0-S6 Estimate and measure accurately using Système International (SI) and other standard units.
Include: SI conversions, significant figures.
GLO : C2

Chemistry with Calculators, Dan Holmquist and Donald Volz, published by Merlan Sciemtific Ltd, Georgetown, ON, 1-800-387-2474, ISBN: 1-929075-04-1

Small-Scale Chemistry Laboratory Manual: Edward L. Waterman and Stephen Thompson, Pearson prentice hall, Boston, ISBN: 0-13-190360-8, page 113

Specific Learning Outcome

C12-5-11: Predict whether an aqueous solution of a given ionic compound will be acidic, basic or neutral given the formula. (1 hour)
GLO: D3

Skills and Attitudes Outcomes

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

Entry-Level Knowledge

In previous grades, students have only been introduced to the physical properties of salts as being soluble or insoluble. So far in their knowledge of chemistry, they have not encountered the chemical properties of salts.

Teacher Notes

In this outcome, students will learn to appreciate that salts can be something other than neutral. Many students have the misconception that salt solutions are always neutral. Students now understand that when an acid combines with a base, a salt and water are produced. However, the resulting aqueous salt solution can be neutral, acidic or basic depending on the strength of the acid and base that are reacted.

Teacher Background

The following table adapted from Chang (see learning Resources) provides a summary of the species involved with hydrolysis. In this form, the table is intended for teachers.

Type of Salt	Examples	Ions that Undergo Hydrolysis	pH
A. Cation from strong base Anion from strong acid	NaCl, KI, KNO_3, RbBr $BaCl_2$	None	≈7
B. Cation from strong base Anion from weak acid	$NaC_2H_3O_2$,KNO_2	Anion	>7
C. Cation from weak base Anion from strong acid	NH_4Cl, NH_4NO_3	Cation	<7
Cation for weak base Anion from weak acid	NH_4NO_2 , $NH_4C_2H_3O_2$ NH_4CN	Cation and Anion	<7 if $K_b < K_a$ ≈ 7 if $K_b \approx K_a$ >7 if $K_b > K_a$

Teacher Notes

To simplify this further:

A. A strong acid and a strong base produce a neutral solution.

B. A strong base plus a weak acid produce a slightly basic salt.

C. A strong acid plus a weak base produce a slightly acidic salt.

Specific Learning Outcome

C12-5-11: Predict whether an aqueous solution of a given ionic compound will be acidic, basic or neutral given the formula. (1 hour)
GLO: D3

Skills and Attitudes Outcomes

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

A salt can react with the water (called salt hydrolysis) and the anions of the dissociated salt may accept hydrogen ions from the water producing a basic solution or the cations of the dissociated salt may donate hydrogen ions from the water producing an acidic solution.

The following detailed examples will show the process that occurs to the various species during hydrolysis.

A. Cation from a strong base plus the anion from a strong acid → pH = 7
No example is necessary as there is no hydrolysis

B. Cation from a strong base plus the anion from a weak acid → pH > 7

<u>Example 1</u> $NaC_2H_3O_2$ Basic solution pH >7

Sodium acetate solid dissolves in water to produce sodium cations ions and acetate anions

$$NaC_2H_3O_{2\,(s)} \xrightarrow{H_2O} Na^+_{(aq)} + C_2H_3O^-_{2\,(aq)}$$

$Na^+_{(aq)} + H_2O_{(l)} \rightarrow$ no reaction because Na^+ is a spectator ion

Because the K_a for $HC_2H_3O_2$ is very small (1.8×10^{-5}), the reaction below tends to go forward as written to remove hydrogen ions from solution and leaving an excess of hydroxide ions.

$$C_2H_3O^-_{2\,(aq)} + H_2O_{(l)} \rightarrow HC_2H_3O_{2\,(aq)} + OH^-_{(aq)}$$

<u>Example 2</u> K_2CO_3 Basic solution pH >7

Since K_2CO_3 comes from a strong base (KOH) and a weak acid (H_2CO_3), a basic solution results. Potassium carbonate dissolves in water to produce potassium cations and carbonate anions.

$$K_2CO_{3\,(s)} \xrightarrow{H_2O} 2K^+_{(aq)} + CO^{2-}_{3\,(aq)}$$

$$2K^+_{(aq)} + H_2O_{(l)} \rightarrow \text{no reaction}$$

Similarly, because the K_a for carbonic acid is very small (4.4×10^{-7}), the reaction below tends to go forward as written to remove hydrogen ions from solution leaving an excess of hydroxide ions.

$$CO^{-2}_{3\,(aq)} + H_2O_{(l)} \rightarrow H_2CO_{3\,(aq)} + OH^-_{(aq)}$$

C. Cation from a weak base plus the anion from a strong acid → pH < 7

Specific Learning Outcome

C12-5-11: Predict whether an aqueous solution of a given ionic compound will be acidic, basic or neutral given the formula. (1 hour)
GLO: D3

Skills and Attitudes Outcomes

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

Example 3 NH_4NO_3 Acidic solution pH <7

Using a similar argument as in the first two examples, we can say that ammonium nitrate dissolves in water to produce ammonium cations and nitrate anions. NH_4NO_3 comes from a weak base (NH_3) and a strong acid (HNO_3), an acidic solution results.

$$NH_4NO_{3\,(aq)} \xrightarrow{H_2O} NH^+_{4\,(aq)} + NO^-_{3\,(aq)}$$

Since ammonium hydroxide is a weak base, the second reaction tends to go forward as written to remove hydroxide ions from solution and leaving an excess of hydrogen ions (hydronium ions)

$$H_2O_{(l)} \xrightarrow{H_2O} H_3O^+_{(aq)} + \cancel{OH^-_{(aq)}}$$

$$NH^+_{4\,(aq)} + \cancel{OH^-_{(aq)}} \rightarrow NH_4OH_{(aq)}$$

$$NH^+_{4\,(aq)} + H_2O_{(l)} \rightarrow NH_4OH_{(aq)} + H_3O^+_{(aq)}$$

Since H_3O^+ is produced the salt is acidic. (The negative ion of any strong acid will not react with water.)

Lab Activity

There is an accessible lab that students could complete on the hydrolysis of a number of salts to complement what was discussed in class.
Laboratory Manual : Antony C. Wilbraham, et al., Pearson Prentice-Hall, Boston, (267)

Suggestions for Assessment

Paper and Pencil Tasks
Students should be able to determine if a salt solution is neutral, acidic or basic given the salt of a weak acid or the salt of a weak base. .

Compare and Contrast
Students should be able to explain why sodium hydrogen carbonate is an effective antacid but sodium hydroxide is not. (p.628 Chemistry: Matter and Change, Dingrando *et al*.,)

Learning Resources Links

Chemistry: Matter and Change, Dingrando *et al*., Glencoe-McGraw-Hill, 2005
Salt Hydrolysis (621)
Prentice Hall Chemistry, Wilbraham *et al*., Pearson Education / Prentice-Hall, 2005
Salts in Solution (618)

Specific Learning Outcome

C12-5-11: Predict whether an aqueous solution of a given ionic compound will be acidic, basic or neutral given the formula. (1 hour)
GLO: D3

Skills and Attitudes Outcomes

C12-0-U1 Use appropriate strategies and skills to develop an understanding of chemical concepts.
Examples: analogies, concept frames, concepts maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles …
GLO: D3

Chemistry: The Molecular Nature of Matter and Change, Martin S. Silberberg, McGraw-Hill Higher Education, 2006. (796)

Chemistry, Raymond Change (9th ed), McGraw-Hill Higher Education, 2007. (674)