# TOPIC 5:
# ACIDS AND BASES

## Topic 5: Acids and Bases

**C12-5-01** Outline the historical development of acid-base theories.
Include: the Arrhenius, Brønsted-Lowry, and Lewis theories

**C12-5-02** Write balanced acid-base chemical equations.
Include: conjugate acid-base pairs and amphoteric behaviour

**C12-5-03** Describe the relationship between the hydronium and hydroxide ion concentrations in water.
Include: the ion product of water, $K_w$

**C12-5-04** Perform a laboratory activity to formulate an operational definition of *pH*.

**C12-5-05** Describe how an acid-base indicator works in terms of colour shifts and Le Châtelier's principle.

**C12-5-06** Solve problems involving pH.

**C12-5-07** Distinguish between strong and weak acids and bases.
Include: electrolytes and non-electrolytes

**C12-5-08** Write the equilibrium expression ($K_a$ or $K_b$) from a balanced chemical equation.

**C12-5-09** Use $K_a$ or $K_b$ to solve problems for pH, percent dissociation, and concentration.

**C12-5-10** Perform a laboratory activity to determine the concentration of an unknown acid or base, using a standardized acid or base.

**C12-5-11** Predict whether an aqueous solution of a given ionic compound will be acidic, basic, or neutral, given the formula.

**Suggested Time: 14 hours**

## *Topic 5: Acids and Bases*

SPECIFIC LEARNING OUTCOMES

C12-5-01: Outline the historical development of acid-base theories.
Include: the Arrhenius, Brønsted-Lowry, and Lewis theories

C12-5-02: Write balanced acid-base chemical equations.
Include: conjugate acid-base pairs and amphoteric behaviour

(2 hours)

SLO: C12-5-01
SLO: C12-5-02

## SUGGESTIONS FOR INSTRUCTION

### Entry-Level Knowledge

In Grade 10 Science (S2-2-08), students experimented to classify acids and bases according to their characteristics. Students were introduced to hydrochloric, sulphuric, and nitric acids, as well as to some bases, such as sodium hydroxide and calcium hydroxide. In Grade 11 Chemistry (Topic 5: Organic Chemistry), students studied organic acids, such as formic and acetic acids.

### Assessing Prior Knowledge

Check for students' understanding of prior knowledge, and review concepts 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

### Common Acids and Bases

Review common acids and bases, including those with which students are familiar. Brainstorming or using a KWL strategy would provide students with an opportunity to describe their prior knowledge. Common examples of acids include lactic acid in sour milk, butyric acid in rancid butter, citric acid in citric fruit, ascorbic acid as vitamin C, and acetylsalicylic acid (ASA) tablets. Example of bases include ammonia as a household cleaner and sodium hydroxide as an oven cleaner.

**General Learning Outcome Connections**

GLO A1: Recognize both the power and limitations of science as a way of answering questions about the world and explaining natural phenomena.

GLO A2: Recognize that scientific knowledge is based on evidence, models, and explanations, and evolves as new evidence appears and new conceptualizations develop.

GLO A4: Identify and appreciate contributions made by women and men from many societies and cultural backgrounds that have increased our understanding of the world and brought about technological innovations.

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOME

**C12-0-U1:** Use appropriate strategies and skills to develop an understanding of chemical concepts.

*Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .*

## Theories of Acids and Bases

Current understanding and definitions of acids and bases are based on the historical contributions of chemists such as Svante Arrhenius, Johannes Brønsted, Thomas Lowry, and Gilbert Newton Lewis.

Each successive definition of acids and bases becomes more inclusive until finally the definition proposed by Lewis (Lewis Dot Diagrams) becomes so general that any reaction in which a pair of electrons is transferred becomes an acid-base reaction.

### The Arrhenius Theory

Swedish scientist Svante Arrhenius (1859–1927) proposed a theory explaining the nature of acids and bases according to their structure and the ions produced when they dissolve in water.

- **Acids:** *Acids* are any substances that dissociate to produce *hydrogen ions* ($H^+$) when dissolved in water.

  *Examples:*

  Hydrochloric acid: $HCl_{(aq)} \longrightarrow H^+_{(aq)} + Cl^-_{(aq)}$

  Nitric acid: $HNO_{3(aq)} \longrightarrow H^+_{(aq)} + NO_3^-{}_{(aq)}$

- **Bases:** *Bases* are any substances that dissociate to produce *hydroxide ions* ($OH^-$) when dissolved in water.

  *Examples:*

  Sodium hydroxide: $NaOH_{(aq)} \longrightarrow Na^+_{(aq)} + OH^-_{(aq)}$

  Barium hydroxide: $Ba(OH)_{2(aq)} \longrightarrow Ba^{2+}_{(aq)} + 2OH^-_{(aq)}$

  A limitation of the Arrhenius theory is that it does not account for reactions between substances that are acidic or basic but do not have a hydrogen or hydroxide ion. A few troublesome species such as carbon dioxide (which lacks the hydrogen ion) and ammonia (which lacks the hydroxide ion) were explained by Arrhenius as first reacting with water.

  *Examples:*

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

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

**Topic 5: Acids and Bases**

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Include: conjugate acid-base pairs and amphoteric behaviour

*(continued)*

### The Brønsted-Lowry Theory

Danish chemist Johannes Brønsted (1879–1947) and English chemist Thomas Lowry (1874–1936) simultaneously proposed a new theory, 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 definition of acids and bases proposed by Arrhenius.

According to the Brønsted-Lowry definition, a substance such as carbon dioxide ($CO_{2(g)}$) can now be clearly seen as an acid that picks up a proton when bubbled through water, according to the following reaction.

*Example:*

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

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

  *Examples:*

  Hydrochloric acid: $HCl_{(aq)} + H_2O_{(l)} \longrightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$

  Nitric acid: $HNO_{3(aq)} + H_2O_{(l)} \longrightarrow H_3O^+_{(aq)} + NO_3^-{}_{(aq)}$

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

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

  *Examples:*

  Sodium hydroxide: $NaOH_{(aq)} \longrightarrow Na^+_{(aq)} + OH^-_{(aq)}$

  Ammonia: $NH_{3(aq)} + H_2O_{(l)} \longrightarrow NH_4^+{}_{(aq)} + OH^-_{(aq)}$

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

SKILLS AND ATTITUDES OUTCOME

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

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

*Example:*

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

| | | | |
|---|---|---|---|
| acid | base | conjugate acid | conjugate base |

Substances that can act as both acids and bases, such as water, are said to be *amphoteric*.

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 $K_a$ table will show that a diprotic acid such as sulphuric acid will have 2 $K_a$ values for each successive dissociation.

*Examples:*

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

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

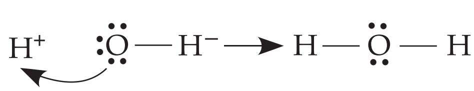
**Note:** The Brønsted-Lowry definition of acids and bases is the most useful for Grade 12 Chemistry and should be the one emphasized. The Lewis definition involves the transfer of electrons and can become quite complex.

**The Lewis Theory**

American chemist Gilbert Newton (G. N.) Lewis (1875–1946) proposed in 1932 that an acid accepts a pair of electrons during a chemical reaction, while a base donates 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 Brønsted-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.



**Topic 5: Acids and Bases**

SPECIFIC LEARNING OUTCOMES

C12-5-01: Outline the historical development of acid-base theories.
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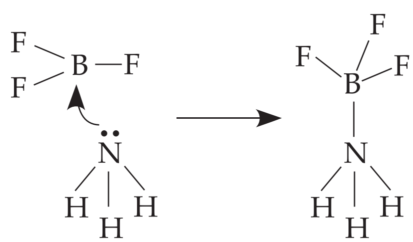
*(continued)*

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 previously called Brønsted-Lowry bases, because any Brønsted-Lowry base must have a pair of non-bonding electrons in order to accept a proton.

However, the Lewis theory vastly expands the category previously called Brønsted-Lowry acids. Any compound that has one or more valence shell orbitals can now act as an acid. This theory explains why boron trifluoride ($BF_3$) reacts instantly with ammonia ($NH_3$). 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.



### Amphoteric Behaviour

Amino acids and proteins are amphoteric, as they both contain a basic amino group ($–NH_2$) and an acid carboxyl group (–COOH).

### Demonstration: Properties of Bases

Ask students to recall "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" (Dingrando, et al., *Glencoe Chemistry: Matter and Change, Teacher Wraparound Edition* 596).

### Learning Activity

Ask students to "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 $Cl^-$" (Dingrando, et al., *Glencoe Chemistry: Matter and Change, Teacher Wraparound Edition* 598).

SKILLS AND ATTITUDES OUTCOME

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

### EAL Strategy

Have English as an additional language (EAL) learners look up and then explain the meanings of several key English prefixes and words used in addressing learning outcomes C12-5-01 and C12-5-02: *mono–*, *di–*, *tri–*, *poly–*, *amphoteric*, *conjugate*, *monoprotic*, *polyprotic* (Dingrando, et al., *Glencoe Chemistry: Matter and Change, Teacher Wraparound Edition* 597).

## SUGGESTIONS FOR ASSESSMENT

### Paper-and-Pencil Tasks

1. 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.
2. Students can complete a Three-Point Approach for Words and Concepts for each of the three acid-base theories discussed (see *SYSTH* 10.22).

### Debates

Have students perform a debate involving the Arrhenius and Brønsted-Lowry theories of acids and bases. One student would defend the Arrhenius theory, while the other would defend the Brønsted-Lowry theory.

### Visual Displays

Students can develop a Concept Map using terms such as the following: *acidic solutions*, *acids*, *bases*, *Arrhenius theory*, *Brønsted-Lowry theory*, *Lewis theory*, *pair of electrons*, *accept*, and *donate.*

## LEARNING RESOURCES LINKS

*Glencoe Chemistry: Matter and Change* (Dingrando, et al.)
Section 19.1: Acids and Bases: An Introduction, 595
(does not include the Lewis definition of acids and bases)

*Glencoe Chemistry: Matter and Change, Teacher Wraparound Edition* (Dingrando, et al. 596–598)

*Prentice Hall Chemistry* (Wilbraham, et al.)
Section 19.1: Acid-Base Theories, 587

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Include: conjugate acid-base pairs and amphoteric behaviour

*(continued)*

## Website

Chemical Education Research Group, Iowa State University. "Chemistry Experiment Simulations and Conceptual Computer Animations." *Chemical Education*. <http://group.chem.iastate.edu/Greenbowe/sections/projectfolder/simDownload/index4.html> (22 Nov. 2012).

In the Acid-Base Equilibria section, download and unzip the following animation: $NH_{3(aq)}$ (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.

**Selecting Learning Resources**

For additional information on selecting learning resources for Grade 11 and Grade 12 Chemistry, see the Manitoba Education website at <www.edu.gov.mb.ca/k12/learnres/bibliographies.html>.

SKILLS AND ATTITUDES OUTCOME

C12-0-U1: Use appropriate strategies and skills to develop an understanding of chemical concepts.

*Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .*

## NOTES

***Topic 5: Acids and Bases***

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, $K_w$

**C12-5-04:** Perform a laboratory activity to formulate an operational definition of *pH*.

**C12-5-05:** Describe how an acid-base indicator works in terms of colour shifts and Le Châtelier's principle.

**C12-5-06:** Solve problems involving pH.

(3 hours)

SLO: C12-5-03
SLO: C12-5-04
SLO: C12-5-05
SLO: C12-5-06

## SUGGESTIONS FOR INSTRUCTION

### Entry-Level Knowledge

In Grade 10 Science (S2-2-08), 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. In Grade 11 Chemistry (Topic 5: Organic Chemistry), students studied organic acids, such as formic and acetic acids.

### Assessing Prior Knowledge

Check for students' understanding of prior knowledge, and review concepts as necessary. Prior knowledge of terms can be reviewed and/or assessed by using any of the KWL strategies (e.g., Concept Map, Knowledge Chart, Think-Pair-Share, Word Cycle, Three-Point Approach, Compare and Contrast—see *SYSTH*, Chapter 9).

### TEACHER NOTES

### The Ion Product Constant for Water ($K_w$)

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

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

**General Learning Outcome Connections**

GLO C2: Demonstrate appropriate scientific inquiry skills when seeking answers to questions.
GLO C5: Demonstrate curiosity, skepticism, creativity, open-mindedness, accuracy, precision, honesty, and persistence, and appreciate their importance as scientific and technological habits of mind.
GLO C8: Evaluate, from a scientific perspective, information and ideas encountered during investigations and in daily life.
GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOMES

**C12-0-U1:** Use appropriate strategies and skills to develop an understanding of chemical concepts.

*Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .*

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

**C12-0-S9:** Draw a conclusion based on the analysis and interpretation of data.

Include: cause-and-effect relationships, alternative explanations, and supporting or rejecting a hypothesis or prediction

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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.

$K_w$ is the dissociation constant for water.

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

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

we get

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

### The Potency of Hydrogen (pH) Scale

Every water solution is neutral, acidic, or basic.

- A *neutral solution* occurs when the hydronium ion concentration is equal to the hydroxide ion concentration.

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

- An *acidic solution* occurs when the hydronium ion concentration is greater than the hydroxide ion concentration.

  $$[H_3O^+] > [OH^-]$$

- 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 (e.g., $4 \times 10^{-8}$ mol/L or 0.00000004 mol/L) and can be difficult to express. In 1909, Danish biochemist Søren P. Sørenson (1868–1939) proposed the *potency of hydrogen (pH) scale*, a scale ranging from 0 to 14 pH used to measure the acidity or alkalinity of a solution.

**Topic 5: Acids and Bases**

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, $K_w$

**C12-5-04:** Perform a laboratory activity to formulate an operational definition of *pH*.

**C12-5-05:** Describe how an acid-base indicator works in terms of colour shifts and Le Châtelier's principle.

**C12-5-06:** Solve problems involving pH.

*(continued)*

Actual pH and concentration are calculated by

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

Similarly,

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

Together,

$pH + pOH = 14$

### Acid-Base Indicators

In Grade 10 Science, students used litmus, bromothymol blue, and phenolphthalein as acid-base indicators to test a number of solutions for pH. A great number of chemical substances can be used as indicators, which will change colour in the presence of an acid or a base. A table identifying some common acid-base indicators and their colour changes and pH range is provided in Appendix 5.1: Selected Neutralization Indicators.

Acid-base indicators are weak organic acids that change colour when the hydronium or hydroxide ion concentration is changed. Indicators (In) change colour over a given pH range. Le Chatelier's principle can be used to explain the colour change.

$$\underset{\text{(acid form)}}{\overset{\text{Colour 1}\ \downarrow}{HIn_{(aq)}}} \rightleftharpoons \underset{\text{(basic form)}}{\overset{\text{Colour 2}\ \downarrow}{H^+_{(aq)} + In^-_{(aq)}}}$$

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.

SKILLS AND ATTITUDES OUTCOMES

**C12-0-U1:** Use appropriate strategies and skills to develop an understanding of chemical concepts.
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**C12-0-S7:** Interpret patterns and trends in data, and infer and explain relationships.

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Include: cause-and-effect relationships, alternative explanations, and supporting or rejecting a hypothesis or prediction

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

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" colour 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 the case for an indicator that possesses two distinct colours (Fischer 265).

Further explanations of how indicators work can be found online.

*Sample Website:*

Clark, Jim. "Acid-Base Indicators." *Chemguide.* 2002, mod. Dec. 2006. <www.chemguide.co.uk/physical/acidbaseeqia/indicators.html> (22 Nov. 2012).

**Extension:** Show students how to select an indicator from a titration curve.

### Laboratory Activity

Have students perform an experiment to develop an operational definition of pH (see Appendix 5.2: Acid-Base Indicators and pH: Lab Activity, Appendix 5.3A: Measuring pH: Lab Activity, and Appendix 5.3B: Measuring pH: Lab Activity [Teacher Notes]).

In this experiment, students do the following:

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

Another option would be to have students perform Quick LAB 19: Indicators from Natural Sources (Wilbraham, et al. 604).

Check the Learning Resources Links for additional investigations.

***Topic 5: Acids and Bases***

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, $K_w$

**C12-5-04:** Perform a laboratory activity to formulate an operational definition of *pH*.

**C12-5-05:** Describe how an acid-base indicator works in terms of colour shifts and Le Châtelier's principle.

**C12-5-06:** Solve problems involving pH.

*(continued)*

### Journal Writing

1. Have students write an operational definition of pH in their journals.
2. Ask students to 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 (Dingrando, et al., *Glencoe Chemistry: Matter and Change, Teacher Wraparound Edition* 612).

### Research Projects

Have students research and report on topics such as the following:

- Acid-containing and acid-free paper
- Acids in cooking
- Biographical sketches of Søren P. Sørensen (who developed the pH scale) or Arnold Orville Beckman (who invented the pH meter)
- Products of a specific pH (e.g., shampoos, antacids)

### Demonstrations

Demonstrations showing colour changes are readily available. For example, a series of four *Chemical Demonstrations* books by Bassam Z. Shakhashiri are available for chemistry teachers who enjoy performing demonstrations for the class. One complete volume of this set is devoted to colour changes in chemistry.

A few procedures for demonstrations are provided below for reference.

- **The pH Rainbow Tube**

  Fill a glass tube with universal indicator solution. Stopper each end. Add two drops of hydrochloric acid (HCl) to one end of the tube and two drops of sodium hydroxide (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.

SKILLS AND ATTITUDES OUTCOMES

**C12-0-U1:** Use appropriate strategies and skills to develop an understanding of chemical concepts.

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

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- **Dry Ice Tube**

  Place dry ice into a 1000 mL graduated cylinder of universal indicator made slightly basic. As the carbon dioxide ($CO_2$) bubbles though the solution, it forms carbonic acid, and the pH gradually changes from basic to acidic.

- **Milk of Magnesia**

  Add 50 mL of milk of magnesia and a few drops of universal indicator to a beaker. Use a magnetic stirrer to mix the solution. Add 50 mL of 0.5 mol/L hydrochloric acid. The colour will change as the basic solution becomes acidified. The colour will change back as the buffering salts in the milk of magnesia raise the pH once again.

- **The Rainbow Connection**

  Secretly place a series of seven combinations of indicators into seven empty glasses. Add a clear acid solution to each of the glasses and have students watch the following colours appear: red, orange, yellow, green, blue, indigo, and violet.

### Simulations/Animations

Have students view online simulations or animations of how an acid-base indicator works in terms of colour shifts.

*Sample Website:*

Chemical Education Research Group, Iowa State University. “Chemistry Experiment Simulations and Conceptual Computer Animations.” *Chemical Education*. <http://group.chem.iastate.edu/Greenbowe/sections/projectfolder/simDownload/index4.html> (22 Nov. 2012).

In the Acid-Base Equilibria section, download and unzip the following simulation:

- pH Measurements of Acids and Bases

  In this simulation, 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.

***Topic 5: Acids and Bases***

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, $K_w$

**C12-5-04:** Perform a laboratory activity to formulate an operational definition of *pH*.

**C12-5-05:** Describe how an acid-base indicator works in terms of colour shifts and Le Châtelier's principle.

**C12-5-06:** Solve problems involving pH.

*(continued)*

## SUGGESTIONS FOR ASSESSMENT

### Paper-and-Pencil Tasks

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 pH range of indicators. Assess students' lab skills and work habits using checklists available in *SYSTH* (6.10, 6.11).

### Laboratory Reports

The lab activity could be assessed using the Laboratory Report Format (see *SYSTH* 14.12). Word processing and spreadsheet software could be used to prepare reports. Also refer to the Lab Report Assessment rubric in Appendix 11.

### Research and Reports/Presentations

1. Have students research plants that grow best in acidic soil and plants that grow best in basic soil. They can investigate how soils can be made more acidic or more basic (Dingrando, et al., *Glencoe Chemistry: Matter and Change, Teacher Wraparound Edition* 609).

2. Have students "research the pH of skin and how various products—particularly basic soaps—can interact with substances that protect the skin" (Dingrando, et al., *Glencoe Chemistry: Matter and Change, Teacher Wraparound Edition* 611).

   Students could present their research findings either individually or in small groups as written reports, oral presentations, or visual displays. Sample presentation rubrics are provided in Appendix 11.

### SKILLS AND ATTITUDES OUTCOMES

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

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

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

## LEARNING RESOURCES LINKS

*A Basic Course in the Theory and Practice of Quantitative Chemical Analysis* (Fischer 265)

*Chemical Demonstrations: A Handbook for Teachers of Chemistry*, Vol. 1 to 4 (Shakhashiri)

*Glencoe Chemistry: Matter and Change, Teacher Wraparound Edition* (Dingrando, et al. 609–612)

### Investigations

*Glencoe Chemistry: Matter and Change* (Dingrando, et al.)
Section 19.3: What Is pH? 608

*Prentice Hall Chemistry* (Wilbraham, et al.)
Quick LAB 19: Indicators from Natural Sources, 604

*Prentice Hall Chemistry: Laboratory Manual, Teacher's Edition* (Wilbraham, Staley, and Matta)
Experiment 40: Estimation of pH, 247–250

*Prentice Hall Chemistry: Small-Scale Laboratory Manual, Teacher's Edition* (Waterman and Thompson)
Experiment 30: Small-Scale Colorimetric pH Meter, 213–215

### Websites

Chemical Education Research Group, Iowa State University. "Chemistry Experiment Simulations and Conceptual Computer Animations." *Chemical Education*. <http://group.chem.iastate.edu/Greenbowe/sections/projectfolder/simDownload/index4.html> (22 Nov. 2012).

Simulation: pH Measurements of Acids and Bases

Clark, Jim. "Acid-Base Indicators." *Chemguide.* 2002, mod. Dec. 2006. <www.chemguide.co.uk/physical/acidbaseeqia/indicators.html> (22 Nov. 2012).

### Appendices

Appendix 5.1: Selected Neutralization Indicators

Appendix 5.2: Acid-Base Indicators and pH: Lab Activity

Appendix 5.3A: Measuring pH: Lab Activity

Appendix 5.3B: Measuring pH: Lab Activity (Teacher Notes)

**Selecting Learning Resources**

For additional information on selecting learning resources for Grade 11 and Grade 12 Chemistry, see the Manitoba Education website at <www.edu.gov.mb.ca/k12/learnres/bibliographies.html>.

**Topic 5: Acids and Bases**

SPECIFIC LEARNING OUTCOMES

C12-5-07: Distinguish between strong and weak acids and bases.
Include: electrolytes and non-electrolytes

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

C12-5-09: Use $K_a$ or $K_b$ to solve problems for pH, percent dissociation, and concentration.

(5 hours)

SLO: C12-5-07
SLO: C12-5-08
SLO: C12-5-09

## SUGGESTIONS FOR INSTRUCTION

### Entry-Level Knowledge

In Topic 1: Reactions in Aqueous Solutions (C12-1-03), students were introduced to acid-base nomenclature and strong acids and bases.

In Topic 4: Chemical Equilibrium (C12-4-03), equilibrium constants were discussed as indicators of whether a reaction went more or less to completion. Students will now use this knowledge to explain the difference between strong and weak acids and bases.

### TEACHER NOTES

### Demonstration

Demonstrate the difference between electrolytes and non-electrolytes using an electrical conductivity tester with distilled water, a salt-water solution, a sugar-water solution, and ordinary tap water.

When the electrodes are placed in the distilled water, the bulb will not light. After a small number of salt crystals dissolve, the bulb will light dimly. As more and more salt crystals dissolve, 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 both tests will result in a glowing filament, but the hydrochloric acid sample will glow brighter than the acetic acid sample—due to its virtual 100% dissociation (strong acid) and the greater number of free ions formed.

**General Learning Outcome Connections**

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOME

**C12-0-U1:** Use appropriate strategies and skills to develop an understanding of chemical concepts.

*Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .*

## Strengths of Acids and Bases

In Grade 11 Chemistry, students learned to understand 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 acids and bases. Clearly, a dilute solution of a strong acid is possible (e.g., 0.0010 mol/L of sulphuric acid), as is a concentrated solution of a weak acid (e.g., 17.4 mol/L acetic acid).

Acids and bases differ greatly in their strength, as discussed below.

- **Strong Acids**

  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 towards products with very little, if any, of the reactant HA left.

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

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

  $$K_{eq} = \frac{[H_3O^+][A^-]}{[HA]}$$ At equilibrium, $K_{eq}$ is very large: $K_{eq} > 1$.

  For a strong acid, such as hydrochloric acid (HCl), 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

  - perchloric acid ($HClO_4$)
  - hydroiodic acid (HI)
  - hydrobromic acid (HBr)
  - sulphuric acid ($H_2SO_4$)

**Topic 5: Acids and Bases**

SPECIFIC LEARNING OUTCOMES

C12-5-07: Distinguish between strong and weak acids and bases.
Include: electrolytes and non-electrolytes

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

C12-5-09: Use $K_a$ or $K_b$ to solve problems for pH, percent dissociation, and concentration.

*(continued)*

- **Strong Bases**

  A strong base also completely dissociates into ions.

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

**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**

  A weak acid dissociates only slightly into ions.

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

  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 hydrocyanic acid (HCN),

  $HCN_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + CN^-_{(aq)}$

  $K_{eq} = 6.2 \times 10^{-10}$

SKILLS AND ATTITUDES OUTCOME

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

---

The equilibrium expression can be simplified, since the concentration of water is very large compared to the concentration of the acid. As a result, the equilibrium expression can be written as

> **Note:**
> The value of $K_a$ or $K_b$ in the case of a base provides a measure of the relative strength of an acid or a base.

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

$$K_a = \frac{[H_3O^+][A^-]}{HA}$$ where $K_a$ is called the acid dissociation constant.

Other examples of weak acids are

- citric acid ($H_3C_6H_5O_7$)
- acetic acid (ethanoic acid) ($CH_3COOH$; $HC_2H_3O_2$)
- boric acid ($H_3BO_3$)
- phosphoric acid ($H_3PO_4$)

- **Weak Bases**

A weak base dissociates only slightly into ions.

An important weak base is ammonia.

$$NH_{3(aq)} + H_2O_{(l)} \rightleftharpoons NH^+{}_{4(aq)} + OH^-{}_{(aq)}$$ A reversible arrow is used.

The equilibrium expression can be written as

$$K_{eq} = \frac{[NH^+{}_4][OH^-]}{[NH_3]}$$

The equilibrium expression can be simplified, since the concentration of water is very large compared to the concentration of the base. As a result, the equilibrium expression can be written as

$$K_b = \frac{[NH^+{}_4][OH^-]}{[NH_3]} = 1.8 \times 10^{-5}$$

Other examples of weak bases are

- aniline base ($C_6H_5NH_2$)
- methylamine base ($CH_3NH_2$)
- pyridine base ($C_5H_5N$)

**Topic 5: Acids and Bases**

SPECIFIC LEARNING OUTCOMES

**C12-5-07:** Distinguish between strong and weak acids and bases.
Include: electrolytes and non-electrolytes

**C12-5-08:** Write the equilibrium expression ($K_a$ or $K_b$) from a balanced chemical equation.

**C12-5-09:** Use $K_a$ or $K_b$ to solve problems for pH, percent dissociation, and concentration.

*(continued)*

**Review**

Appendix 5.4: Relative Strengths of Acids provides a $K_a$ chart for acids. The larger the $K_a$ is, the stronger the acid is and the greater the tendency to release $H^+$ ($H_3O^+$) ions into solution. If we follow this argument, the species on the right 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 toward 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 summarize:

*Acids*

Stronger acid ⇒ higher % dissociation ⇒ higher $[H_3O^+]$ ⇒ larger $K_a$

Conversely,

Smaller $K_a$ ⇒ lower $[H_3O^+]$ ⇒ lower % dissociation ⇒ weaker acid

*Bases*

Stronger base ⇒ higher % dissociation ⇒ higher $[OH^-]$ ⇒ larger $K_b$

Conversely,

Smaller $K_b$ ⇒ lower $[OH^-]$ ⇒ lower % dissociation ⇒ weaker base

**Demonstration**

Add equal amounts and concentrations of hydrochloric acid (HCl) and acetic acid ($CH_3COOH$) to magnesium metal. While HCl will react vigorously, $CH_3COOH$ will not. This is because of the number of hydronium ions produced by each acid. (This demonstration can also be used to reinforce the concepts of reaction rates and concentrations of reactants.)

SKILLS AND ATTITUDES OUTCOME

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

### Animations

Have students view online animations of strong and weak acids and bases.

*Sample Website:*

Chang, Raymond. "Essential Study Partner." *Chemistry*. 7th ed. *McGraw Hill Online Learning Centre*. <http://highered.mcgraw-hill.com/sites/0073656011/student_view0/chapter15/essential_study_partner.html#> (21 Mar. 2012).

This website provides a variety of animations related to acids and bases:

- *Acid Strength* shows the difference in ionization between a strong acid solution and a weak acid solution.
- *Base Strength* shows the difference in ionization between a strong base solution and a weak base solution.

## SUGGESTIONS FOR ASSESSMENT

### Types of Problems

When having students solve problems using $K_a$ or $K_b$, ask the questions in a variety of ways, including the following variables: initial concentration, $[H_3O^+]$, $[OH^-]$, percent dissociation, pH, pOH, $K_a$, and $K_b$.

Avoid presenting too many different types of questions before students have understood and mastered the basic questions (e.g., assign questions with reverse calculations only after students understand the forward calculations). Add pH and pOH later.

There are basically two types of questions for a weak acid and/or a weak base, as described below.

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

   *Example:*

   Using a 0.75 mol/L solution of a weak base ammonia ($NH_3$) and $[OH^-]$ = $1.0 \times 10^{-4}$ mol/L, find $K_b$.

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

   Write the equilibrium expression.

   $$K_b = \frac{[NH^+_4][OH^-]}{[NH_3]}$$

**Topic 5: Acids and Bases**

SPECIFIC LEARNING OUTCOMES

**C12-5-07:** Distinguish between strong and weak acids and bases.
Include: electrolytes and non-electrolytes

**C12-5-08:** Write the equilibrium expression ($K_a$ or $K_b$) from a balanced chemical equation.

**C12-5-09:** Use $K_a$ or $K_b$ to solve problems for pH, percent dissociation, and concentration.

*(continued)*

Substitute the given values.

$$K_b = \frac{\left[1.0 \times 10^{-4}\right]\left[1.0 \times 10^{-4}\right]}{[0.75]}$$

$$\left[NH^+{}_4\right] = \left[OH^-\right] = 1.0 \times 10^{-4} \text{ mol/L, since the stoichiometry is } 1:1$$

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

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

*Example:*

Using 0.75 mol/L solution of a weak acid hydrogen peroxide ($H_2O_2$), find $[H_3O^+]$ and the percent dissociation.

The $K_a$ is taken from a $K_a$ table (see Appendix 5.4: Relative Strengths of Acids).

$$H_2O_{2(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+{}_{(aq)} + HO_2{}^-{}_{(aq)}$$

The equilibrium expression is

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

Let $x$ = amount that dissociates.

Therefore, at equilibrium,

$[H_2O_2] = 0.75 - x$

$[H_3O^+] = 0 + x$

$[HO_2{}^-] = 0 + x$

**Note:**
In Topic 4: Chemical Equilibrium, students were introduced to the ICE table and the BIR/PEC methods of accounting.

SKILLS AND ATTITUDES OUTCOME

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

Substitute the equilibrium concentration values into the $K_a$ expression and solve for $x$.

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

When solving this problem according to mathematical procedures, the quadratic formula would be used.

**Note:**
Avoid using 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 formula.

- If $x$ is much less than the initial concentration of the weak acid or the weak base, $x$ can be neglected when compared to 0.75, and so on. Hence, (0.75 mol/L – $x$) becomes 0.75 to two 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

$$x = 1.3 \times 10^{-6}$$

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

***Topic 5: Acids and Bases***

SPECIFIC LEARNING OUTCOMES

**C12-5-07:** Distinguish between strong and weak acids and bases.
Include: electrolytes and non-electrolytes

**C12-5-08:** Write the equilibrium expression ($K_a$ or $K_b$) from a balanced chemical equation.

**C12-5-09:** Use $K_a$ or $K_b$ to solve problems for pH, percent dissociation, and concentration.

*(continued)*

Hence,

$$x = [H_3O^+] = [HO_2^-] = 1.3 \times 10^{-6} \text{ mol/L}$$

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

$$= \frac{1.3 \times 10^{-6}}{0.75} \times 100$$

$$= 1.7 \times 10^{-4}\% \text{ or } 0.00017\%$$

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

### $K_a$ and $K_b$ Constants and Le Châtelier's Principle

There is another type of question that can be asked that involves $K_a$ and $K_b$ constants and Le Châtelier's principle. Some examples are provided below.

For each of the sample problems, have students do the following:

- Complete the acid-base reaction with the help of tables.
- Specify the two acids and bases involved.
- Specify the stronger and weaker of the acids.
- Indicate whether reactants or products are favoured at equilibrium.

*Sample Problems:*

a) $H_3PO_4 + CH_3COO^- \rightleftharpoons$

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

| | | | |
|---|---|---|---|
| Acid$_1$ | Base$_1$ | CB | CA |
| $K_a = 7.5 \times 10^{-3}$ | | $K_a = 1.8 \times 10^{-5}$ | |
| Stronger acid | | Weaker acid | |

Products favoured $\longrightarrow$

SKILLS AND ATTITUDES OUTCOME

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

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

$SO_3^{2-} + NH_4^+ \rightleftharpoons HSO_3^{1-} + NH_3$

| | | | |
|---|---|---|---|
| $\text{Base}_1$ | $\text{Acid}_1$ | CA | CB |
| $K_a = 5.7 \times 10^{-10}$ | | $K_a = 6.2 \times 10^{-8}$ | |
| Weaker acid | | Stronger acid | |

$\longleftarrow$ Reactants favoured

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

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

| | | | |
|---|---|---|---|
| $\text{Acid}_1$ | $\text{Base}_1$ | CB | CA |
| $K_a = 4.4 \times 10^{-14}$ | | $K_a = 1.2 \times 10^{-15}$ | |
| Stronger acid | | Weaker acid | |

Products favoured $\longrightarrow$

*Challenge Questions:*

One mL of 0.10 mol/L HCl is added to each of five test tubes containing 10 mL of 1.0 mol/L solutions of the five ions listed below.

In each case,

- write the acid-base reaction according to Brønsted
- identify the acids and bases on both sides of the reaction
- specify in which case the hydronium ion concentration is lowered the most by the reaction with HCl

a) $CO_3^{2-}$

b) $HCO_3^-$

c) $HPO_4^{2-}$

d) $CH_3COO^-$

e) $HSO_3^-$

**Topic 5: Acids and Bases**

SPECIFIC LEARNING OUTCOMES

**C12-5-07:** Distinguish between strong and weak acids and bases.
Include: electrolytes and non-electrolytes

**C12-5-08:** Write the equilibrium expression ($K_a$ or $K_b$) from a balanced chemical equation.

**C12-5-09:** Use $K_a$ or $K_b$ to solve problems for pH, percent dissociation, and concentration.

*(continued)*

*Solutions:*

B A CA CB

a) $CO_3^{2-} + HCl \rightleftharpoons HCO_3^{1-} + Cl^{1-}$

$K_a$ very large $K_a = 4.7 \times 10^{-11}$

b) $HCO_3^{1-} + HCl \rightleftharpoons H_2CO_3 + Cl^{1-}$

$K_a$ very large $K_a = 4.4 \times 10^{-7}$

c) $HPO_4^{2-} + HCl \rightleftharpoons H_2PO_4^{1-} + Cl^{1-}$

$K_a$ very large $K_a = 6.3 \times 10^{-8}$

d) $CH_3COO^{1-} + HCl \rightleftharpoons CH_3COOH + Cl^{1-}$

$K_a$ very large $K_a = 1.8 \times 10^{-5}$

e) $HSO_3^{1-} + HCl \rightleftharpoons H_2SO_3 + Cl^{1-}$

$K_a$ very large $K_a = 6.2 \times 10^{-8}$

As the $K_a$ for HCl is constant in each reaction, we are comparing the $K_a$ values for the conjugate acids.

Since the $K_a$ for $CH_3COOH$ is the largest compared to the others, that reaction will go the least to the right. The $K_a$ for $HCO_3^{1-}$ is the smallest, having the least effect on the $K_a$ for HCl, and, therefore, that reaction will go the furthest to the right, thus causing the hydronium concentration to be lowered the most.

### Paper-and-Pencil Tasks

1. Students should be able to write the equilibrium expression ($K_a$ or $K_b$) from a balanced chemical equation.

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

SKILLS AND ATTITUDES OUTCOME

**C12-0-U1:** Use appropriate strategies and skills to develop an understanding of chemical concepts.

*Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .*

### Compare and Contrast

Ask students to complete a Compare and Contrast frame for weak and strong acids and for weak and strong bases (see *SYSTH* 10.24).

## LEARNING RESOURCES LINKS

*Glencoe Chemistry: Matter and Change* (Dingrando, et al.)
Chapter 19: Acids and Bases

*Prentice Hall Chemistry* (Wilbraham, et al.)
Chapter 19: Acids and Bases

### Appendix

Appendix 5.4: Relative Strengths of Acids

**Selecting Learning Resources**

For additional information on selecting learning resources for Grade 11 and Grade 12 Chemistry, see the Manitoba Education website at <www.edu.gov.mb.ca/k12/learnres/bibliographies.html>.

**Topic 5: Acids and Bases**

Specific Learning Outcome

C12-5-10: Perform a laboratory activity to determine the concentration of an unknown acid or base, using a standardized acid or base.

(3 hours)

SLO: C12-5-10

## Suggestions for Instruction

### Entry-Level Knowledge

In Grade 10 Science (S2-2-02), students explained how acids and bases interact to form a salt and water in the process of neutralization.

In Topic 1: Reactions in Aqueous Solutions (C12-1-04), students performed a lab activity to demonstrate the stoichiometry of a neutralization reaction between a strong base and a strong acid.

### Assessing Prior Knowledge

The lab experiment that students will perform for this learning outcome requires a complete understanding of the process and theory of neutralization from Topic 1: Reactions in Aqueous Solutions. To reduce the possibility of poor quantitative results, do a thorough review of neutralization before assigning the lab experiment.

Check for understanding of students' prior knowledge, and review concepts 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).

**General Learning Outcome Connections**

GLO B3: Identify the factors that affect health, and explain the relationships among personal habits, lifestyle choices, and human health, both individual and social.

GLO B5: Identify and demonstrate actions that promote a sustainable environment, society, and economy, both locally and globally.

GLO C1: Recognize safety symbols and practices related to scientific and technological activities and to their daily lives, and apply this knowledge in appropriate situations.

GLO C2: Demonstrate appropriate scientific inquiry skills when seeking answers to questions.

GLO C5: Demonstrate curiosity, skepticism, creativity, open-mindedness, accuracy, precision, honesty, and persistence, and appreciate their importance as scientific and technological habits of mind.

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), and emergency equipment

**C12-0-S5:** Collect, record, organize, and display data using an appropriate format.

*Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware . . .*

**C12-0-S6:** Estimate and measure accurately using Système International (SI) and other standard units.

Include: SI conversions and significant figures

## TEACHER NOTES

### Acid-Base Titration Lab Activities

Burettes found in schools will differ greatly in quality. Many schools still have burettes with a length of rubber hose, a glass tip, part of an eyedropper, and a pinch clamp to regulate the stream of liquid. The number and size of drops are not easy to control with these burettes, and so their accuracy and reliability could be less than those of Teflon spigots and a 120-second tip.

In Topic 1: Reactions in Aqueous Solutions, 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 burette before and must first be introduced to the care and correct use of this delicate piece of equipment.

The lab activity provided in Appendix 5.5: Quantitative Analysis: Acid-Base Titration: Lab Activity assumes that enough burettes are available for each student in the class to have one for the acid and another for the base. If this is not possible, two students could share a common burette for the standard solution, but each should have his or her own unknown solution in a separate burette.

If students are asked to do Part B of the lab activity, which involves the titration of a solid acid, they will need an accurate quantitative method of dissolving the sample of acid provided. This is best done with a volumetric flask, as is indicated in Appendix 5.5. Note that having an electronic balance that reads to 0.001 g would help increase the accuracy of the results.

If students do both parts of the lab activity, review the procedure after students have first read the lab instructions as an assignment (prior knowledge). Then initiate a discussion of lab skills and experimental errors. At this time, explain what accuracy and reliability are with respect to this experiment.

If teachers wish to expose students to various types of titration curves (e.g., strong acid–weak base, weak acid–strong base, weak acid–weak base), refer to Appendix 5.9: Samples of Various Titration Curves (Teacher Notes).

**Topic 5: Acids and Bases**

SPECIFIC LEARNING OUTCOME

C12-5-10: Perform a laboratory activity to determine the concentration of an unknown acid or base, using a standardized acid or base.

*(continued)*

**Laboratory Activities**

Have students complete the lab activity outlined in Appendix 5.5: Quantitative Analysis: Acid-Base Titration: Lab Activity.

Depending on the time available, teachers may wish to use alternative or additional lab activities that involve the titration process, such as the following:

- Appendix 5.6: Analysis of Household Vinegar: Lab Activity
- Appendix 5.7: Analysis of Aspirin: Lab Activity
- Appendix 5.8: Potentiometric Analysis of Acid in Soft Drinks: Cola versus Non-cola: Lab Activity
- Titration of Sodium Hypochlorite in Bleach with Sodium Thiosulfate (Waterman and Thompson 113)
- *Chemistry with Vernier* (Holmquist, Randall, and Volz) suggests two additional experiments:
  - Experiment 31: Time-Released Vitamin C Tablets
  - Experiment 35: Determining the Phosphoric Acid Content in Soft Drinks

See Learning Resources Links for references.

## SUGGESTIONS FOR ASSESSMENT

**Paper-and-Pencil Tasks**

Ask students to do the following:

1. Compare and contrast or define the following terms: *titrate*, *titrant*, *end point*, *equivalence point*, *indicator*, *aliquot*, *standard solution*, and *dilute*. Students could use a Word Cycle, Compare and Contrast frames, or other vocabulary strategies to demonstrate their understanding of the terms (see *SYSTH* 10.21, 10.24).
2. Explain why adding more solvent water to the sample being titrated has no effect on the end point.
3. Discuss the lab results, including a discussion of experimental errors.

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), and emergency equipment

**C12-0-S5:** Collect, record, organize, and display data using an appropriate format.

*Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware . . .*

**C12-0-S6:** Estimate and measure accurately using Système International (SI) and other standard units.

Include: SI conversions and significant figures

## Laboratory Skills

Students should be able to titrate a strong acid with a strong base.

Lab skills might include

- massing of a solid acid
- quantitative transfer of solids
- use of a volumetric flask
- reading a burette to ± 0.01
- performing the process of titration

To assess students' lab skills and work habits, refer to checklists in *SYSTH* (6.10, 6.11).

## Research Skills

Teachers may wish to have students search (e.g., on the Internet) for examples of various research and industrial applications of the titration process, such as the following:

- testing of acid rain
- pH soil testing
- efficacy of antacid tablets or acetylsalicylic acid (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
- determination of the surface area of marine algae used by marine biologists to determine the condition of marine coral reefs
- testing the phosphoric acid content in soft drinks

Specific Learning Outcome

C12-5-10: Perform a laboratory activity to determine the concentration of an unknown acid or base, using a standardized acid or base.

*(continued)*

*Sample Websites:*

Sea and Sky. "Reefkeeper's FAQ." *Aquarium Resources.* <www.seasky.org/aquarium/aquarium_faq_page01.html> (21 Mar. 2012)

This website provides information on how marine scientists monitor the environment of coral reefs.

SparkNotes Editors. "SparkNote on Titrations." *SparkNotes.com.* SparkNotes LLC. <www.sparknotes.com/chemistry/acidsbases/titrations/section1.html> (21 Mar. 2012).

This website provides definitions and explanations of titration and the related terms.

## Learning Resources Links

*Chemistry* (Chang 656)

*Chemistry: The Molecular Nature of Matter and Change* (Silberberg 796)

*Glencoe Chemistry: Matter and Change* (Dingrando, et al.)
Salt Hydrolysis, 621

*Prentice Hall Chemistry* (Wilbraham, et al.)
Salt in Solution, 618

**Investigations**

*Chemistry with Vernier* (Holmquist, Randall, and Volz)
Experiment 31: Time-Released Vitamin C Tablets
Experiment 35: Determining the Phosphoric Acid Content in Soft Drinks

*Glencoe Chemistry: Matter and Change* (Dingrando, et al)
ChemLab 19: Standardizing a Base Solution by Titration, 626
Antacids, 628

*Prentice Hall Chemistry: Small-Scale Chemistry Laboratory Manual* (Waterman and Thompson)
Part 2: Titration of Sodium Hypochlorite in Bleach with Sodium Thiosulfate, 113

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), and emergency equipment

**C12-0-S5:** Collect, record, organize, and display data using an appropriate format.

*Examples: labelled diagrams, graphs, multimedia applications, software integration, probeware . . .*

**C12-0-S6:** Estimate and measure accurately using Système International (SI) and other standard units.

Include: SI conversions and significant figures

## Websites

Sea and Sky. "Reefkeeper's FAQ." *Aquarium Resources.* <www.seasky.org/aquarium/aquarium_faq_page01.html> (21 Mar. 2012).

SparkNotes Editors. "SparkNote on Titrations." *SparkNotes.com.* SparkNotes LLC. <www.sparknotes.com/chemistry/acidsbases/titrations/section1.html> (21 Mar. 2012).

## Appendices

Appendix 5.5: Quantitative Analysis: Acid-Base Titration: Lab Activity

Appendix 5.6: Analysis of Household Vinegar: Lab Activity

Appendix 5.7: Analysis of Aspirin: Lab Activity

Appendix 5.8: Potentiometric Analysis of Acid in Soft Drinks: Cola versus Non-cola: Lab Activity

Appendix 5.9: Samples of Various Titration Curves (Teacher Notes)

**Selecting Learning Resources**

For additional information on selecting learning resources for Grade 11 and Grade 12 Chemistry, see the Manitoba Education website at <www.edu.gov.mb.ca/k12/learnres/bibliographies.html>.

**Topic 5: Acids and Bases**

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)

SLO: C12-5-11

## SUGGESTIONS FOR INSTRUCTION

### Entry-Level Knowledge

In previous grades, students have 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 addressing learning outcome C12-5-11, 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 should 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.

### Hydrolysis of Salts

The following table (intended for teachers) provides a summary of the species involved with hydrolysis of salts (see Chang 678).

| Hydrolysis of Salts | | | |
|---|---|---|---|
| **Type of Salt** | **Examples** | **Ions That Undergo Hydrolysis** | **pH** |
| Cation from strong base<br>Anion from strong acid | $NaCl$, $KI$, $KNO_3$, $RbBr$, $BaCl_2$ | None | $\approx 7$ |
| Cation from strong base<br>Anion from weak acid | $NaC_2H_3O_2$, $KNO_2$ | Anion | $> 7$ |
| Cation from weak base<br>Anion from strong acid | $NH_4Cl$, $NH_4NO_3$ | Cation | $< 7$ |
| Cation from weak base<br>Anion from weak acid | $NH_4NO_2$, $NH_4C_2H_3O_2$, $NH_4CN$ | Anion and cation | $< 7$ if $K_b < K_a$<br>$\approx 7$ if $K_b \approx K_a$<br>$> 7$ if $K_b > K_a$ |

**General Learning Outcome Connections**

GLO D3: Understand the properties and structures of matter, as well as various common manifestations and applications of the actions and interactions of matter.

SKILLS AND ATTITUDES OUTCOME

**C12-0-U1:** Use appropriate strategies and skills to develop an understanding of chemical concepts.

*Examples: analogies, concept frames, concept maps, manipulatives, particulate representations, role-plays, simulations, sort-and-predict frames, word cycles . . .*

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This information can be simplified further:

- A strong acid and a strong base produce a neutral solution.
- A strong base plus a weak acid produce a slightly basic salt.
- A strong acid plus a weak base produce a slightly acidic salt.

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.

- **Cation from a strong base plus the anion from a strong acid $\longrightarrow$ pH $\approx$ 7**

  No example is necessary, as there is no hydrolysis.

- **Cation from a strong base plus the anion from a weak acid $\longrightarrow$ pH > 7**

  *Example 1:*

  $NaC_2H_3O_2$ Basic solution pH > 7

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

  $$NaC_2H_3O_{2(s)} \xrightarrow{H_2O} Na^+_{(aq)} + C_2H_3O_2{}^-{}_{(aq)}$$

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

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

  $$C_2H_3O_2{}^-{}_{(aq)}) + H_2O_{(l)} \longrightarrow HC_2H_3O_{2(aq)} + OH^-{}_{(aq)}$$

**Topic 5: Acids and Bases**

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.

*(continued)*

*Example 2:*

$K_2CO_3$ 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.

$$K_2CO_{3(s)} \xrightarrow{H_2O} 2K^+_{(aq)} + CO_3^{2-}{}_{(aq)}$$

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

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

$$CO_3^{-2}{}_{(aq)} + H_2O_{(l)} \longrightarrow H_2CO_{3(aq)} + OH^-_{(aq)}$$

- **Cation from a weak base plus the anion from a strong acid ⟶ pH < 7**

*Example 3:*

$NH_4NO_3$ Acidic solution pH < 7

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 ($HNO_3$), resulting in an acidic solution.

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

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

$$H_2O_{(l)} \xrightarrow{H_2O} H_3O^+{}_{4(aq)} + \cancel{OH^-_{(aq)}}$$

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

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

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

SKILLS AND ATTITUDES OUTCOME

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

### Laboratory Activity

Students could complete a simple lab activity on the hydrolysis of a number of salts to complement class discussion (see Wilbraham, Staley, and Matta, *Prentice Hall Chemistry: Laboratory Manual* 267.)

## SUGGESTIONS FOR ASSESSMENT

### Paper-and-Pencil Task

Students should be able to determine whether 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

Using a Compare and Contrast frame, students should be able to explain why sodium hydrogen carbonate is an effective antacid but sodium hydroxide is not (see Dingrando, et al. 628). For a Compare and Contrast frame, see *SYSTH* 10.24.

## LEARNING RESOURCES LINKS

*Chemistry*, 9th ed. (Chang 678)

*Chemistry: The Molecular Nature of Matter and Change* (Silberberg 796)

*Glencoe Chemistry: Matter and Change* (Dingrando, et al. 621, 628)

*Prentice Hall Chemistry* (Wilbraham, et al. 618)

**Investigation**

*Prentice Hall Chemistry: Laboratory Manual* (Wilbraham, Staley, and Matta)
Experiment 44: Salt Hydrolysis, 267

**Selecting Learning Resources**

For additional information on selecting learning resources for Grade 11 and Grade 12 Chemistry, see the Manitoba Education website at <www.edu.gov.mb.ca/k12/learnres/bibliographies.html>.