Unit 2
ACIDS AND BASES
Specific Curriculum Outcomes
Suggested Time: 35 Hours

Acids and Bases

Introduction

Acids and bases have an effect on aqueous systems. Many acid-base systems involve proton transfer and are described quantitatively. Students will be encouraged to value the role of precise observation and careful experimentation while looking at safe handling, storage, and disposal of chemicals. There are several ways of defining acids and bases.

Focus and Context

Problem-solving and decision making are used throughout this unit. Student laboratory skills will be developed. Teachers could provide examples of products and processes that use knowledge of acids and bases. Emphasis through WHMIS could also be placed on handling these chemicals. There are many opportunities to discuss the relationships among science, technology, society, and the environment in this acid-base chemistry unit.

Science Curriculum Links

In Science 1206, students would have studied writing formulae and balancing equations and have been introduced to acid-base concepts. Students would have studied moles and stoichiometric calculations in Chemistry 2202. The nature of solutions and expressing solution concentration would have been addressed in Chemistry 2202 before this acid and base unit.

Curriculum Outcomes

STSE

Students will be expected to

Nature of Science and Technology

114-2 explain the roles of evidence, theories, and paradigms in the development of scientific knowledge

114-9 explain the importance of communicating the results of a scientific or technological endeavour, using appropriate language and conventions

115-7 explain how scientific knowledge evolves as new evidence comes to light and as laws and theories are tested and subsequently restricted, revised, or replaced

Relationships Between Science and Technology

116-2 analyse and describe examples where scientific understanding was enhanced or revised as a result of the invention of a technology

Social and Environmental Contexts of Science and Technology

117-2 analyse society's influence on scientific and technological endeavours

117-7 identify and describe science- and technology-based careers related to the science they are studying

118-6 construct arguments to support a decision or judgment, using examples and evidence and recognizing various perspectives

Skills

Students will be expected to

Initiating and Planning

212-3 design an experiment identifying and controlling major variables

212-8 evaluate and select appropriate instruments for collecting evidence and appropriate processes for problem solving, inquiring, and decision making

Performing and Recording

213-3 use instruments effectively and accurately for collecting data

213-9 demonstrate a knowledge of WHMIS standards by selecting and applying proper techniques for handling and disposing of lab materials

Analysing and Interpreting

214-1 describe and apply classification systems and nomenclature used in the sciences

214-3 compile and display evidence and information, by hand or computer, in a variety of formats, including diagrams, flow charts, tables, graphs, and scatter plots

214-4 identify a line of best fit on a scatter plot and interpolate or extrapolate based on the line of best fit

214-5 interpret patterns and trends in data, and infer or calculate linear and nonlinear relationships among variables

214-17 identify new questions or problems that arise from what was learned

Communication and Teamwork

215-2 select and use appropriate numeric, symbolic, graphical, and linguistic modes of representation to communicate ideas, plans, and results

Knowledge

Students will be expected to

320-1 describe various acid-base definitions up to the Brønsted-Lowry definition

320-2 predict products of acid-base reactions

320-3 compare strong and weak acids and bases using the concept of equilibrium

320-4 calculate the pH of an acid or a base given its concentration, and vice versa

320-6 determine the concentration of an acid or base solution using stoichiometry

320-7 explain how acid-base indicators function

ACC-5 state general examples of how our lives are affected by acid-base chemistry

ACC-6 define a buffer according to both its components and its function

ACC-7 recognize that blood is a buffer and that without this natural buffering, homeostasis would not be maintained

Properties and Definitions of Acids and Bases

Outcomes

Students will be expected to

- explain how acid-base theory evolved as new evidence and laws and theories are tested and revised, or replaced (115-7)
- describe and apply classification systems and nomenclature used in acids and bases (214-1)
  - define acids and bases operationally in terms of their effect on pH, taste, reactions with metals, reactions with each other, solution conductivity, and effect on indicators
  - identify that an operational definition can only classify a substance as acidic or basic, but is not useful in determining chemical formulas
- explain the roles of evidence, theories, and paradigms in acid-base theories (114-2)
  - trace the development of acid-base theories from the original operational definition to Arrhenius theory, to the modern revised Arrhenius concept up to the Brønsted-Lowry theory

Elaborations—Strategies for Learning and Teaching

From various activities, students should define acids and bases operationally in terms of their effect on pH, taste, reactions with metals, neutralization reactions with each other, conductivity, and indicators.

Teachers could begin by having students write a list of all the things they know about acids and bases. Students could contribute these to a class list by suggesting things they might want to know about acids. Students could conduct a lab using various household substances that can be tested in the classroom, to try to classify various chemicals into groups based on their properties the following tests could be used: conductivity, litmus paper, pH paper, Mg ribbon, and $CaCO_3$ chips. After summarizing the results in a table, students could identify each solution as acidic, basic, neutral ionic, or neutral molecular.

Students could examine the labels on various packaged food to determine which chemicals are present. They could then look up the formulae and/or do tests to determine which are acidic, basic, or neutral. To do this, the students could use the Handbook for Physics and Chemistry, The Merck Index, or Internet sites.

Students should explain how some substances helped revise Arrhenius' theoretical definition of acids. For example, Arrhenius theory can not explain why NH_3 is a base, or CO_2 and SO_2 are acids. This outcome will be the underlying theme as the various theoretical definitions of acids are studied.

The development of the acid-base theories up to Brønsted-Lowry could be traced to show how knowledge and thinking changed to explain new observations.

Properties and Definitions of Acids and Bases

Tasks for Instruction and/or Assessment

Performance

- Using appropriate tests, students could classify the following as an acid, a base, or neutral (neither acidic nor basic):
  - sodium carbonate
  - hydrochloric acid
  - sulfuric acid
  - potassium hydroxide
  - calcium hydroxide
  - ammonia
  - sugar (214-1, 320-1)

Paper and Pencil

- Students could account for the brightness of the bulb when doing conductivity tests. (214-1, 320-1)
- Students could be asked what must be present in order for a solution to conduct electricity. (214-1, 320-1)

Presentation

- Using a concept map, students could organize the Arrhenius and Brønsted-Lowry acid and base definitions. (114-2, 115-7)
- Students could prepare a short, oral presentation from the list of all the things they know about acids and bases generated in class. This is an exploratory exercise. Expectations are that they question, analyze, describe, and/or evaluate the structure using the scientific principles with which they are familiar. (214-1)

Journal

- Students could compare the conductivity of solutions to that of metals. (214-1, 320-1)

Resources/Notes

www.gov.nl.ca/edu/science_ref/main.htm

MGH Chemistry, pp. 548-549

MGH Chemistry, pp. 548-554

Properties and Definitions of Acids and Bases *(continued)*

Outcomes

Students will be expected to

- describe various acid-base definitions up to the Brønsted-Lowry definition, including the limitations of these definitions (320-1)
  - define and identify Arrhenius, modern Arrhenius and Brønsted-Lowry acids and bases.
  - write representative chemical equations for species acting as an acid or a base

Elaborations—Strategies for Learning and Teaching

Students should define, identify, and write ionization equations for the behaviour of Arrhenius, modern Arrhenius and Brønsted-Lowry acids as shown by:

Arrhenius: $HBr_{(aq)} \rightarrow H^+_{(aq)} + Br^-_{(aq)}$

Modern Arrhenius: $HCl_{(aq)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$

Brønsted-Lowry: $HNO_{3(aq)} + HCO^-_{3(aq)} \rightarrow H_2CO_{3(aq)} + NO^-_{3\,(aq)}$

Students should define, identify and write equations for the behaviour of Arrhenius, modern Arrhenius and Brønsted-Lowry bases as shown by:

Arrhenius

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

Modern Arrhenius

$NH_{3(l)} + H_2O_{(l)} \rightarrow NH_4OH_{(aq)} \rightarrow NH^+_{4\,(aq)} + OH^-_{(aq)}$

Brønsted-Lowry

$HPO^{2-}_{4\,(l)} + CH_3COOH_{(aq)} \rightarrow CHCOO^-_{(aq)} + H_2PO^-_{4\,(aq)}$

Note: The modern Arrhenius theory would not be used for an ionic hydroxide base such as sodium hydroxide, since the result would give the same equation as the Arrhenius theory.

Ionization of weak bases using equations (such as NH_3) should be included in discussion.

Students should interpret equations in Brønsted-Lowry terms and identify the acid and base species. Examples should include:

$HCl_{(aq)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$

$H_2SO_{4(l)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + HSO^-_{4\,(aq)}$

Students could compare the Arrhenius and Brønsted-Lowry definitions by using a chart to help with their organization of the information.

Properties and Definitions of Acids and Bases *(continued)*

Tasks for Instruction and/or Assessment

Paper and Pencil

- Students could write an equation for the dissociation of ionic compounds such as, $Mg(OH)_{2(s)}$. (320-1)
- Students could write an equation for the ionization of compounds such as, $HClO_{3(aq)}$. (320-1)

Paper and Pencil

- Students could identify which reactant is the Brønsted-Lowry acid and which is the Brønsted-Lowry base. (320-1)

$$HSO_4^-{}_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+{}_{(aq)} + SO_4^{2-}{}_{(aq)}$$
$$HCN_{(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+{}_{(aq)} + CN^-{}_{(aq)}$$

Resources/Notes

MGH Chemistry, pp. 549-554

Properties and Definitions of Acids and Bases *(continued)*

Outcomes

Students will be expected to

- describe various acid-base definitions up to the Brønsted-Lowry definition, including the limitations of these definitions (320-1) (**Cont'd**)
  - – identify the limitations of the operational, Arrhenius and modern Arrhenius definitions of acids and bases
- identify new questions or problems that arise from what was learned (214-17)
  - – identify the Brønsted-Lowry acid, base, conjugate acid and conjugate base in a Brønsted Lowry acid-base equation
  - – define and identify amphoteric substances as examples of species that can either accept or donate a proton
  - – illustrate the amphoteric nature of water by writing chemical equations where water acts as an acid, when combined with a stronger base, and where water acts as a base, when combined with a stronger acid

Elaborations—Strategies for Learning and Teaching

Students could summarize the differences between the theoretical definitions using a table or chart (on page 558 of the textbook). It is important that students understand why several theories of acids and bases developed and why scientists might not use the "latest" theory to explain phenomena.

Teachers should recognize that some equations fall within the realm of both the modern Arrhenius and Brønsted-Lowry definitions. For example, the reaction of NH_3 in water (as shown in the modified Arrhenius example previously) may be interpreted as a Brønsted-Lowry equation given that the NH_3 accepts a proton from H_2O. The significance of the modified Arrhenius theory is the introduction of the hydronium ion, H_3O^+, for acids and the ability to explain non-hydroxide bases by means of a reaction of the basic species with water to produce OH^-. The utility of the Brønsted-Lowry definition is that water is not required in the definition of an acid or base.

Students should be able to identify conjugate acid-base pairs, as in:

$$HPO_4^{2-}{}_{(aq)} + HCO_3^-{}_{(aq)} \rightleftharpoons H_2PO_4^-{}_{(aq)} + CO_3^{2-}{}_{(aq)}$$

Base Acid Acid Base

In the above equation: $HPO_4^{2-}{}_{(aq)}$ and $H_2PO_4^-{}_{(aq)}$; and; $HCO_3^-{}_{(aq)}$ and $CO_3^{2-}{}_{(aq)}$ are conjugate acid-base pairs.

Teachers could use the above example to illustrate that while the HCO_3^- ion commonly reacts as a base (as in $NaHCO_{3(s)}$ - baking soda), it may react as an acid. The determination of HCO_3^- as an acid in the above equilibrium is made using an acid-base relative strength chart.

The following two reactions show the amphoteric nature of $HCO_3^-{}_{(aq)}$:

As a base: $HCO_3^-{}_{(aq)} + HNO_{2(aq)} \rightleftharpoons H_2CO_{3(aq)} + NO_2^-{}_{(aq)}$

As an acid: $HCO_3^-{}_{(aq)} + HPO_4^{2-}{}_{(aq)} \rightleftharpoons CO_3^{2-}{}_{(aq)} + H_2PO_4^-{}_{(aq)}$

After seeing that HCO_3^- is amphoteric the new questions which arise are:

"Under which conditions is HCO_3^- a base?"

"Under which conditions is HCO_3^- an acid?"

To answer these questions, a student must be able to use a table of relative strengths of acids and bases. By introducing the acid/base strength table in this manner, the teacher is able to progress from solving the above questions concerning amphoterism to predicting Brønsted-Lowry acid-base reactions in a logical, time efficient manner.

Properties and Definitions of Acids and Bases *(continued)*

Tasks for Instruction and/or Assessment

Presentation

- Students could illustrate the donation of a proton from an acid to a base using $HCl_{(aq)}$ and $NaOH_{(aq)}$; $HCl_{(aq)}$ and $H_2O_{(aq)}$; $NH_{3(aq)}$ and $H_2O_{(aq)}$. (320-1, 114-9)
- Students could do a visual presentation on the timeline of the evolution of acid-base theories.
- Students could identify the acid, base, conjugate acid and conjugate base in the following: $H_2O_{(l)} + NH_{3(aq)} \rightleftharpoons NH_4{}^+{}_{(aq)} + OH^-{}_{(aq)}$. (214-17)

Paper and Pencil

- Teachers could ask students what characteristics make a substance amphiprotic. They should give an example. (214-17)
- Students could find the conjugate acid and conjugate base of:
  (a) H_2O
  (b) HCO_3^-
  (c) HBO_3^{2-}
  (d) $H_2PO_4^-$ (214-17)

Performance

- Using the relative acid strength table, ask students to explain why $H_2PO_4^-$ is labelled as shown below: (214-17)
  (i) $H_2PO_4^- + HSO_3^- \rightleftharpoons$
  base

  (ii) $H_2PO_4^- + HBO_3^{2-} \rightleftharpoons$
  acid

Resources/Notes

MGH Chemistry, pp. 549-554

MGH Chemistry, pp. 554-556, p. 831

MGH Chemistry, pp. 557-558

MGH Chemistry, p. 558

Acids/Base Reactions

Outcomes

Students will be expected to

- identify new questions or problems that arise from what was learned (214-17) (**Cont'd**)
  - define the relative strength of an acid or a base in terms of percent ionization
  - use a table of relative acid/base strengths to determine the:
    - (i) relative acid strength of one species compared to another
    - (ii) relative base strength of one species compared to another

Elaborations—Strategies for Learning and Teaching

The relative strengths of acids and bases are dependent upon their percent ionization in water; only strong acids (or strong bases) are 100% ionized.

In the previous equilibrium between HPO_4^{2-} and HCO_3^-

$$HPO_4^{2-}{}_{(aq)} + HCO_3^-{}_{(aq)} \rightleftharpoons H_2PO_4^-(aq) + CO_3^{2-}{}_{(aq)}$$

HCO_3^- acts as an acid because, according to the acid strength table, it is a stronger acid than HPO_4^{2-}. Note, HCO_3^- is not a strong acid, simply stronger thanHPO_4^{2-}. This allows prediction of the correct products upon H^+ transfer from acid to base.

Acids/Base Reactions

Tasks for Instruction and/or Assessment

Journal

- Students could explain why a 0.10 M HCl solution has a low pH. (320-4, 212-4)

Paper and Pencil

- Students could do predictions of which is the acid and which is the base in the following pairs:

  (a) HSO_4^- and $H_2PO_4^-$

  (b) HSO_3^- and $HOOCCOO^-$

  (c) HCO_3^- and HS^- (214-17)

Resources/Notes

MGH Chemistry, pp. 560-562

MGH Chemistry, pp. 562-563

Acids/Base Calculations

Outcomes

Students will be expected to

- predict products of acid-base reactions (320-2)
  - predict the most likely acid-base reaction using a table of relative acid-base strength
  - write total ionic and net ionic equations specific to acid-base reactions
  - predict whether reactants or products are favoured in an acid-base equilibrium, should an equilibrium result

Elaborations—Strategies for Learning and Teaching

It is important for teachers to note that this outcome refers to the acid-base reaction between any potential acid-base pair, not only the quantitative acid-base reactions employed in titrations. Teachers could work through a sample problem such as the one below:

Problem: Determine the acid-base neutralization that occurs between aqueous solutions of sodium hydrogen sulfite and ammonium bicarbonate.

Solution: Upon inspection of the formulae $NaHSO_3$ and NH_4HCO_3, it is not directly evident which substance is the acid or base. Accordingly, students should use the following multi-step method:

Step 1: Write all species as they exist in an aqueous environment
Step 2: Identify possible acids and bases according to the B-L definition

For our example: SA (above HSO_3^-), SB (above HCO_3^-)

$$Na^+_{(aq)},\ \underset{A,\,B}{HSO^-_{3\,(aq)}},\ \underset{A}{NH^+_{4\,(aq)}},\ \underset{A,\,B}{HCO^-_{3\,(aq)}},\ \underset{A,\,B}{H_2O_{(l)}}$$

Note: in this example there are three amphoteric species.

Step 3: Identify the strongest acid (SA) and strongest base (SB) using a table of acid-base strength. The SA is HSO_3^- ; the SB is HCO_3^-. With these identified, all other species, while in solution, are spectators.

Step 4: React the strongest acid with the strongest base according to B-L Theory.

$$HSO^-_{3\,(aq)} + HCO^-_{3\,(aq)} \rightleftharpoons SO^{2-}_{3\,(aq)} + H_2CO_{3\,(aq)}$$

A single arrow should only be employed when the reaction involves a strong acid **or** a strong base, and is quantitative.

In the equation, identify and compare the relative strengths of the acid and the conjugate acid. The stronger of the two is the best proton donor. In the example above, the acid and conjugate acid are the $HSO^-_{3\,(aq)}$ and $H_2CO_{3\,(aq)}$ species, respectively. Since, according to the acid strength chart H_2CO_3 is slightly stronger, the equation will favour the reactants side.

Using the information from Step 2 above, students should be able to write the total ionic equation that shows all species as they exist under aqueous conditions. For the previous $NaHSO_{3(aq)}/NH_4HCO_{3(aq)}$ example:

$$Na^+_{(aq)} + HSO^-_{3\,(aq)} + NH^+_{4\,(aq)} + HCO^-_{3\,(aq)} \rightleftharpoons Na^+_{(aq)} + SO^{2-}_{3\,(aq)} + NH^+_{4\,(aq)} + H_2CO_{3(aq)}$$

The net ionic equation is the result of cancelling spectator species from the total ionic equation: $HSO^-_{3\,(aq)} + HCO^-_{3\,(aq)} \rightleftharpoons SO^{2-}_{3\,(aq)} + H_2CO_{3(aq)}$

It is important for students to realize that this equation matches the final equation from the multi-step process above. The total ionic equation illustrates the nature of the aqueous equilibrium system.

Acids/Base Calculations

Tasks for Instruction and/or Assessment

Paper and Pencil

- Students could predict the products for the following acid-base reactions and whether reactants or products are favoured.
  - (a) Aqueous hydrofluoric acid added to aqueous sodium sulfate.
  - (b) Aqueous sodium dihydrogen phosphate added to aqueous potassium hydrogen sulfate.
  - (c) Aqueous boric acid added to aqueous sodium hydrogen sulfate. (320-2)

Resources/Notes

MGH Chemistry, pp. 562-564

Acids/Base Calculations *(continued)*

Outcomes

Students will be expected to

- perform calculations on acid or base solution using stoichiometry (320-6)
  - calculate $[H_3O^+]$ given the concentration of strong acids, or $[OH^-]$ given concentrations of strong bases

Elaborations—Strategies for Learning and Teaching

In completing this outcome, students should develop a strong background in determining $[H_3O^+]$ or $[OH^-]$ from an acid or ionic species. This will assist the introduction of the pH concept. Teachers could review ionization and dissociation equations with students for the purpose of determining $[H_3O^+]$ or $[OH^-]$ concentrations. For example: for a 0.010 M $HCl_{(aq)}$ solution,

$$HCl_{(aq)} + H_2O \rightarrow H_3O^+_{(aq)} + Cl^-_{(aq)}$$

0.010 M 0.010 M 0.010 M

for a 1.0×10^{-6} M $Mg(OH)_{2(aq)}$ solution,

$$Mg(OH)_{2(aq)} \rightarrow Mg^{2+}_{(aq)} + 2\,OH^-_{(aq)}$$

1.0×10^{-6} M 1.0×10^{-6} M 2.0×10^{-6} M

Emphasis should be placed on the fact that the above is valid for **only strong** acids and bases. Students should be aware that many hydroxide salts have very low solubilities (such as $Ca(OH)_2$) and thus problems will only have "reasonable" numeric answers (i.e., low concentrations must be used).

- define pH and calculate it for an acid (or base) given the initial concentration and vice-versa (320-4)
  - write the equilibrium for the self-ionization (auto-ionization) of water, and its corresponding equilibrium expression.
  - define K_w

The self-ionization of water produces a system at equilibrium for which we can write an equilibrium constant for water, K_w. Teachers should stress the small value for K_w, and the meaning of this in terms of which side of the equilibrium is favoured. The fact that pure water, a molecular compound, conducts electricity to a small degree provides evidence that this equilibrium does exist. Teachers could use this as an introduction to both K_w and the pH scale. Students could note the exponent on K_w is "-14", which will provide the basis of the upper end of the pH scale. (Teachers should note, however, that it is possible to have pH ranges beyond 0 and 14 in extreme situations.) Students should perform calculations involving rearranging K_w for either $[H_3O^+]$ or $[OH^-]$.

Acids/Base Calculations *(continued)*

Tasks for Instruction and/or Assessment

Paper and Pencil

- Students could perform calculations similar to the following:
  determine the $[H_3O^+]$ in:
  (a) 0.15 mol/L solution of HBr
  (b) 0.022 mol/L solution of $HClO_4$
  (c) 3.25×10^{-2} mol/L solution of HNO_3
  determine the $[OH^-]$ in:
  (a) 0.0025 mol/L solution of $Ba(OH)_2$
  (b) 0.55 mol/L solution of LiOH
  (c) 7.5×10^{-5} mol/L solution of $Ca(OH)_2$ (320-6)

Performance

- Teachers could get students to act out the ionization of water. (320-4)

Resources/Notes

MGH Chemistry, pp. 560, 562

MGH Chemistry, pp. 564-565

MGH Chemistry, p. 565

Acids/Base Calculations *(continued)*

Outcomes

Students will be expected to

- define pH and calculate it for an acid (or base) given the initial concentration and vice-versa (320-4) (**Cont'd**)
  - – define the pH and pOH of systems in terms of the base 10 logarithms of the respective ions

Elaborations—Strategies for Learning and Teaching

pH was defined mathematically as pH = -log [H_3O^+] by Sören Sörensen, a Danish biochemist. The letter "p" comes from the German word "potenz", meaning "power of (or exponent of)". With a base 10 logarithm in the formula, this refers to a "power of 10", i.e., pH is the power of the hydrogen ion concentration measured in powers of ten. From this statement, teachers should establish that a **factor of ten** between two different [H_3O^+] is equivalent to a difference of only **one** pH unit.

Teachers should emphasize that the pH concept is valuable in combining both the ideas of strength **and** concentration in describing the potency of an acid solution according to these variables. A teacher could pose the question: which solution has a greater hydrogen ion power: a $1x10^{-6}$ mol/L solution of $HCl_{(aq)}$ or a $1x10^{-1}$ mol/L solution of $CH_3COOH_{(aq)}$? The solution of this problem requires both the percent ionization (strength) of the acid combined with the result [H_3O^+] in the pH formula. The result is that the $HCl_{(aq)}$ solution has a pH + 6 while the $CH_3COOH_{(aq)}$ has pH = 2.89. Note that the weak acid at a higher concentration has a greater potency than the dilute strong acid, $HCl_{(aq)}$. Similarly, students could examine two solutions of pH = 4, one being HCl, the other CH_3COOH. In this case, a pH of 4 results from a dilute, strong acid (with a low [H_3O^+]), or, a concentrated, weak acid (with a high [H_3O^+]), i.e.,

1.0×10^{-4} mol/L of HCl is pH = 4

7.7×10^{-3} mol/L of CH_3COOH is pH = 4

With pH mathematically defined, pOH should be introduced: pOH = −log [OH^-]. Teachers could use [H_3O^+] (or [OH^-]) from actual "real-life" acids and bases to determine the pH of these substances. Teachers should give the mathematical formulae for deriving: $\left[H_3O^+\right]=10^{-pH}$ and

$\left[OH^-\right]=10^{-pOH}$.

Acids/Base Calculations *(continued)*

Tasks for Instruction and/or Assessment

Journal

- Students could be asked questions such as:
  - How can a pH be negative? (320-4, 212-4)
  - How are acidity and pH related? (320-4)

Paper and Pencil

- Students could describe the significance of pH in one of the following:
  - the maintenance of viable aquatic and/or terrestrial environments
  - the body fluids of living systems
  - the formation of various products; for example, shampoo, cleaners (320-4, 117-2, 117-7, 118-6)

Resources/Notes

MGH Chemistry, pp. 567-568

Acid/Base Equilibria

Outcomes

Students will be expected to

- define pH and calculate it for an acid (or base) given the initial concentration and vice-versa (320-4) (**Cont'd**)
  - define the relationship between $[H_3O^+]$, $[OH^-]$, pH, and pOH and convert between any two
  - calculate any of $[H_3O^+]$, $[OH^-]$, pH or pOH given either: the concentration of a strong monoprotic acid or the mass of a solid ionic hydroxide dissolved
  - perform dilution calculations involving changes in the volume of the solution and calculate the resultant pH, pOH, $[H_3O^+]$ and $[OH^-]$

Elaborations—Strategies for Learning and Teaching

A very useful relationship between pH and pOH is the fact that pH + pOH = 14. Teachers could derive the above equation by applying the "-log" function to both sides of the K_w expression.

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

$$1.0\times10^{-14} = [H_3O^+][OH^-]$$

$$-\log(1.0\times10^{-14}) = -\log([H_3O^+][OH^-])$$

$$14.00 = (-\log[H_3O^+]) + (-\log[OH^-])$$

$$14.00 = pH + pOH$$

In summarizing this topic, teachers could use a visual such as:

	acidic	neutral	basic
pH	0.00	7.00	14.00
pOH	14.00	7.00	0.00
$[H_3O^+]$ in mol/L	1.0	1.0×10^{-7}	1.0×10^{-14}
$[OH^-]$ in mol/L	1.0×10^{-14}	1.0×10^{-7}	1.0

The visual could be used to reinforce: 1. relationships between pH, pOH, $[H_3O^+]$ and $[OH^-]$; 2. A neutral solution has $[H_3O^+] = [OH^-]$; and, 3. Every aqueous solution has both H_3O^+ and OH^- present, as required by the self ionization of water and K_w.

Teachers should note that these pH calculations are only for strong acids and bases. If students attempt to use percent ionization with weak acid concentrations, teachers should emphasize that percent ionization is dependent upon concentration; the values given in the Chemistry 3202 data table only apply to 0.10 solutions (this is a major reason why equilibrium expressions are so useful to chemists). Teachers could use examples such as: calculate the $[H_3O^+(aq)]$ if 5.0 g of NaOH is dissolved to make 200.0 mL of solution.

There are numerous possibilities for these dilution problems, yet they are all based upon the fact that dilution simply changes the volume of the solution and not the number of moles of solute present. This means the number of moles of H_3O^+ or OH^- stays constant during dilution. This is very similar to dilution problems encountered in Chemistry 2202 - recall: $C_iV_i = C_fV_f$. For the acid-base dilution problems, the "inputs" and "outputs" to the C_i and C_f terms may be $[H_3O^+]$ or $[OH^-]$, which in turn could have been calculated from pH or pOH data.

Acid/Base Equilibria

Tasks for Instruction and/or Assessment

Paper and Pencil

- Students could calculate the pH of 100.0 mL of 0.150 mol/L $HCl_{(aq)}$, and, the pH of 150.0 mL of 0.0900 mol/L $NaOH_{(aq)}$? (320-3, 320-4)
- Students could calculate the pH of a 0.025 M NaOH solution. (320-4)
- The pH of the rain precipitation near a power plant is 4.35. Students could be asked to calculate the $[OH^-]$ in this precipitation? (320-4)

Performance

- Students could find 10 substances in their home which are acidic or basic. Using a pH test paper or pH meter, students could determine the pH and then calculate the $[OH^-]$ and $[H_3O^+]$. (320-4, 213-3)

Resources/Notes

MGH Chemistry, pp. 565-571, pp. 830-831

MGH Chemistry, pp. 572-574

Acid/Base Equilibria *(continued)*

Outcomes

Students will be expected to

- define pH and calculate it for an acid (or base) given the initial concentration and vice-versa (320-4) (**Cont'd**)
  - distinguish between the concentration versus the strength of an acid
  - differentiate between strength and concentration operationally, using pH, indicator colour, and rate of reaction with metals (acids), for acid and base solutions of equal concentration
- compare strong and weak acids and bases using the concept of equilibrium (320-3)
  - define K_a and K_b qualitatively and write the equilibrium constant expression from the equation of reaction with water
  - understand that the strength of acid/base systems is described by percent ionization and K_a (or K_b)

Elaborations—Strategies for Learning and Teaching

A common misconception is that "strength" and "concentration" are terms which may be used interchangeably. It is possible that a highly concentrated solution of a weak acid (0.10 mol/L $CH_3COOH_{(aq)}$) could have a lower pH than a dilute solution of strong acid ($1.0x10^{-6}$ mol/L $HCl_{(aq)}$). Based on concentration and strength of the acid, the weak acid contains more H_3O^+ than the strong acid, i.e.,

$$0.10\,{}^{mol}\!/_{L}\ CH_3COOH \xrightarrow{1.3\%} 0.0013\,{}^{mol}\!/_{L}[H_3O^+] \longrightarrow pH = 2.89$$
$$1.0\times10^{-6}\,{}^{mol}\!/_{L}\ HCl \xrightarrow{100\%} 1.0\times10^{-6}\,{}^{mol}\!/_{L}[H_3O^+] \longrightarrow pH = 6.00$$

Concentration refers to amount of solute present per volume and strength refers to the amount of ionization or dissociation into H_3O^+ or OH^-. Teachers may now further differentiate between strength and concentration operationally.

Some teaching suggestions to illustrate strength vs. concentration for acids may include: 1. Measure and compare the pH of 0.10 mol/L solutions of $HCl_{(aq)}$ and $CH_3COOH_{(aq)}$(try comparing the rate of reaction by reacting each with Mg to produce $H_{2(g)}$); 2. Use universal indicator paper to test and compare the pH of 0.10 mol/L solutions of $HCl_{(aq)}$ and $CH_3COOH_{(aq)}$; and; 3. Add similar-sized pieces of mossy zinc metal to equal volumes of 0.10 mol/L solutions of $HCl_{(aq)}$ and $CH_3COOH_{(aq)}$ to compare the rate of reaction (production of $H_{2(g)}$).

With acid and base strength defined operationally, it follows that students should make the connection between K_a (or K_b) and acid/base strength. Teachers could take this opportunity to reinforce that percent ionization values are concentration dependent, showing the need for further study and use of K_a (or K_b) in acid-base equilibria.

Students should realize that K_a and K_b are simply equilibrium constants applied specifically to acids and bases respectively. Students should define K_a and K_b qualitatively and relate their values to their strength. Students should write appropriate K_a and K_b equilibrium constant expressions from the equations, knowing that water as a liquid is omitted in the equilibrium expression. For example, the acetic acid is vinegar in water:

$$CH_3COOH_{(aq)} + H_2O(l) \rightleftharpoons H_3O^+_{(aq)} + CH_3COO^-_{(aq)}$$

$$K_a = \frac{[H_3O^+][CH_3COO^-]}{[CH_3COOH]} = 1.80\times10^{-5}$$

Acid/Base Equilibria *(continued)*

Tasks for Instruction and/or Assessment

Paper and Pencil

- HF ($K_a = 6.6 \times 10^{-4}$) and HCN ($K_a = 6.2 \times 10^{-10}$) are two weak acids that appear in this equilibrium:

  $HCN_{(aq)} + F^-_{(aq)} \rightleftharpoons HF_{(aq)} + CN^-_{(aq)}$

– Students could use this information to explain qualitatively which equilibrium direction is favoured. They could determine which acts as an acid and which acts as a base. (320-4, 320-3, 320-2)

- Students could calculate the equilibrium concentrations for all the species of a 0.020 mol/L C_6H_5COOH solution with a pH of 2.96. Students could also be asked to calculate the equilibrium constant as an introduction to the K_a. (320-4)

Journal

- Students could determine how the K_a value of an acid relates to the pH of its solution. (320-4, 212-4)

Resources/Notes

MGH Chemistry, pp. 560-563

MGH Chemistry, pp. 587-593, p. 831

Acid/Base Equilibria *(continued)*

Outcomes

Students will be expected to

- compare strong and weak acids and bases using the concept of equilibrium (320-3) (**Cont'd**)
  - calculate the value of one of K_a (or K_b) and equilibrium concentrations given all other values
  - calculate pH given the initial concentration of a weak acid (or weak base) and K_a (or K_b)

Elaborations—Strategies for Learning and Teaching

Students should calculate the value of one of K_a or equilibrium concentration given all other values. Given that pH = $-\log_{10}[H_3O^+]$, students could also, as a natural extension, be asked to find the pH of such solutions. Teachers should do a variety of problems in this area, including problems which must employ a quadratic equation in the analysis.

The magnitude of K_a (or K_b) has a major impact on how these problems are solved. If K_a (or K_b) is small in relation to the initial concentration of acid (or base) a simplifying assumption may be made. While chemistry textbooks vary in the parameters required for the simplifying assumption, the parameters for Chemistry 3202 are that the K_a (or K_b) must be at least five hundred times smaller than the initial acid (or base) concentration in magnitude. To illustrate the validity of the assumption, students could use their calculators to subtract a very small number (such as one to two) from a very large number (such as one billion, $1x10^9$). Not only does this reflect the magnitude of difference between the initial concentration and the change in concentration for the weak acid (weak base), once the subtraction is attempted on a calculator, essentially the large number results (on 8-digit calculator, the large number value is often returned as the difference).

Students should follow the following procedure:

Step 1: Write the acid/base dissociation equation.

Step 2: Construct a table to organize known and unknown data; often called an ICE table.

Step 3: Check to see if a simplifying assumption can be made.

$\frac{[\ ]_i}{K_a} < 500$ quadratic must be used

$\frac{[\ ]_i}{K_a} > 500$ simplifying assumption must be stated; ie: amount dissociated ("x") is negligible compared to the initial concentration of the acid or for example: $0.025 - x \approx 0.025$

Some students may choose to omit Step 3 and solve the quadratic even though the simplifying assumption works. This is acceptable, however, students should be aware of situations when a check can lead to a simplifying assumption. Teachers should stress the efficiency and value of using the assumption where possible. Moreover, applying the valid assumption, when appropriate, shows a deeper understanding of chemical equilibrium. Some teachers/students may also choose to check their simplifying assumption using the 5% rule.

Acid/Base Equilibria *(continued)*

Tasks for Instruction and/or Assessment

Paper and Pencil

- HF ($K_a = 6.6 \times 10^{-4}$) and HCN ($K_a = 6.2 \times 10^{-10}$) are two weak acids that appear in this equilibrium:

  $HCN_{(aq)} + F^-_{(aq)} \rightleftharpoons HF_{(aq)} + CN^-_{(aq)}$. (320-3)

– Using K_a expressions and the K_a values provided, students could calculate the numerical value of the equilibrium constant for the reaction. (320-3)

- Students could write the equilibrium constant expressions for the following:

  (i) acids - HOCl and HCOOH

  (ii) bases - HS^- and CH_3NH_2 (320-3)

Resources/Notes

MGH Chemistry, pp. 587-593, p. 831

MGH Chemistry, pp. 590-595

Acid/Base Equilibria *(continued)*

Outcomes

Students will be expected to

- compare strong and weak acids and bases using the concept of equilibrium (320-3) (**Cont'd**)
  - calculate K_a (or K_b) given the initial concentration and pH

Elaborations—Strategies for Learning and Teaching

Step 4: Write a K_a (or K_b) expression from the equation

Step 5: Substitute known and unknown values into the K expression

Step 6: Solve for "*x*" which is the ,$\left[H_3O^+\right]/\left[OH^-\right]$; then solve for pH (if required).

Teachers should note that problems of this type are not restricted to acid-base equilibria. Equilibrium problems such as those in Unit I may require finding equilibrium concentrations from initial concentrations and K value.

Students should solve problems such as: Calculate the K_a for a 0.10 M formic acid solution given its pH = 2.09. An ICE table could be used to guide the students' solution:

$$HCOOH + H_2O \rightleftharpoons H_3O^+ + HCOO^-$$

	$HCOOH$	H_3O^+	$HCOO^-$
I	0.10	0	0
C	-x	+x	+x
E	0.10-x	x	x

$$\left[H_3O^+\right]_{eq} = x = 10^{-pH} = 10^{-2.09} = 0.0082\ {}^{mol}\!/\!_{L}$$

$$[HCOOH]_{eq} = x = 0.0082\ {}^{mol}\!/\!_{L}$$

$$[HCOOH]_{eq} = 0.10\text{-}x = 0.10 - 0.0082 = 0.09$$

$$K_a = \frac{\left[H_3O^+\right]\left[HCOO^-\right]}{[HCOOH]} = \frac{(0.0082)\ (0.0082)}{0.09} = 7 \times 10^{-4}$$

Acid/Base Equilibria *(continued)*

Tasks for Instruction and/or Assessment

Paper and Pencil

- The pH of a 0.072 mol/L solution of benzoic acid, $HC_7H_5O_2$ is 2.68. Students could calculate the numerical value of the K_a for this acid. (320-3)
- The pH of a 0.072 mol/L solution of benzoic acid, $HC_7H_5O_2$ is 2.68. Students could calculate the numerical value of the K_a for this acid. (320-3)

Resources/Notes

MGH Chemistry, pp. 590-595

Acid/Base Equilibria *(continued)*

Outcomes

Students will be expected to

- state general examples of how our lives are affected by acid-base chemistry (ACC-5)
- analyze society's influence on scientific and technological endeavours using examples from acid-base chemistry (117-2)
- construct arguments to support a decision, recognizing various perspectives, concerning acid deposition (118-6)
- define a buffer according to both its components and its function (ACC-6)
- recognize that blood is a buffer and that without this natural buffering, homeostasis would not be maintained (ACC-7)
- describe science and technology based careers related to acid-base chemistry (117-7)

Elaborations—Strategies for Learning and Teaching

The CORE STSE component of this unit incorporates a broad range of Chemistry 3202 outcomes. More specifically, it targets (in whole or in part) ACC-5, 117-2, 118-6, ACC-5, ACC-6, ACC-7 and 117-7. The STSE component, *Acids Around Us,* can be found in Appendix A.

Acid/Base Equilibria *(continued)*

Tasks for Instruction and/or Assessment

Journal

- Students could investigate how the pH of human blood remains extremely constant. (Hint: [$HCO_{3\ (aq)}^{-}$] ions are present.) (ACC-7)

Resources/Notes

Core STSE #2: *"Acids Around Us"*, **Appendix A**

Acid/Base Titrations

Outcomes

Students will be expected to

- calculate the concentration of an acid or base solution using stoichiometry (320-6)
  – write chemical equations for strong acid - strong base neutralization reactions
  – describe the process of a titration
  – define primary standard and recognize its importance in a titration procedure
  – differentiate between indicator end point and equivalence (stoichiometric) point
  – perform stoichiometric titration calculations where one of molarity of acid, molarity of base, volume of acid or volume of base is to be determined from the others

Elaborations—Strategies for Learning and Teaching

Teachers should emphasize the proper use of chemical equations to solve titration problems. Students should be familiar with the neutralization reaction written in the same format as a double replacement reaction from Chemistry 2202. Moreover, titration processes always involve quantitative reactions; the emphasis should be on stoichiometry (another connection to Chemistry 2202).

Students should know the terminology involved with titrations: pipet, burette, endpoint, equivalence point, primary standard, standard solution, standardization and indicator.

In evaluating the lab reports of titration experiments, teachers may consider allocating marks to precision in repeated trials and/or quality of endpoints obtained using observation and checklists.

Teachers should ensure that students understand that the accuracy of the titration process is dependent upon the accuracy of the primary standard, standard solution, and specialized glassware. Teachers could use the titration process as an excellent illustration of the difference between accuracy and precision. Students should understand the importance of obtaining titration data within a given volume range for several trials (textbooks may vary in their acceptable ranges).

Teachers should also stress that the best end point is one which has the slightest detectable permanent colour change. For example, when using a phenolphtalein indicator which changes from colourless to pink with added base, a very slight pink, not a intense pink indicates the endpoint.

Students should compare the qualitative term, endpoint, with the quantitative term, equivalence point.

Students should perform a variety of titration problems which use various acids and bases, including polyprotic acids. This activity could help with lab questions and stoichiometry problems.

Acid/Base Titrations

Tasks for Instruction and/or Assessment

Paper and Pencil

- Students could examine diagrams of apparatus used in titrations and describe the use of each. Examples should include the burette and Erlenmeyer flask. (320-6)
- Bobby and Mary use 2.00 g of a solid potassium hydrogen phthalate, to titrate with 34.7 mL of a NaOH solution. The molar mass of the acid is 204.2 g/mol. Students could calculate the molarity of the NaOH solution. (320-6, 215-6)
- Debbie and Ron titrated 35.0 mL of liquid drain cleaner, containing NaOH, with 50.1 mL of 0.41 M HCl to reach the equivalence point. Students could answer, "What is the concentration of the base in the cleaner?" or "Would a computer analysis be helpful here?" They should explain their answers. (320-6, 215-6)
- Cheryl and Craig want to find the molarity of a lactic acid solution. A 150.0 mL sample of lactic acid, $CH_3CHOHCOOH$, is titrated with 125 mL of 0.75 M NaOH. They could calculate the molarity of the acid sample. (215-6, 320-6)
- Students could calculate the pH of a solution formed by mixing 100 mL of 0.150 mol/L HCl(aq) with 150 mL of 0.0900 mol/L NaOH(aq)? (320-6)

Journal

- A NaOH solution has a pH of 10.50. Students could be asked to calculate what volume of 0.010 M HCl would be required to titrate this solution to the equivalence point? However, before they begin, they should determine what additional information is required to solve this problem. (320-6, 215-2, 215-6)

Performance

- Students could design an experiment to test the neutralization effectiveness of various brands of antacid. They should show their procedure to their teacher for approval. Include all safety procedures and cautions. They should write an advertisement for the antacid they judge to be the most effective. If the experiment is performed, they should include data from their experiments in their ad. (215-2, 213-3, 214-5, 215-6, 212-8)

Resources/Notes

MGH Chemistry, pp. 599-600, p. 831

MGH Chemistry, pp. 603-605

MGH Chemistry, p. 603

MGH Chemistry, pp. 600-602

Acid/Base Titrations *(continued)*

Outcomes

Students will be expected to

- use instruments effectively and accurately for collecting titration data (213-3)
  - perform a titration experiment and related calculations to determine the concentration of an acid or base solution
- select appropriate instruments and use them safely, for collecting evidence and appropriate processes for titrations (212-8)
- select and use appropriate symbolic, graphical modes of representation to communicate titrations and results (215-2)
- interpret patterns and trends in data and infer or calculate relationships among variables from titration labs (214-5)
- explain the importance of communicating the results of acid-base reactions using appropriate language and conventions (114-9)
- demonstrate a knowledge of WHMIS standards by using proper techniques for handling and disposing of lab materials (213-9)

Elaborations—Strategies for Learning and Teaching

The Laboratory outcomes 213-3, 213-8, 212-8, 215-2, 214-5, 114-9, 213-9 and, in part, 320-6 are addressed by completing *The Concentration of Acetic Acid in Vinegar,* CORE LAB #3.

Teachers could apply the titration procedure to real-world applications of chemistry. Problems could involve the analysis of antacid tablets for amount of base (i.e., $CaCO_3$) present, analysis of vitamin C (ascorbic acid) in a juice sample or amount of H^+ ion in a drinking water sample.

Students should recognize the usefulness of WHMIS standards. Students could do a project on WHMIS standards. In the lab, students could be shown apparatus that might be used in a future acid-base titration experiment and decide on the safe and proper use of the apparatus. Teachers could demonstrate the proper use of the equipment. Students could be asked to think about how they would safely dispose of acids and bases. Then, information collected could help students know how to use apparatus safely. The proper way to handle and dispose of acids and bases is part of WHMIS knowledge that is useful in the laboratory, workplace, and home.

Students could graph sample data collected from one of the titration experiments or data provided by their teacher. As students become more familiar with acid-base data throughout this unit, students could plot and interpret their own graphs.

Students should interpret and extrapolate what a titration graph curve means in terms of neutralization.

Students could explain the titration graph involving a polyprotic base with a strong acid, for example, hydrochloric acid, a strong acid with sodium carbonate. Students should explain the results of a titration graph involving a polyprotic acid with a strong base, for example, phosphoric acid with sodium hydroxide. Students should explain the pH at the equivalence point when strong acids are mixed with weak bases and vice versa. Teachers might mention hydrolysis here to help explain titration curves.

Reporting of lab results should be done. Students could present their lab results so that their understanding of pH and titrations is clearly shown. Students might use graphs, videos, charts, a computer, activities, or oral reports to consolidate their titration information.

Acid/Base Titrations *(continued)*

Tasks for Instruction and/or Assessment

Informal Observation

- Teachers could observe student use of the equipment in an acid-base titration and allow students to practise the safe and efficient use of the equipment. (213-8, 213-9)

Performance

- Students could create a poster illustrating both proper and improper acid-base disposal. (213-9)
- Students could show the proper care and maintenance of a burette. (213-8)

Journal

- Neutralization is a process that is controlled in lab experiments. Teachers could ask students: "How do you think this process works?" or "Does it work in other environments, such as a lake or your stomach?" (214-17, 320-2, 114-9)

Paper and Pencil

- Teachers could ask students: "Why is a burette, not a graduated cylinder, used in a titration?" (213-3)
- Students could define and explain a titration. (213-3, 215-2)

Resources/Notes

Core Lab #3: *"The Concentration of Acetic Acid in Vinegar"*, pp. 606-607

Acid/Base Titrations *(continued)*

Outcomes

Students will be expected to

- explain how acid-base indicators function (320-7)
  - define acid/base indicators operationally
  - define acid/base indicators theoretically
  - determine an appropriate indicator for an acid-base titration
  - determine the appropriate pH of a solution using indicator colours, and vice versa
- analyze and describe examples where acid/base understanding was enhanced as a result of using titration curves (116-2)
  - calculating any of $[H_3O^+]$, $[OH^-]$, pH or pOH in strong acid-strong base mixtures where there is an excess of one of the reagents

Elaborations—Strategies for Learning and Teaching

Students should understand the operational definition of indicators and apply it to specific indicators beyond the traditional phenolphthalein indicator. Students could do a microlab lab that determines the pH of various acids and bases using indicators

Teachers should indicate that a given indicator has a weak acid (HIn) and has a conjugate base form (In^-). The observed colour of the indicator is dependent upon which is predominant in solution. The general equilibrium below may then be applied to any indicator

$$HIn \rightleftharpoons In^- + H^+$$

Colour "A"   Colour 'B'

Students should choose appropriate acid-base indicators given a table of effective pH ranges from various acid-base indicators and the pH at the equivalence point **or** the titration curve for the neutralization. (A more detailed look at titration curves follows.)

Students should solve problems in which a selection of indicators is used to differentiate between solutions of differing pH values. Problems of this sort could include asking students to: 1. identify a pH = 2.0 solution versus a pH = 4.0 solution given appropriate indicators
2. determine the pH range of a solution given the behaviour of two appropriate indicators 3. identify the colour of an indicator given the pH of a solution.

Students should perform a variety of acid-base problems whereby there is a limiting amount of either acid or base, and therefore, the amount of excess reagent may be identified and the resulting pH determined. Teachers could reference the Public Examination Standards document (available on the Department of Education web site) for solved examples of these type of problems.

Acid/Base Titrations *(continued)*

Tasks for Instruction and/or Assessment

Performance

- Students could conduct an experiment focusing on an acid-base equilibrium using Le Châtelier's principle and report their findings. (320-7)

Paper and Pencil

- Students could be asked, "What is the key when choosing an indicator in order to have an accurate titration?" (320-7)
- Students could explain how the colour change of an indicator is related to pH. (213-3, 212-8, 320-7)
- Students could be asked what indicators they might use when a solution of HCl, a strong acid, is added to a solution of Na_2CO_3, a weak base? (320-7, 116-2)
- Teachers could ask students: "What is equivalence point? endpoint?" and "Why is it important that both occur at approximately the same pH in a titration?" (320-7)
- If a titration between a weak acid and a strong base has an equivalence point pH of 9.5, students could determine which indicators could be used to detect the equivalence point of the titration. (320-7, 116-2)
- For the following titrations, students could select the best indicator from these choices: bromophenol blue, bromothymol blue, phenol red.
  - HCOOH, formic acid, with NaOH
  - HCl with potassium hydroxide
  - ammonia with hydrochloric acid (116-2, 320-7)
- Students could determine which indicators would work best for a titration with
  - an equivalence point at a pH of 4.0
  - a weak base with a strong acid

  They should use an indicator chart as a reference and justify their choice. (116-2, 320-7)

Performance

- Teachers could give students a solution to test for pH. Students should submit a plan to the teacher outlining exactly how they would test the solution. If approved, they could conduct the test and report the results. (215-2, 213-3, 214-5, 215-6, 212-8, 320-7)

Resources/Notes

MGH Chemistry, pp. 599-601

MGH Chemistry, pp. 608-609, p. 616

MGH Chemistry, p. 616

Acid/Base Titrations *(continued)*

Outcomes

Students will be expected to

- identify a line of best fit on a scatter plot and interpolate and extrapolate based on the line of best fit (214-4)
  - draw titration curve graphs, using data from titration experiments involving acids and bases in various combinations

Elaborations—Strategies for Learning and Teaching

Teachers could design a project in which students calculate the changes in pH which occur as a titrant is progressively added to a unknown solution. From such data, a pH curve can be quantitatively drawn. Such a project could be time-consuming with repetitive calculations. Cooperative learning may be employed and class or group data pooled. Teachers may also choose to use a pH meter to acquire experimental data for a pH curve, plot the curve and perform an analysis of the graph.

Outcomes

- interpret patterns and trends in data and infer or calculate relationships among variables from titration labs (214-5)
  - interpret titration curve graphs
  - write single-step and overall equations for the acid-base reactions of a substance that can donate more than one proton or accept more than one proton

Elaborations—Strategies for Learning and Teaching

Students should identify from a pH curve:

- the equivalence point(s)
- the pH at the equivalence point(s)
- the type of titrant
- the type of unknown (strong acid or weak acid, strong base or weak base) mono-, di- or triprotic acid (mono-, di- or tribasic species).

Teachers should revisit choice of indicators in light of pH curve analysis.

Teachers should combine the study of these stepwise reactions and the overall neutralization reaction of a polyprotic (polybasic) species with its corresponding titration curve. This would allow students to relate the graphical identification of each endpoint with the corresponding stepwise reaction which occurs at that point.

Acid/Base Titrations *(continued)*

Tasks for Instruction and/or Assessment

Paper and Pencil

- Students could write an equation for each of the three ionization steps where phosphoric acid would donate three hydrogen ions (i.e., protons). (214-5)
- Students could be given a titration curve and asked to identify the following:
  - (i) what substance is in the flask and burette
  - (ii) the initial concentration of the acid
  - (iii) the volume of acid and base added at the equivalence point
  - (iv) the pH at the equivalence point
  - (v) the strength of acid and base
  - (vi) the appropriate indicator (214-4, 214-5)
- Students could complete a problem such as: A titration is carried out when 50.0 mL of a 0.150 M HI solution is titrated with 0.115 M LiOH. Calculate the:
  - (i) volume of base needed to completely neutralize the acid
  - (ii) pH before any base is added
  - (iii) pH at 10.0 mL before the equivalence point
  - (iv) pH at 1.0 mL before the equivalence point
  - (v) pH at 1.0 mL after the equivalence point
  - (vi) pH at 10.0 mL after the equivalence point

  After completing these calculations, students should construct a properly labelled titration curve for the data. (214-4, 214-5)

Resources/Notes

MGH Chemistry, pp. 608-609

MGH Chemistry, pp. 609-612

Acid/Base Titrations *(continued)*

Outcomes

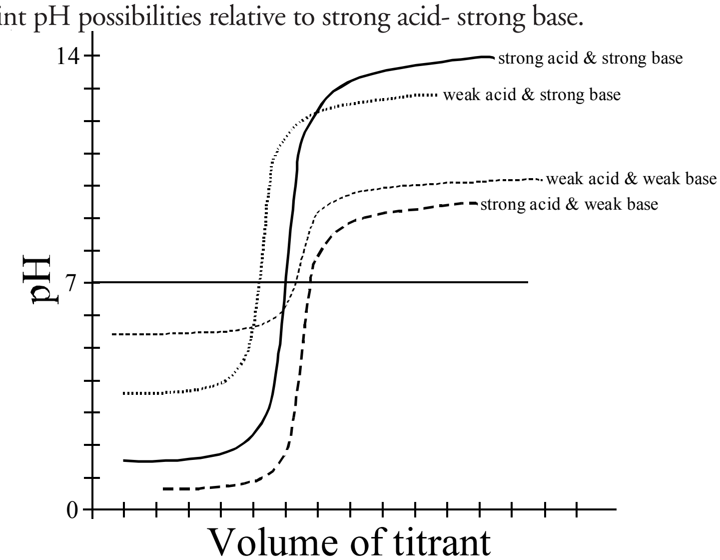
Students will be expected to

- interpret patterns and trends in data and infer or calculate relationships among variables from titration labs (214-5) (**Cont'd**)
  - sketch and interpret titration curves qualitatively

Elaborations—Strategies for Learning and Teaching

Given the identity of the titrant and unknown, students should be able to qualitatively draw the titration curve, and vice-versa. Students are not expected to have accurately determined equivalence point pH values for sketches involving polyprotic or polybasic unknowns; the correct general appearance of the curve will suffice.

Teachers could present the various possibilities for the endpoint pH of various reactions by first presenting the pH = 7 endpoint for a strong acid-strong base titration on a set of titration curve axes (see below). The same axes may then be used to present the other titration and equivalence point pH possibilities relative to strong acid- strong base.



Teachers could present a similar plot for a basic titrant, or leave such an exercise for the students.

Teachers should note that the shape of a titration curve and equivalence point for a weak base with a weak acid is complex (it depends on several factors, including the relative strength of the acid and base). Students may like to see an example weak base - weak acid curve, therefore it could be included on the above pH curve. While this type of titration would not give a quantitative reaction, addressing this point would revisit the equilibria (studied earlier), which occurs when weak acid and weak base are mixed.

- determine qualitatively the nature of the equilibrium at the stoichiometric equivalence point when a strong acid is mixed with a weak base and vice versa

Students should realize that the pH at the equivalence point of a titration is pH=7 only when a strong acid reacts with a strong base. When a strong acid (base) titrant reacts with a weak base (acid) solution, the resulting conjugate acid (base) hydrolyses in water and thus determines the equivalence point. Qualitatively, this means that the titration of: strong acid + weak base means pH at equivalence point is less than 7; strong base + weak acid means pH at equivalence point is greater than 7.

Acid/Base Titrations *(continued)*

Tasks for Instruction and/or Assessment

Paper and Pencil

- Students could sketch titration curves for each of the following:
  - (i) formic acid titrated with sodium hydroxide
  - (ii) hydrochloric acid titrated with potassium hydroxide
  - (iii) ammonia titrated with hydrobromic acid (214-4, 214-5)

- In the titration of a weak acid with a strong base, the pH of the equivalence point is higher than 7. Students could use the concept of conjugate acids and bases to explain why the pH is in the basic hydrolysis range. (320-6, 215-2)

Resources/Notes

MGH Chemistry, pp. 608-609

Determining K_a

Outcomes

Students will be expected to

- perform an experiment identifying and controlling major variables (212-3)
- evaluate and select appropriate instruments for collecting evidence and appropriate processes for problem solving, inquiring, and decision making (212-8)
- compile and display data in charts, tables and graphs (214-3)
- use instruments effectively, accurately and safely for collecting data (213-3)

Elaborations—Strategies for Learning and Teaching

The Laboratory outcomes 212-3, 212-8, 214-3, 213-3 and, in part, 214-5 are addressed by completing *K_a of Acetic Acid,* CORE LAB #4.

Determining K_a

Tasks for Instruction and/or Assessment

Presentation

- Students could research applications of the titration process. For example, water treatment, breathalyzer and blood analysis.(212-8, ACC-5)

Resources/Notes

Core Lab #4: *"K_a of Acetic Acid"*, pp. 4613-614