Synthesis

(m) Based on this investigation, acidic solutions must be diluted by a very large amount to change the pH value. If a solution is diluted by a factor of ten, the pH changes by one unit. Thus, acid waste should not be dumped into rivers and lakes. A small amount of acidic waste could have a significant impact on the pH of surrounding water.

(n) If 0.1-mol/L sodium hydroxide solution, $NaOH_{(aq)}$, had been used in this investigation, the results would be similar in that, as the solution is diluted by a factor of ten, the pH changes by one unit. However, the pH value would start high, such as 13, and decrease by one pH unit for each dilution.

(o) The dilution of concentrated solutions is commonly performed to adjust the strength of the active ingredient for practical use. For example, floor cleaners are commonly diluted prior to use.

Part 2: pH of a Water Sample

(p) Results will vary depending on the pH of the unknown sample. A sample pH value is given in **Table 1**.

Analysis

(q) The calculated $[H^+]$ in the water sample will depend on the pH of the unknown solution. The $[H^+]$ of the sample is given in **Table 1**.

Evaluation

(r) Student answers will vary depending on students' analyses of their experimental design and procedure. One source of error is incorrectly interpreting the pH indicator. Using a pH indicator and colorimetric analyses are subject to error during interpretation. Evidence that is more precise may be gathered using a pH meter instead of a pH indicator to determine the final pH value of the sample.

Synthesis

(s) A colorimeter measures the absorption of different wavelengths of light by a sample. Many colorimeters contain light-emitting diodes that produce lights of four different colours (**Table 2**). The colorimeter also has a photodiode that measures the quantity of light that passes through a sample. This quantity is the quantity of transmitted light, or percent transmission. Most colorimeters are interfaced to a computer, which displays the quantity of transmitted light.

Table 2 Colour and Wavelength

Colour	Blue	Green	Orange	Red
Wavelength (nm)	460	565	630	697

Data from a colorimeter can be used to create a graph of the percent-transmitted light versus the sample concentration, and the optical density versus the sample concentration. Using these graphs, you can estimate the concentration of a coloured component in an unknown sample.

A colorimeter may improve the accuracy of results obtained in this investigation by providing a sensitive method of measuring colour changes of the pH indicator.

The results obtained using a colorimeter would be very similar to values measured with a pH meter. Both techniques provide a precise, accurate way to determine the pH of a solution. To obtain the most reliable measurements, pH values can be determined using both methods.

4.10 INVESTIGATION: ACID–BASE REACTIONS

(Pages 312–315)

Prediction

(a) **Part 1**

$Zn_{(s)} + 2\ HCl_{(aq)} \rightarrow H_{2(g)} + ZnCl_{2(aq)}$

$NaHCO_{3(s)} + HCl_{(aq)} \rightarrow H_2O_{(l)} + CO_{2(g)} + NaCl_{(aq)}$

$CaCO_{3(s)} + 2\ HCl_{(aq)} \rightarrow H_2O_{(l)} + CO_{2(g)} + CaCl_{2(aq)}$

$2\ Al_{(s)} + 6\ NaOH_{(aq)} \rightarrow 2\ Na_3AlO_{3(aq)} + 3\ H_{2(g)}$

Part 2

$S_{(s)} + O_{2(g)} \rightarrow SO_{2(g)}$ $\quad$ $SO_{2(g)} + H_2O_{(l)} \rightarrow H_2SO_{3(aq)}$ (sulfurous acid)

$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$ $\quad$ $CO_{2(g)} + H_2O_{(l)} \rightarrow H_2CO_{3(aq)}$ (carbonic acid)

$2\ Mg_{(s)} + O_{2(g)} \rightarrow 2\ MgO_{(s)}$ $\quad$ $MgO_{(s)} + H_2O_{(l)} \rightarrow Mg(OH)_{2(aq)}$ (magnesium hydroxide)

$3\ Fe_{(s)} + 2\ O_{2(g)} \rightarrow Fe_3O_{4(s)}$ $\quad$ $Fe_3O_{4(s)} + H_2O_{(l)} \rightarrow$ no reaction

(b) Acids that contribute to acid precipitation are carbonic acid, $H_2CO_{3(aq)}$, sulfuric acid, $H_2SO_{4(aq)}$, sulfurous acid, $H_2SO_{3(aq)}$, and nitric acid, $HNO_{3(aq)}$. Carbonic acid and sulfurous acid appear as products in Part 2 of the investigation.

Part 1: Reactions of Acids and Bases

Observations

Table 1 Observations of Chemical Reactions of Acids and Bases

Reactants	Observations of chemical reaction	Test for products
mossy zinc hydrochloric acid	Bubbles indicate that a gas is produced.	There is a loud ‘popping’ noise when a lighted splint is brought near the opening of the test tube.
sodium hydrogen carbonate hydrochloric acid	Bubbles indicate that a gas is produced.	Limewater becomes cloudy as it trickles down the side of the test tube.
marble chip hydrochloric acid	Bubbles indicate that a gas is produced.	Limewater becomes cloudy as it trickles down the side of the test tube.
aluminum sodium hydroxide solution	The test tube feels warm. Bubbles indicate that a gas is produced.	There is a loud “popping” noise when a lighted splint is brought near the opening of the test tube.

Analysis

(c) When the lighted splint was placed at the mouth of the test tube in step 2, there was a loud popping noise. This sound indicates that hydrogen gas is produced.

(d) Zinc metal + hydrochloric acid → hydrogen gas + zinc chloride
$Zn_{(s)} + 2\ HCl_{(aq)} \rightarrow H_{2(g)} + ZnCl_{2(aq)}$

(e) As the limewater was added to the test tube in step 3, it began to turn cloudy, indicating the presence of carbon dioxide gas.
sodium hydrogen carbonate + hydrochloric acid → water + carbon dioxide + sodium chloride
$NaHCO_{3(s)} + HCl_{(aq)} \rightarrow H_2O_{(l)} + CO_{2(g)} + NaCl_{(aq)}$

(f) As the limewater was added to the test tube in step 4, it began to turn cloudy, indicating the presence of carbon dioxide gas.
calcium carbonate + hydrochloric acid → water + carbon dioxide + calcium chloride
$CaCO_{3(s)} + 2\ HCl_{(aq)} \rightarrow H_2O_{(l)} + CO_{2(g)} + CaCl_{2(aq)}$

(g) The chemical test for carbon dioxide gas is to add limewater. If the limewater turns cloudy, carbon dioxide gas is present. Limewater, or aqueous calcium hydroxide, reacts with carbon dioxide gas to produce water and calcium carbonate precipitate. The precipitate gives the limewater a cloudy appearance.

(h) As a lighted splint was brought near the test tube in step 6, there was a loud popping noise. This sound indicates that the gas produced from the reaction in step 5 is likely hydrogen.

(i) Some of the characteristic chemical reactions of acids are that they react with metals to produce hydrogen gas and that they react with carbonates to produce carbon dioxide gas. Bases react with metals to produce hydrogen gas and release heat.

Evaluation

(j) Acids react with metals to produce hydrogen gas and react with carbonates to produce carbon dioxide gas. Bases react with metals to produce hydrogen gas and heat.

(k) Student answers will vary depending on the Prediction. Refer to question (a) for the predicted chemical equations of each reaction.

(l) Student answers may vary. Sources of uncertainty or error include not observing the changes and impurities in the reactants. Suggestions for improvements include increasing the quantities of reactants or attaching a one-hole rubber stopper and glass tube to the test tube that directs the carbon dioxide produced directly through the limewater.

Synthesis

(m) $2\ Al_{(s)} + 6\ NaOH_{(aq)} \rightarrow 2\ Na_3AlO_{3(aq)} + 3\ H_{2(g)}$
This chemical reaction can clear a drain that is clogged with fat because the alkali component (sodium) reacts with the fat to chemically disrupt the clog in a drain. The formation of hydrogen gas also causes bubbling to help with the mechanical disruption of a fat blockage.

(n) Baking soda, $NaHCO_3$, reacts with an acid to produce water and carbon dioxide gas. The carbon dioxide gas acts as a leavening agent to cause baked goods to rise. The production of carbon dioxide gas is most efficient when baking soda is combined with an acidic ingredient, such as buttermilk or sour milk.

Part 2: Acidic and Basic Oxides

Observations

Table 2 Properties of Oxides

Element burned		Observations during burning		Oxide produced	Indicator colour of oxide solution	pH of oxide solution	Nature of oxide in water (acid, base, or neutral)
Name	Symbol	In air	In oxygen				
sulfur	S	burns	bright blue flame	SO_2, SO_3	red	varies	acid
carbon	C	burns	burns brightly, sparks	CO_2	red	varies	acid
magnesium	Mg	burns	burns very brightly	MgO	blue	varies	base
iron	Fe	burns	burns brightly, sparks	Fe_3O_4	no change	varies	neutral

Analysis

(o) Each of the elements burned more vigorously in pure oxygen than in air.

(p) Metal oxides react with water to form basic or neutral solutions. Nonmetal oxides react with water to form acidic solutions.

(q) The pH of the water does not change when combined with iron oxide because the oxide, Fe_3O_4, is insoluble.

(r)

Element in oxygen	Oxide in water
$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$	$CO_{2(g)} + H_2O_{(l)} \rightarrow H_2CO_{3(aq)}$ (carbonic acid)
$S_{(s)} + O_{2(g)} \rightarrow SO_{2(g)}$	$SO_{2(g)} + H_2O_{(l)} \rightarrow H_2SO_{3(aq)}$ (sulfurous acid)
$2\ S_{(s)} + 3\ O_{2(g)} \rightarrow 2\ SO_{3(g)}$	$SO_{3(g)} + H_2O_{(l)} \rightarrow H_2SO_{4(aq)}$ (sulfuric acid)
$2\ Mg_{(s)} + O_{2(g)} \rightarrow 2\ MgO_{(g)}$	$MgO_{(g)} + H_2O_{(l)} \rightarrow Mg(OH)_{2(aq)}$ (magnesium hydroxide)

(s) Oxide solutions formed from nonmetals react with water to form acids. The two major acids present in acidic precipitation are sulfuric acid, $H_2SO_{4(aq)}$, and nitric acid, $HNO_{3(aq)}$. Thus, aqueous oxide solutions of nonmetals are the major components of acid precipitation.

The reaction of sulfur oxides with water explains how sulfurous and sulfuric acids are formed in the atmosphere. Sulfuric acid is a strong acid, like hydrochloric acid, so it reacts with metal window frames and ornaments, breaking down the metal and producing hydrogen gas. Similarly, acid precipitation reacts with limestone or marble structures, including statues, to release carbon dioxide gas. In both cases, the solids deteriorate during the chemical reactions that occur.

Evaluation

(t) Student answers may vary. Sources of error include the loss of the gas produced during some of the reactions, the quantities used, the purity of the samples, and the time for the reaction. A suggestion for improvements may include increasing the quantities of reactants.

Synthesis

(u) If an acidic solution, such as lemon juice or a soft drink, were allowed to remain on the metal shelves in a refrigerator, the metal would likely corrode or become oxidized. This effect could lead to the deterioration of the metal shelves.

(v) You should never use an oven cleaner on aluminum pots and pans because oven cleaner contains a base, such as sodium hydroxide, which reacts with aluminum to form hydrogen gas. The pots and pans would become damaged by this reaction, and there is a potential explosion from the large amounts of hydrogen gas produced.

(w) Some buildings, marble statues, and metal bridges are composed of limestone, $CaCO_3$, and metals. All of these substances react with acidic solutions. Therefore, acidic precipitation can cause the deterioration of these structures.

4.11 REACTIONS OF ACIDS AND BASES

PRACTICE

(Page 318)

Understanding Concepts

1. (a) A characteristic chemical reaction of a known reactant yields specific products. For example, all acids react with active metals to produce hydrogen gas. You can gain clues about an unknown substance by seeing how it participates in a reaction and by observing the formation of specific products.

   (b) Acid–metal reaction: acid + active metal $\rightarrow$ salt + $H_{2(g)}$
   $2\ HCl_{(aq)} + Cu_{(s)} \rightarrow CuCl_{2(aq)} + H_{2(g)}$
   Acid–carnbonate reaction: acid + carbonate $\rightarrow$ salt + $CO_{2(g)} + H_2O_{(l)}$
   $2\ HCl_{(aq)} + MgCO_{3(s)} \rightarrow MgCl_{2(aq)} + CO_{2(g)} + H_2O_{(l)}$
   Acid–base reaction: acid + base $\rightarrow$ salt + $H_2O_{(l)}$
   $2\ HCl_{(aq)} + Ba(OH)_{2(aq)} \rightarrow BaCl_{2(aq)} + 2\ H_2O_{(l)}$

2. (a) Balanced chemical equations for the neutralization of hydrochloric acid:
   $6\ HCl_{(aq)} + 2\ Al_{(s)} \rightarrow 2\ AlCl_{3(aq)} + 3\ H_{2(g)}$
   $HCl_{(aq)} + NaOH_{(aq)} \rightarrow NaCl_{(aq)} + H_2O_{(l)}$
   $2\ HCl_{(aq)} + Na_2CO_{3(s)} \rightarrow 2\ NaCl_{(aq)} + CO_{2(g)} + H_2O_{(l)}$

   (b) The advantage of neutralizing hydrochloric acid with aluminum is that one mole of aluminum, $Al_{(s)}$, neutralizes three times as much hydrochloric acid, $HCl_{(aq)}$. One disadvantage of neutralizing hydrochloric acid with aluminum is that potentially explosive hydrogen gas is produced.

   The advantage of neutralizing hydrochloric acid with sodium hydroxide, $NaOH_{(aq)}$, is that harmless sodium chloride, $NaCl_{(aq)}$, and water are produced. The disadvantage of neutralization with a strong base is that the reaction may release dangerous amounts of heat.

   The advantage of neutralizing hydrochloric acid with sodium carbonate, $Na_2CO_{3(s)}$, is that one mole of sodium carbonate neutralizes two times as much hydrochloric acid. The disadvantage of neutralizing hydrochloric acid with sodium carbonate is that carbon dioxide gas is released, which may cause a glass container to explode.

3. (a) $KOH_{(aq)} + HCl_{(aq)} \rightarrow KCl_{(aq)} + H_2O_{(l)}$
   (b) $LiOH_{(aq)} + HNO_{3(aq)} \rightarrow LiNO_{3(aq)} + H_2O_{(l)}$
   (c) $2\ KOH_{(aq)} + H_2SO_{4(aq)} \rightarrow K_2SO_{4(aq)} + 2\ H_2O_{(l)}$