1. Both acids and bases change color of indicator and are electrolytes. Acids taste sour, react with active metals to release \( H_2(g) \), and react with bases to form salt and water. Bases taste bitter, feel slippery, and react with acids to form salt and water.

2. a. Binary acids consist of hydrogen and a more electronegative element. They are named using the prefix hydro-, followed by the root name of the second element and the suffix -ic. Oxyacids consist of hydrogen, oxygen, and a third element (usually a nonmetal). Oxyacid names are based on the name of the anion.
   
   b. Examples of binary acids: HF, HCl, HBr; examples of oxyacids: HClO₃, HNO₃, H₂SO₄

3. H₂SO₄ is the most common acid, a dehydrating agent, used to make fertilizers, in petroleum refining, in metallurgy, and in automobile batteries. H₃PO₄ is used in making fertilizers, cleaners, and animal feed and as a flavoring agent. HNO₃ is a volatile, unstable liquid that stains proteins yellow. It is used to make fertilizers, explosives, rubber, plastics, dyes, and drugs. HCl, also called muriatic acid, is used as a cleaning agent, in food processing, to pickle iron, and in activating oil wells. Hydrochloric acid is also produced in the stomach to aid digestion. Acetic acid is an organic acid. It is a clear, colorless liquid produced by fermentation of malt, barley, and fruit juices, found in household vinegar, and used to make plastics, food supplements, and fungicides.

4. HCl(g) consists of covalently bonded molecules that do not ionize. Nonpolar solvent molecules do not attract HCl molecules to cause them to be ionized.

5. a. Strong acids ionize completely in dilute aqueous solution; weak acids ionize much less.
   b. Examples of strong acids: HCl, HNO₃; examples of weak acids: HF, H₃PO₄

6. The strength of an acid depends on the degree of ionization; not on the amount of hydrogen in the molecule. HCl ionizes completely. H₃PO₄ ionizes only slightly.

7. a. Concentration of OH⁻ ions in solution
   b. Answers will vary. Example: NaOH, strongly basic; NH₃(aq), weakly basic

8. Monoprotic acids, such as HCl, can donate only one proton per molecule; diprotic acids, such as H₂SO₄, can donate two protons per molecule; and triprotic acids, such as H₃PO₄, can donate three protons per molecule.

9. The Lewis definition is the broadest. Any substance defined as an Arrhenius or Brønsted-Lowry acid is also an acid as defined by the Lewis theory. The reverse is not always true.

10. a. A conjugate base remains after an acid has given up a proton. Example: HF + H₂O → H₂O⁺ + F⁻; acid: HF; conjugate base: F⁻
    b. A conjugate acid is what forms when a proton is added to a base.
       base: H₂O; conjugate acid: H₃O⁺

11. a. The stronger an acid is, the weaker its conjugate base is.
    b. The stronger a base is, the weaker its conjugate acid is.

12. a. Production of the weaker acid and weaker base is favored.
    b. It depends on the relative strengths of the acids and bases involved. For an acid-base reaction to approach completion, the reactants must be much stronger acids and bases than the products.

13. a. The term that describes a species that can react as either an acid or a base
    b. Example: H₃PO₄; the conjugate base of H₃PO₄, and can act as acid to further ionize to HPO₄⁻

    b. Acid: H₂O, conjugate base: OH⁻; base: HCO₃⁻, conjugate acid: H₂CO₃
    c. Acid: HNO₃, conjugate base: NO₃⁻; base: SO₄²⁻, conjugate acid: HSO₄⁻

15. a. HNO₃
    b. H₂S
    c. HS⁻
    d. NO₃⁻

16. Strong acids and bases are readily ionized in solution. For them to remain ionized, the corresponding conjugate base and acid, respectively, must be too weak to compete successfully with them.

17. a. Hydrochloric acid
    b. Hydrobromic acid

18. a. Nitric acid
    b. Sulfurous acid
    c. Chloric acid
    d. Nitrous acid

19. a. HCl
    b. HI

20. a. HBrO₄
    b. HClO₂
    c. H₃PO₄
    d. HClO

21–44 See page 479A.


**REVIEW ANSWERS**

Continued from page 479

21. a. \( \text{H}_2\text{SO}_4(aq) + \text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{O}^+(aq) + \text{HSO}_4^-(aq); \)
\( \text{HSO}_4^-(aq) + \text{H}_2\text{O}(l) \rightarrow 2\text{H}_2\text{O}^+(aq) + \text{SO}_4^{2-}(aq) \)

b. The degree of ionization in the first stage is much greater than that in the second.

22. a. \( \text{HCl}(aq) + \text{KOH}(aq) \rightarrow \text{KCl}(aq) + \text{H}_2\text{O}(l) \)

b. \( \text{H}_2\text{O}^+(aq) + \text{Cl}^-(aq) + \text{K}^+(aq) + \text{OH}^-(aq) \rightarrow \text{K}^+(aq) + \text{Cl}^-(aq) + 2\text{H}_2\text{O}(l) \)

c. \( \text{H}_2\text{O}^+(aq) + \text{OH}^-(aq) \rightarrow 2\text{H}_2\text{O}(l) \)

23. a. \( \text{H}_3\text{PO}_4(aq) + 3\text{NaOH}(aq) \rightarrow 3\text{Na}_2\text{PO}_4(aq) + 3\text{H}_2\text{O}(l) \)

b. \( 3\text{H}_2\text{O}^+(aq) + \text{PO}_4^{3-}(aq) + 3\text{Na}^+(aq) + 3\text{OH}^-(aq) \rightarrow 3\text{Na}^+(aq) + \text{PO}_4^{3-}(aq) + 6\text{H}_2\text{O}(l) \)

c. \( \text{H}_2\text{O}^+(aq) + \text{OH}^-(aq) \rightarrow 2\text{H}_2\text{O}(l) \)

24. a. \( \text{Zn}(s) + 2\text{HCl}(aq) \rightarrow \text{ZnCl}_2(aq) + \text{H}_2(g) \)

Zn(s) + 2H_2O^+(aq) \rightarrow Zn^{2+}(aq) + H_2(g) + 2H_2O(l)

b. \( 2\text{Al}(s) + 3\text{H}_2\text{SO}_4(aq) \rightarrow \text{Al}_2(\text{SO}_4)_3(aq) + 3\text{H}_2(g) \)

2Al(s) + 6H_2O^+(aq) \rightarrow 2Al^{3+}(aq) + 3H_2(g) + 6H_2O(l)

c. \( \text{H}_2\text{O}^+(aq) + \text{OH}^-(aq) \rightarrow 2\text{H}_2\text{O}(l) \)

25. a. \( \text{Ca}(s) + 2\text{HCl}(aq) \rightarrow \text{CaCl}_2(aq) + \text{H}_2(g) \)

Ca(s) + 2H_2O^+(aq) \rightarrow Ca^{2+}(aq) + H_2(g) + 2H_2O(l)

26. a. \( \text{HCl}(aq) + \text{NaOH}(aq) \rightarrow \text{NaCl}(aq) + \text{H}_2\text{O}(l) \)

b. \( \text{H}_2\text{O}^+(aq) + \text{Cl}^-(aq) + \text{Na}^+(aq) + \text{OH}^-(aq) \rightarrow \text{Na}^+(aq) + \text{Cl}^-(aq) + 2\text{H}_2\text{O}(l) \)

27. \( \text{H}_2\text{PO}_4(aq) + 3\text{Mg(OH)}_2(aq) \rightarrow 3\text{Mg}_2\text{PO}_4(aq) + 6\text{H}_2\text{O}(l) \)

6OH^-(aq) + 2PO_4^{3-}(aq) + 3Mg^{2+}(aq) + 6OH^-(aq) \rightarrow 3Mg_2^{2+}(aq) + 2PO_4^{3-}(aq) + 12H_2O(l)

28. a. \( \text{BaCO}_3(s) + 2\text{HCl}(aq) \rightarrow \text{BaCl}_2(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g) \)

b. \( \text{MgCO}_3(s) + 2\text{HNO}_3(aq) \rightarrow \text{Mg(NO}_3)_2(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g) \)

c. \( \text{Na}_2\text{CO}_3(s) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{Na}_2\text{SO}_4(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g) \)

d. \( 3\text{CaCO}_3(s) + \text{2H}_2\text{PO}_4(aq) \rightarrow \text{Ca}_3(\text{PO}_4)_2(aq) + 3\text{H}_2\text{O}(l) + 3\text{CO}_2(g) \)

29. a. \( \text{RbOH}(aq) + \text{HClO}_4(aq) \rightarrow \text{RbClO}_4(aq) + \text{H}_2\text{O}(l) \)

b. \( \text{Ba(OH)}_2(aq) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{BaSO}_4(s) + 2\text{H}_2\text{O}(l) \)

(There are no spectator ions, so the net ionic equation is the same as the overall ionic equation.)
c. \( \text{Ca(OH)}_2(aq) + 2\text{HCl}(aq) \rightarrow \text{CaCl}_2(aq) + 2\text{H}_2\text{O}(l) \)
\( \text{Ca}^{2+}(aq) + 2\text{OH}^- (aq) + 2\text{H}_2\text{O}(aq) + 2\text{Cl}^- (aq) \rightarrow \text{Ca}^{2+}(aq) + 2\text{Cl}^- (aq) + 4\text{H}_2\text{O}(l) \)
\( \text{H}_2\text{O}(aq) + \text{OH}^- (aq) \rightarrow 2\text{H}_2\text{O}(l) \)
(Cancellation of spectator ions gives \( 2\text{H}_2\text{O}^+(aq) + 2\text{OH}^- (aq) \rightarrow 4\text{H}_2\text{O}(l) \); we then divide out the common factor of 2 to give the net ionic equation with smallest integers.)

d. \( 2\text{KOH}(aq) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{K}_2\text{SO}_4(aq) + 2\text{H}_2\text{O}(l) \)
\( 2\text{K}^+(aq) + 2\text{OH}^- (aq) + 2\text{H}_2\text{O}_2^+(aq) + \text{SO}_4^{2-} (aq) \rightarrow 2\text{K}^+(aq) + \text{SO}_4^{2-} (aq) + 4\text{H}_2\text{O}(l) \)
\( \text{H}_2\text{O}_2^+(aq) + \text{OH}^- (aq) \rightarrow 2\text{H}_2\text{O}(l) \) (written with smallest integers)

30. a. 96.9 g ZnSO_4
   b. 13.4 L H_2

31. a. 47.1 g, 24.0 L CO_2
   b. 6.7 g CaCO_3
   c. 0.065 L

33. \( 5.36 \times 10^4 \) kg H_2SO_4

34. a. \( \text{HNO}_3(aq) + \text{LiOH}(aq) \rightarrow \text{LiNO}_3(aq) + \text{H}_2\text{O}(l) \)
   b. \( \text{H}_2\text{O}^+(aq) + \text{NO}_3^-(aq) + \text{Li}^+(aq) + \text{OH}^- (aq) \rightarrow \text{Li}^+(aq) + \text{NO}_3^-(aq) + 2\text{H}_2\text{O}(l) \)
   c. \( \text{H}_2\text{O}^+(aq) + \text{OH}^- (aq) \rightarrow 2\text{H}_2\text{O}(l) \)

35. \( \text{Mg}(s) + 2\text{HCl}(aq) \rightarrow \text{MgCl}_2(aq) + \text{H}_2(g) \)

36. \( \text{H}_2\text{PO}_4(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{H}_2\text{PO}_4^-(aq) \);
greatest degree of ionization
\( \text{H}_2\text{PO}_4(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{HPO}_4^{2-} (aq) \);
less ionization
\( \text{HPO}_4^{2-} (aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{PO}_4^{3-} (aq) \);
least ionization

37. a. hydrofluoric acid
   b. CH_3COOH
   c. H_3PO_4
   d. perchloric acid
   e. phosphoric acid
   f. HBr
   g. hypochlorous acid
   h. carbonic acid
   i. H_2SO_4

38. Answers will vary. Students should provide examples of acids that do not contain oxygen, such as HCl or HBr. They should discuss the different ways an acid can be defined that can either narrow or broaden the definition and that do not in any case require the presence of oxygen in the acid.

39. a. Oxides of nonmetals are acidic.
   b. Acidic anhydrides are oxide compounds that react with water to form acids.

40. a. Basic oxides come from elements on the far left of the table. Elements in the metalloid region of the table form amphoteric oxides. Nonmetals form acidic oxides. Oxide character within a group is related to metallic character within a group.
   b. Reactions of CO_2 with excess NaOH will produce Na_2CO_3. Reactions of CO_2 with a limited amount of NaOH (less than the mole ratio) will result in the production of NaHCO_3.

41. Sulfuric acid is involved in many technical and manufacturing processes. Typically, the more highly industrialized a country is, the greater the level of sulfuric acid consumed by that country in the course of its everyday industrial activities. Thus, sulfuric acid production can serve as a measure of the degree of industrialization and economic activity of a country.

42. Refer to the One-Stop Planner CD-ROM for appropriate scoring rubrics. Answers should include an explanation of how buffers cause solutions to be resistant to changes in acidity or basicity.

43. Answers will vary.

44. Answers should include CaCO_3, NaHCO_3, Mg(OH)_2, and Al(OH)_3.

45. Check the design of students’ experiments before they proceed.