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.

8. Repetition in titration — as elsewhere in science — increases the reliability of the answer. Mistakes can be easily identified and omitted, and averaging several measured values always reduces the effect of normal experimental error.

Applying Inquiry Skills

9. $2\ KOH_{(aq)} \quad + \quad H_2SO_{4(aq)} \rightarrow K_2SO_{4(aq)} + 2\ H_20_{(l)}$

   9.44 mL   10.00 mL

   0.0506 mol/L C

$$n_{KOH} = 9.44\ m\cancel{L} \times \frac{0.0506\ mol}{1\ \cancel{L}} = 0.478\ mmol$$

$$n_{H_2SO_4} = 0.478\ mmol \times \frac{1}{2} = 0.239\ mmol$$

$$C_{H_2SO_4} = \frac{0.239\ \cancel{m}mol}{10.00\ \cancel{m}L}$$

$$C_{H_2SO_4} = 0.0239\ mol/L = 23.9\ mmol/L$$

or $$C_{H_2SO_4} = 9.44\ \cancel{mL}\ \cancel{KOH} \times \frac{0.0506\ \cancel{mol}\ \cancel{KOH}}{1\ L\ \cancel{KOH}} \times \frac{1\ mol\ H_2SO_4}{2\ \cancel{mol}\ \cancel{KOH}} \times \frac{1}{10.00\ \cancel{mL}}$$

$$C_{H_2SO_4} = 0.0239\ mol/L = 23.9\ mmol/L$$

The concentration of sulfuric acid in the water is 23.9 mmol/L.

10. (a) **Evidence**

Table 4: Volume of 0.0161 mol/L Sodium Hydroxide Required to Neutralize 10.00 mL of Diluted Oxalic Acid

Trial	1	2	3	4
Final buret reading (mL)	14.3	27.8	41.1	13.8
Initial buret reading (mL)	0.2	14.3	27.8	0.4
Volume of $NaOH_{(aq)}$ used (mL)	14.1	13.5	13.3	13.4

(b) **Analysis**

$2\ NaOH_{(aq)} \quad + \quad H_2C_2O_{4(aq)} \rightarrow K_2C_2O_{4(aq)} + 2\ H_20_{(l)}$

13.4 mL   10.00 mL

0.0161 mol/L C

$$n_{NaOH} = 13.4\ m\cancel{L} \times \frac{0.0161\ mol}{1\ \cancel{L}} = 0.216\ mmol$$

$$n_{H_2C_2O_4} = 0.216\ mmol \times \frac{1}{2} = 0.108\ mmol$$

$$C_{H_2C_2O_4} = \frac{0.108\ \cancel{m}mol}{10.00\ \cancel{m}L}$$

$$C_{H_2C_2O_4} = 0.0108\ mol/L$$

or $$C_{H_2C_2O_4} = 13.4\ \cancel{mL}\ \cancel{NaOH} \times \frac{0.0161\ \cancel{mol}\ \cancel{NaOH}}{1\ L\ \cancel{NaOH}} \times \frac{1\ mol\ H_2C_2O_4}{2\ \cancel{mol}\ \cancel{NaOH}} \times \frac{1}{10.00\ \cancel{mL}}$$

$$C_{H_2C_2O_4} = 0.0108\ mol/L$$

The concentration of oxalic acid in the rust remover is 100 times the concentration of the diluted acid used in the titration, or 1.08 mol/L.

(c) **Evaluation**

$$\text{difference} = \text{experimental value} - \text{predicted value}$$

$$= 1.08\ mol/L - 1.11\ mol/L$$

$$\text{difference} = -\ 0.03\ mol/L$$

$$\%\ \text{difference} = \left|\frac{\text{difference}}{\text{predicted value}}\right| \times 100\%$$

$$= \frac{0.03\ \cancel{\text{mol}}/\text{L}}{1.11\ \cancel{\text{mol}}/\text{L}} \times 100\%$$

$$= 3\%$$

The % difference is 3%, which is quite acceptable for school lab work.

The prediction based on the manufacturer's label is quite accurate from a scientific point of view: the percentage difference is only 3%, which is quite acceptable.

Note: You might discuss with students that from a legal perspective there *could* be a problem. A commercial label is a legally guaranteed minimum unless specifically stated otherwise, so if the solution *really* has a concentration below 1.11 mol/L, the manufacturer of the rust remover may be in trouble.

11. (a) **Evidence**

Table 5: Titration of 10.00-mL Samples of $HCl_{(aq)}$ with 0.974 mol/L $Ba(OH)_{2(aq)}$

Trial	1	2	3	4
Final buret reading (mL)	15.6	29.3	43.0	14.8
Initial buret reading (mL)	0.6	15.6	29.3	1.2
Volume of $Ba(OH)_{2(aq)}$ added (mL)	15.0	13.7	13.7	13.6
Colour at endpoint	blue	green	green	green

(b) **Analysis**

$$Ba(OH)_{2(aq)} + 2\ HCl_{(aq)} \rightarrow BaCl_{2(aq)} + 2\ H_20_{(l)}$$

13.7 mL   10.00 mL

0.974 mol/L C

$$n_{Ba(OH)_2} = 13.7\ \text{m}\cancel{\text{L}} \times \frac{0.974\ \text{mol}}{1\ \cancel{\text{L}}} = 13.3\ \text{mmol}$$

$$n_{HCl} = 13.3\ \text{mmol} \times \frac{2}{1} = 26.6\ \text{mmol}$$

$$C_{HCl} = \frac{26.6\ \cancel{\text{m}}\text{mol}}{10.00\ \cancel{\text{m}}\text{L}}$$

$$C_{HCl} = 2.66\ \text{mol/L}$$

or $$C_{HCl} = 13.7\ \cancel{\text{mL}}\ Ba\cancel{(OH)_2} \times \frac{0.974\ \cancel{\text{mol}}\ Ba\cancel{(OH)_2}}{} \times \frac{2\ \text{mol HCl}}{1\ \cancel{\text{mol}}\ Ba\cancel{(OH)_2}} \times \frac{1}{10.00\ \cancel{\text{mL}}}$$

$$C_{HCl} = 2.66\ \text{mol/L}$$

The concentration of hydrochloric acid is 2.66 mol/L.

12. $$2\ NaOH_{(aq)} + H_2SO_{4(aq)} \rightarrow Na_2SO_{4(aq)} + 2\ H_20_{(l)}$$

11.48 mL   10.00 mL

0.484 mol/L C

$$n_{NaOH} = 11.48\ \text{m}\cancel{\text{L}} \times \frac{0.484\ \text{mol}}{1\ \cancel{\text{L}}} = 5.56\ \text{mmol}$$

$$n_{H_2SO_4} = 5.56\ \text{mmol} \times \frac{1}{2} = 2.78\ \text{mmol}$$

$$C_{H_2SO_4} = \frac{2.78\ \cancel{\text{m}}\text{mol}}{10.00\ \cancel{\text{m}}\text{L}}$$

$$C_{H_2SO_4} = 0.278\ \text{mol/L}$$

or $$C_{H_2SO_4} = 11.48\ \cancel{\text{mL}}\ \cancel{\text{NaOH}} \times \frac{0.484\ \cancel{\text{mol}}\ \cancel{\text{NaOH}}}{1\ \text{L}\ \cancel{\text{NaOH}}} \times \frac{1\ \text{mol}\ H_2SO_4}{2\ \cancel{\text{mol}}\ \cancel{\text{NaOH}}} \times \frac{1}{10.00\ \cancel{\text{mL}}}$$

$$C_{H_2SO_4} = 0.278\ \text{mol/L}$$

The concentration of sulfuric acid is 0.278 mol/L.

SECTION 8.5 QUESTIONS

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Understanding Concepts

1. Answers will vary, but may include the following typical acid reactions.

   Reaction with active metals:
   $2\ HCl_{(aq)} + Mg_{(s)} \rightarrow H_{2(g)} + MgCl_{2(aq)}$

   Reaction with strong bases:

   $HNO_{3(aq)} + NaOH_{(s)} \rightarrow H_2O_{(l)} + NaNO_{3(aq)}$

   Reaction with carbonate compounds:

   $2\ HCl_{(aq)} + K_2CO_{3(s)} \rightarrow H_2CO_{3(aq)} + 2\ KCl_{(aq)}$

   or $2\ HCl_{(aq)} + K_2CO_{3(s)} \rightarrow H_2O_{(l)} + CO_{2(g)} + 2\ KCl_{(aq)}$

2. $Al(OH)_{3(s)} + 3\ HCl_{(aq)} \rightarrow AlCl_{3(aq)} + 3\ H_2O_{(l)}$

   0.912 g $\quad v$

   78.01 g/mol $\quad$ 0.10 mol/L

   $$n_{Al(OH)_3} = 0.912\ \cancel{g} \times \frac{1\ mol}{78.01\ \cancel{g}} = 0.0117\ mol$$

   $$n_{HCl} = 0.0117\ mol \times \frac{3}{1} = 0.0351\ mol$$

   $$v_{HCl} = 0.0351\ \cancel{mol} \times \frac{1\ L}{0.10\ \cancel{mol}}$$

   $$v_{HCl} = 0.35\ L$$

   or $$v_{HCl} = 0.912\ \cancel{g}\ Al\cancel{(OH)}_3 \times \frac{1\ \cancel{mol}\ Al\cancel{(OH)}_3}{78.01\ \cancel{g}\ Al\cancel{(OH)}_3} \times \frac{3\ \cancel{mol}\ \cancel{HCl}}{1\ \cancel{mol}\ Al\cancel{(OH)}_3} \times \frac{1\ L\ HCl}{0.10\ \cancel{mol}\ \cancel{HCl}}$$

   $$v_{HCl} = 0.35\ L$$

   The volume of hydrochloric acid neutralized is 0.35L.

3. $Ca(OH)_{2(s)} + H_2SO_{4(aq)} \rightarrow CaSO_{4(s)} + 2\ H_2O_{(l)}$

   1.0×10^6 g $\quad v$

   74.10 g/mol $\quad 1.2 \times 10^{-3}$ mol/L

   $$n_{Ca(OH)_2} = 1.0 \times 10^6\ \cancel{g} \times \frac{1\ mol}{74.10\ \cancel{g}} = 1.4 \times 10^4\ mol$$

   $$n_{H_2SO_4} = 1.4 \times 10^4\ mol \times \frac{1}{1} = 1.4 \times 10^4\ mol$$

   $$v_{H_2SO_4} = 1.4 \times 10^4\ \cancel{mol} \times \frac{1\ L}{1.2 \times 10^{-3}\ \cancel{mol}}$$

   $$v_{H_2SO_4} = 1.1 \times 10^7\ L$$

   or $$v_{H_2SO_4} = 1.0 \times 10^6\ \cancel{g}\ Ca\cancel{(OH)}_2 \times \frac{1\ \cancel{mol}\ Ca\cancel{(OH)}_2}{74.10\ \cancel{g}\ Ca\cancel{(OH)}_2} \times \frac{1\ \cancel{mol}\ H_2\cancel{SO}_4}{1\ \cancel{mol}\ Ca\cancel{(OH)}_2} \times \frac{1\ L\ H_2SO_4}{\quad}$$

   $$v_{H_2SO_4} = 1.1 \times 10^7\ L$$

   The volume of lake water sulfuric acid that can be neutralized is 1.1×10^7 L (or $1.1 \times 10^4\ m^3$).

Applying Inquiry Skills

4. **Experimental Design (1)**

A sample of sodium hydroxide solution is titrated with standard hydrochloric acid, and the concentration of sodium hydroxide is calculated from the measured volume of hydrochloric acid using the stoichiometric method.

Materials (1)

- lab apron
- eye protection
- standard $HCl_{(aq)}$
- $NaOH_{(aq)}$
- bromothymol blue
- wash bottle of pure water
- 100-mL or 150-mL beake
- 250-mL beaker
- 50-mL buret
- 10-mL volumetric pipet
- pipet bulb
- ring stand
- buret clamp
- stirring rod
- small funnel
- 250-mL Erlenmeyer flask
- meniscus finder

Experimental Design (2)

A sample of sodium hydroxide solution is reacted with excess lead(II) nitrate solution, and the precipitate is filtered and dried; and the concentration of sodium hydroxide is calculated from the measured mass of lead(II) hydroxide precipitate using the stoichiometric method.

Materials (2)

- lab apron
- eye protection
- standard $Pb(NO_3)_{2(aq)}$
- $NaOH_{(aq)}$
- wash bottle of pure water
- 250-mL beaker
- 400-mL beaker
- 10-mL volumetric pipet
- pipet bulb
- ring stand
- iron ring
- stirring rod
- small funnel
- filter paper
- centigram balance

5. **Experimental Design**

A sample of oxalic acid solution is titrated with standard sodium hydroxide solution, and the concentration of oxalic acid is calculated from the measured volume of sodium hydroxide using the stoichiometric method.

Materials (1)

- lab apron
- eye protection
- standard $NaOH_{(aq)}$ (known concentration)
- $H_2C_2O_{4(aq)}$
- bromothymol blue
- wash bottle of pure water
- 100-mL beaker
- 150-mL beaker
- 50-mL buret
- 10-mL volumetric pipet
- pipet bulb
- ring stand
- buret clamp
- tirring rod
- small funnel
- 250-mL Erlenmeyer flask
- meniscus finder
- toxic waste disposal container

Procedure

1. Obtain about 50 mL of oxalic acid in a clean, dry 100-mL beaker.
2. Obtain about 70 mL of $NaOH_{(aq)}$ in a clean, dry, labelled 150-mL beaker.
3. Set up the buret with $NaOH_{(aq)}$ following the accepted procedure for rinsing and clearing the air bubble (see Skills Handbook).
4. Pipet a 10.00-mL sample of oxalic acid into a clean Erlenmeyer flask. (Caution: Oxalic acid is toxic. Use a pipet bulb.)
5. Add 1 or 2 drops of bromothymol blue indicator.
6. Record the initial buret reading to the nearest 0.1 mL.
7. Titrate the sample with $NaOH_{(aq)}$ until a single drop produces a permanent change from pale yellow to pale blue.
8. Record the final buret reading to the nearest 0.1 mL.
9. Dispose of the flask contents by rinsing into a toxic waste container.
10. Repeat steps 4 to 9 until three consistent results (to $\pm$ 0.1 mL) are obtained.