8.3 WORKING WITH SOLUTIONS

PRACTICE

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Applying Inquiry Skills

1.

Name	Use
Erlenmeyer flask	for temporarily containing reacting substances (specifically shaped to allow mixing of contents by swirling) and also for approximate measure of various volumes
graduated pipet	for very precise addition of various (smaller) volumes
graduated cylinder	for precise measurement of various (larger) volumes
volumetric flask and stopper	for very precise measurement (and mixing) of a single specific volume
buret	for very precise addition of various (small) volumes
graduated beaker	for temporarily containing reacting substances, and for approximate measure of various (large) volumes

PRACTICE

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Making Connections

2. Typical answers might include information such as:
   Teaching Chemistry requires a minimum four years of university training, with five or six years usually seen as preferable. Specifically, such a person would require a B.Sc. degree in physical sciences, plus background in mathematics, as well as education course requirements. (Courses vary from province to province.) Teachers must be certified by the provincial government. At publication date, a nationwide shortage of teachers is being felt in this subject area, making future job prospects good.

   GO TO www.science.nelson.com, Chemistry 11, Teacher Centre.

8.4 ACID – BASE THEORIES

PRACTICE

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Understanding Concepts

1. Sour taste for acids is not an appropriate lab test, because many lab acids are dangerous: toxic and/or highly reactive. It *would* be of practical use in a household kitchen.
2. (a) $Mg_{(s)} + 2\ HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_{2(g)}$ fast (strong acid)

   (b) $Mg_{(s)} + 2\ HC_2H_3O_{2(aq)} \rightarrow Mg(C_2H_3O_2)_{2(aq)} + H_{2(g)}$ slow (weak acid)

   (c) $2\ HCl_{(aq)} + CaCO_{3(s)} \rightarrow H_2O + CO_{2(g)} + CaCl_{2(aq)}$ fast (strong acid)

   (d) $2\ HC_2H_3O_{2(aq)} + CaCO_{3(s)} \rightarrow Ca(C_2H_3O_2)_{2(aq)} + H_2O_{(g)} + CO_{2(g)}$ slow (weak acid)
3. The best properties to distinguish strong acids from weak acids would be the rates of reaction with active metals and/or carbonates, the last two properties listed in Table 1. The other tests would distinguish acids from bases, but not strong acids from weak acids.
4. Strong acids are molecular substances that theoretically ionize in aqueous solution to a very large extent (essentially completely), to produce hydrogen ions. Weak acids are molecular substances that theoretically ionize in aqueous solution to a very small extent, to produce hydrogen ions.

5. (a) The concentration of hydrogen ions in the strong acid solution will be 100 ions per litre, and in the weak acid solution will be 2 ions per litre.
   (b) Strong acids react much faster and (in equal concentration) have a lower pH, because their solutions have more hydrogen ions present.

Applying Inquiry Skills

6. **Prediction**

   Strong bases should react much faster and (in equal concentration) have a higher pH than weak bases, because their solutions should have more hydroxide ions present.

   Experimental Design

   Solutions of several bases (independent variable) of equal concentrations (controlled variable) will be tested for pH (dependent variable).

7. (a) **Experimental Design**

   Solutions of several acids (independent variable) of equal concentrations (controlled variable) will be tested for pH (dependent variable).

   (b) **Analysis**

   According to pH values, in order of *decreasing* strength, the acids are:
   hydrochloric and nitric acid (equal in pH)
   hydrofluoric acid
   methanoic acid
   ethanoic acid
   hydrocyanic acid

8. **Experimental Design**

   Equally concentrated solutions of the substances are tested for pH and for electrical conductivity.

   Analysis of the Design

   The reasoning behind this design is that, of the two acidic solutions, $HCl_{(aq)}$ will have a lower pH than $HC_2H_3O_{2(aq)}$, because $HCl_{(aq)}$ is a strong acid, and $HC_2H_3O_{2(aq)}$ is a weak acid. Of the two neutral solutions, $NaCl_{(aq)}$ is ionic and will conduct, and $C_{12}H_{22}O_{11(aq)}$ is molecular and will not conduct. The two bases can be distinguished by adding $Na_2SO_{4(aq)}$ solution to each, which will precipitate $BaSO_{4(s)}$ from the $Ba(OH)_{2(aq)}$ solution, but not from the $KOH_{(aq)}$ solution.

   Note: The $Ba(OH)_{2(aq)}$ solution will have a higher pH and conduct electricity better than the $KOH_{(aq)}$ solution, because the dissociation of $Ba(OH)_{2(aq)}$ produces two hydroxide ions per formula unit, and the dissociation of $KOH_{(aq)}$ produces only *one* hydroxide ion per formula unit (but the course of study in the text has not yet addressed this point).

Making Connections

9. Personal experience indicates that acids "eat away" materials quite slowly — even those "instant" lime and scale removers advertised on television. The stronger acids are more dangerous. Entertainment media are unlikely to portray acid reactivity accurately; exaggeration is their "selling" point.
10. Acid deposition (acid rain) is acidic "fallout" from the atmosphere, initially mostly produced by vehicle exhausts and industrial pollution sources. The two predominant acids are nitric and sulfuric (both strong acids). Nitrous and sulfurous acids (both weak acids) may also be present. All rainwater contains dissolved carbon dioxide (carbonic acid), so normal unpolluted rainwater has a pH of about 5.6 — very slightly acidic. You might predict that strong acids would affect the environment more, but living systems are so complex that this would almost certainly be an over-simplification.

    GO TO www.science.nelson.com, Chemistry 11, Teacher Centre.

Reflecting

11. The maximum concentration of the hydrogen ions in a 0.01 mol/L acid solution is (with a few exceptions) 0.01 mol/L. This maximum concentration will be attained by strong acids but not by weak acids. There is no way to predict what the $H^+_{(aq)}$ concentration will be in a 0.01 mol/L unknown acid solution, with the concepts studied to this point. If the acid were identified as strong, or the % ionization value were provided, that information would aid the accuracy of prediction.

PRACTICE

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Understanding Concepts

12. Early ideas about acids were that they were hydrogen compounds that ionized in water to produce hydrogen ions. However, some acidic solutions were found to be solutions of compounds that contain no hydrogen atoms. Furthermore, hydrogen ions are theoretically impossible structures.
13. In the original Arrhenius theory, acids are molecular substances that ionize in aqueous solution to produce hydrogen ions, and bases are ionic substances that dissociate in aqueous solution to produce hydroxide ions. This theory predicts and explains quite a few acidic and basic substances, but there are lots of exceptions — too many to leave the theory unrevised.
14. We now assume acidic solution properties are due to the presence of hydrated protons, commonly called hydronium ions, symbolized $H_3O^+_{(aq)}$.
15. (a) $HCN_{(aq)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + CN^-_{(aq)}$

    (b) $HNO_{3(aq)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + NO^-_{3(aq)}$

    (c) $Na_2SO_{4(aq)} \rightarrow 2\ Na^+_{(aq)} + SO^{2-}_{4(aq)}$ followed by

    $SO^{2-}_{4(aq)} + H_2O_{(l)} \rightarrow HSO^-_{4(aq)} + OH^-_{(aq)}$

    (d) $Sr(OH)_{2(aq)} \rightarrow Sr^{2+}_{(aq)} + 2\ OH^-_{(aq)}$
16. (a) weak acid
    (b) strong acid
    (c) weak base
    (d) strong base

PRACTICE

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Understanding Concepts

17. According to Brønsted-Lowry definitions, acids differ from bases in that acids lose (donate) protons in a proton-transfer reaction, and bases gain (accept) protons in a proton-transfer reaction.
18. (Reactants are shown in bold type.)

    (a) The acids are: $\mathbf{HF_{(aq)}}$ and $HSO^-_{3(aq)}$

    The bases are: $F^-_{(aq)}$ and $\mathbf{SO^{2-}_{3(aq)}}$

    (b) The acids are: $\mathbf{HC_2H_3O_{2(aq)}}$ and $HCO^-_{3(aq)}$

    The bases are: $C_2H_3O^-_{2(aq)}$ and $\mathbf{CO^{2-}_{3(aq)}}$

    (c) The acids are: $\mathbf{H_3PO_{4(aq)}}$ and $HOCl_{(aq)}$

    The bases are: $H_2PO^-_{4(aq)}$ and $\mathbf{OCl^-_{(aq)}}$
19. (a) $HSO^-_{4(aq)} + HCO^-_{3(aq)} \rightarrow SO^{2-}_{4(aq)} + H_2CO_{3(aq)}$

    (b) One acid–base pair is: $HSO^-_{4(aq)}$ and $SO^{2-}_{4(aq)}$

    and the other pair is: $H_2CO_{3(aq)}$ and $HCO^-_{3(aq)}$
20. Brønsted-Lowry theory removes restrictions to acid–base reactions in that the theory does not depend on the characteristics of solutions, nor does it require that water be a solvent, or, in fact, that the reactants be dissolved.

SECTIONS 8.3–8.4 QUESTIONS

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Understanding Concepts

1. In strong acids a high percentage of molecules react with water to form hydronium ions. In weak acids a low percentage of molecules react with water to form hydronium ions. It is this difference in hydronium ion concentration that gives strong and weak acids their distinctive properties.
2. Soluble ionic hydroxides are strong bases, as indicated by their empirical properties in solution — they not only taste bitter, feel slippery, turn red litmus blue, and neutralize acids like all bases, but they also have very high pH values (eleven or above) and electrical conductivity, and react rapidly (compared to weak bases with equal concentration). The latter high pH, conductivity, and reaction rate for strong bases are explained by theorizing that they exist (100%) in water as hydroxide ions and electrically balancing cations (e.g., hydroxide ions and sodium ions).
3. Weak bases have the properties of strong bases, but to a lesser degree. In particular, compared to strong base solutions with equal concentration, weak bases form aqueous solutions with pH values above seven (but not above, say, ten), and have conductivity and reaction rates that are low. This is explained by the theory that weak bases are substances that, when they dissolve, react only partially with water to form a low percentage of hydroxide ions in solution.
4. (a) $HBr_{(g)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + Br^-_{(aq)}$

   (b) $KOH_{(s)} \rightarrow K^+_{(aq)} + OH^-_{(aq)}$

   (c) $HC_7H_5O_{2(s)} + H_2O_{(l)} \rightarrow H_3O^+_{(aq)} + C_7H_5O^-_{2(aq)}$

   (d) $Na_2S_{(s)} \rightarrow 2\ Na^+_{(aq)} + S^{2-}_{(aq)}$ followed by $S^{2-}_{(aq)} + H_2O_{(l)} \rightarrow HS^-_{(aq)} + OH^-_{(aq)}$
5. (a) According to the Arrhenius concept, acids are substances that dissolve in water to produce hydrogen ions.
   (b) According to the revised Arrhenius concept, acids are substances that react with water to produce hydronium ions.
   (c) According to the Brønsted-Lowry concept, acids are substances that donate protons in proton-transfer reactions.
6. (a) According to the Arrhenius concept, bases are substances that dissolve in water to produce hydroxide ions. Weak bases are not explained by this concept.
   (b) According to the revised Arrhenius concept, bases are substances that dissolve in water or react with water to produce hydroxide ions. Weak bases react only slightly with water.
   (c) According to the Brønsted-Lowry concept, bases are substances that accept protons in proton-transfer reactions. Weak bases attract protons less strongly than strong bases.
7. According to the Brønsted-Lowry concept, an acid–base reaction involves the transfer of a proton from the acid to the base.
8. (a) Both of the acids and bases in the reaction are listed. The reactant acid and base asked for in the question are given in bold type.

   The acids are $\mathbf{HCO^-_{3(aq)}}$ and $HS^-_{(aq)}$

   The bases are $\mathbf{S^{2-}_{(aq)}}$ and $CO^{2-}_{3(aq)}$

   (b) The acids are $\mathbf{H_2CO_{3(aq)}}$ and $H_2O_{(l)}$

   The bases are $\mathbf{OH^-_{(aq)}}$ and $HCO^-_{3(aq)}$
9. (a)$HSO^-_{4(aq)} + PO^{3-}_{4(aq)} \rightarrow SO^{2-}_{4(aq)} + HPO^{2-}_{4(aq)}$

   (b)$H_3O^+_{(aq)} + HPO^{2-}_{4(aq)} \rightarrow H_2O_{(aq)} + H_2PO^-_{4(aq)}$
10. One acid–base pair is $HCO^-_{3(aq)}$ and $CO^{2-}_{3(aq)}$,

    and the other pair is $H_2CO_{3(aq)}$ and $HCO^-_{3(aq)}$
11. (a) One acid–base pair is $H_3O^+_{(aq)}$ and $H_2O_{(aq)}$,

    and the other pair is $H_2SO_{3(aq)}$ and $HSO^-_{3(aq)}$

    (b) One acid–base pair is $H_2O_{(aq)}$ and $OH^-_{(aq)}$,

    and the other pair is $HSO^-_{3(aq)}$ and $SO^{2-}_{3(aq)}$

Applying Inquiry Skills

12. Baking soda will react both with strong bases and with acids. It releases carbon dioxide gas upon reaction with acids. Since it can react either as an acid or as a base, it is not simple to predict how it will react in any given situation.

    GO TO www.science.nelson.com, Chemistry 11, Teacher Centre.

Making Connections

13. Uses of baking soda include:
    baking — reacts with food acids to produce $CO_{2(g)}$ for leavening
    brushing teeth — a mild non-abrasive non-toxic cleaner
    acid spills — neutralizes them for cleanup
    base spills — neutralizes them for cleanup
    odour removal — reacts with acidic or basic odorous gases in refrigerators, kitchens, and carpets
    firefighting — releases carbon dioxide, which smothers flames
    cleaning — makes a solution for washing surfaces

8.5 ACID–BASE REACTIONS

PRACTICE

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Understanding Concepts

1. Acids react with active metals to produce hydrogen and an ionic compound; react with carbonate compounds to produce carbon dioxide gas and water; and neutralize bases to produce water.
2. (a) $2\ HBr_{(aq)} + Zn_{(s)} \rightarrow H_{2(g)} + ZnBr_{2(aq)}$

   $HBr_{(aq)} + NaOH_{(s)} \rightarrow H_2O_{(l)} + NaBr_{(aq)}$

   $2\ HBr_{(aq)} + Na_2CO_{3(s)} \rightarrow H_2CO_{3(aq)} + 2\ NaBr_{(aq)}$

   or $2\ HBr_{(aq)} + Na_2CO_{3(s)} \rightarrow H_2O_{(l)} + CO_{2(g)} + 2\ NaBr_{(aq)}$

   (b) The first neutralization produces hydrogen, which is flammable and dangerous, and uses zinc, which is not commonly available.
   The second neutralization uses lye (a strong base), which is very corrosive and not easy to handle.
   The third neutralization is practical. It uses washing soda, which is non-hazardous, inexpensive, and commonly available; and produces no dangerous products.
3. (a) $3\ H_2C_2O_{4(aq)} + 2\ Al_{(s)} \rightarrow 3\ H_{2(g)} + Al_2(C_2O_4)_{3(s)}$

   (b) $H_2C_2O_{4(aq)} + CaCl_{2(aq)} \rightarrow 2\ HCl_{(aq)} + CaC_2O_{4(s)}$

   or $H_2C_2O_{4(aq)} + Ca^{2+}_{(aq)} \rightarrow 2\ H^{+}_{(aq)} + CaC_2O_{4(s)}$

   (c) $3\ H_2C_2O_{4(aq)} + FeCl_{3(aq)} \rightarrow 6\ HCl_{(aq)} + Fe_2(C_2O_4)_{3(s)}$

   or $3\ H_2C_2O_{4(aq)} + Fe^{3+}_{(aq)} \rightarrow 6\ H^{+}_{(aq)} + Fe_2(C_2O_4)_{3(s)}$

   Iron(III) ions are removed from solution by reaction with oxalate, effectively preventing the body from using them.

Practice

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Understanding Concepts

4. Acids react with active metals to produce hydrogen and an ionic compound; react with carbonate compounds to produce carbon dioxide gas and water; and neutralize bases to produce water.
5. The requirements are that the chemical reaction must be spontaneous, rapid, quantitative, and stoichiometric.
6. The two reactants in a titration are the sample, usually in an Erlenmeyer flask, and the titrant, usually in a buret.
7. A standard solution is one with a precisely known concentration.

