(c) The concentration of acetic acid given on the label is 5%, that is, 5% W/V, or 5 g of acetic acid per 100 mL of vinegar. To find the concentration of acetic acid on the label,

$m_{HC_2H_3O_2} = 5.0 \text{ g}$

$v_{HC_2H_3O_2} = 100 \text{ mL} = 0.100 \text{ L}$

$M_{HC_2H_3O_2} = 60.06 \text{ g/mol (calculated from periodic table values)}$

$c_{HC_2H_3O_2} = ?$

$n_{HC_2H_3O_2} = 5.0 \text{ g } HC_2H_3O_2 \times \dfrac{1 \text{ mol } HC_2H_3O_2}{60.06 \text{ g } HC_2H_3O_2}$

$n_{HC_2H_3O_2} = 0.083 \text{ mol } HC_2H_3O_2$

$c_{HC_2H_3O_2} = \dfrac{n_{HC_2H_3O_2}}{v_{HC_2H_3O_2}}$

$\qquad = \dfrac{0.083 \text{ mol } HC_2H_3O_2}{0.100 \text{ L}}$

$c_{HC_2H_3O_2} = 0.83 \text{ mol/L}$

$\% \text{ difference} = \dfrac{|0.86 \text{ mol/L} - 0.83 \text{ mol/L}|}{0.83 \text{ mol/L}} \times 100\%$

$\% \text{ difference} = 3.6\%$

The molar concentration of acetic acid in a sample of vinegar from the school cafeteria is only about 3.6% more than the advertised value of 0.83 mol/L.

Evaluation

(d) The observations obtained appear satisfactory because three consistent results were obtained and no unexpected or unusual observations were made. Titration is a well-known experimental technique and it appears adequate in this quality control analysis.

(e) It is unlikely that someone is diluting the vinegar. The slight difference between the experimental value and the concentration from the label can be accounted for by various experimental errors, such as measurement uncertainties in the pipette, burette, and volumetric flask, and some slight error in the given concentration of the sodium hydroxide solution.

4.13 ACID RAIN

TRY THIS ACTIVITY: A MARBLE REACTION

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Observations from the activity are recorded in **Table 1.**

Table 1 Observations of Reaction of Marble Chips with $H_2SO_{4(aq)}$

Reactants	Initial mass of marble chips (g)	Observations of reaction	Mass of dried unreacted marble chips (g)
marble chips and dilute sulfuric acid	5.652	• when sulfuric acid is added, vigorous bubbling occurs • bubbles form on the surfaces of the marble chips and rise to the surface of the sulfuric acid solution	5.294

(a) The mass of the marble chips decreased from 5.652 g to 5.294 g, a decrease of 0.358 g.

(b) The limestone (calcium carbonate) in the marble chips reacted with the sulfuric acid, according to the following equation:

$$CaCO_{3(s)} + H_2SO_{4(aq)} \rightarrow CaSO_{4(s)} + CO_{2(aq)} + H_2O_{(l)}$$

Since the marble chips contain large amounts of calcium carbonate, they do not react completely with the sulfuric acid that is available. The mass of marble chips that remains after the reaction is complete is less than the original mass of the marble chips because some of the calcium carbonate has been converted to dissolved calcium sulfate, carbon dioxide, and water.

SECTION 4.13 QUESTIONS

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Understanding Concepts

1. (a) The approximate pH of normal rain is 5.6.

   (b) The pH of normal rain is not 7.0 because rain contains carbonic acid, $H_2CO_{3(aq)}$, and is, therefore, slightly acidic. Carbonic acid is formed when carbon dioxide, $CO_{2(g)}$, which is produced by all living organisms, reacts with water in the atmosphere.

2. (a) Nitrogen oxides, $NO_{x(g)}$, and sulfur oxides, $SO_{x(g)}$, are largely responsible for acid precipitation.

   (b) Nitrogen oxides are naturally produced by lightning strikes and plant decay. These gases are also produced during the combustion of fossil fuels in an internal combustion engine.
   Sulfur oxides are naturally produced by volcanic eruptions. Sulfur dioxide, $SO_{2(g)}$, is a product of the combustion of coal and oil, and the smelting of sulfur-containing ores.

3. The steps involved in the formation of acid precipitation begin with the release of nitrogen oxides and sulfur oxides, in the form of gases, from a variety of natural and human-related sources. These oxides can travel long distances in the atmosphere, which allows time for the oxides to react with water to produce acids. These acids lower the pH of the precipitation to below 5.6, forming acid precipitation.

4. Liming is one chemical method that is used to reverse the process of acidification in a lake. Large amounts of calcium carbonate, or limestone, are added to a lake to reduce the acidity of the water and surrounding soil. Calcium carbonate, $CaCO_{3(s)}$, is a basic compound that neutralizes acids in the lake water.

5. (a) $CO_{2(g)} + H_2O_{(l)} \rightarrow H_2CO_{3(aq)}$

   (b) $2\ NO_{2(g)} + H_2O_{(l)} \rightarrow HNO_{3(aq)} + HNO_{2(aq)}$

   (c) $SO_{2(g)} + H_2O_{(l)} \rightarrow H_2SO_{3(aq)}$

6. Student answers may vary. Burning fossil fuels and wood, burning coal that contains sulfur, and smelting metal ore that contains sulfur

7. Acid rain is less of a problem in the Great Lakes Basin than in lakes in northern Ontario because much of the bedrock in the Great Lakes basin is composed of limestone, or calcium carbonate, $CaCO_{3(s)}$. Limestone neutralizes much of the acid precipitation that falls in this area. Lakes in northern Ontario are more affected by acid precipitation because of the low limestone content of the granite and igneous rocks of the Canadian Shield. In northern Ontario, little neutralization of acid precipitation occurs before the water enters waterways, streams, and lakes.

Making Connections

8. Student answers will vary depending on the topic chosen and the research resources used.

   Environmental consequences of acid rain

   Acid rain has many environmental consequences. Acidified lakes cannot support the same variety of life as healthy lakes (refer to **Table 1** in the Student Text). Some organisms, such as lake-bottom plants and mosses, and blackfly larvae, benefit from the increased acidity. As fish and other organisms disappear from the lake, terrestrial wildlife and fish-eating birds also disappear.

   Acid rain affects trees by damaging the surfaces of leaves and needles, and inhibiting plant germination and reproduction. Forest soils also lose valuable nutrients after exposure to acid rain, which causes trees to grow more slowly or to stop growing. The loss of nutrients in forest soils may affect the sustainability of forests in areas susceptible to acid rain.

   Acid rain can also affect human health. Fine airborne particles of sulfate, which pose a health hazard, are formed when sulfur dioxide reacts with water vapour and other chemicals in the air.

Economic consequences of acid rain

Acid rain affects fish populations, forests, and plants. Lower productivity in fisheries, forestry, and agriculture means lower profits and fewer jobs for these industries. Acid rain also causes metal structures to corrode, and limestone buildings and marble statues to deteriorate. The cost of maintaining structures or repairing affected structures increases costs.

There are also costs involved in human health, such as the costs of increased care for people affected by sulfur dioxide emissions. Acid rain indirectly causes 550 premature deaths per year, 1520 emergency room visits per year, and 210 070 asthma symptom days per year. It is estimated that the costs involved in these health issues range from $500 million per year to $5 billion per year.

9. Trees and other plants use carbon dioxide in the process of photosynthesis. By planting a greater number of trees, the amount of carbon dioxide in the atmosphere would be reduced. As carbon dioxide levels decrease, less carbonic acid would form and fall as acid precipitation.

Extension

10. Students' position papers will vary depending on the role chosen and the resources used. A list of questions is provided for each of the roles. These questions are intended as a starting point for students to begin their research.

Local provincial politician/Municipal politician

- What impact does the pulp and paper company have on the local economy?
- What is the general consensus among voters?
- How many new jobs will be created by this company?
- Will any jobs or occupations be in jeopardy by the presence of this company?
- What views regarding environmental concerns does my political party hold?
- What laws or regulations governing new industry or environmental protection are in place?

Spokesperson for the company

- What measures are we taking to reduce the impact of the pulp and paper plant on the environment?
- Have we met all laws and regulations regarding the new plant and its environmental impact?
- What contribution will my company make to the community?
- If pollution does occur, how will my company attempt to rectify the situation?

Environmental activist

- What effect does acid rain have on trees and soil?
- How does the effect of acid rain on trees and soil affect us?
- What happens when lakes and aquatic systems become acidic?
- How will the new pulp and paper plant contribute to acid rain?
- What are the danger signs of the effect of acid rain on aquatic systems?
- Are there any health problems associated with acid rain?
- What are some of the indirect effects of acid rain on humans? Does acid rain affect our sources of food, water, and air?

Aboriginal person from the nearby community

- What is the effect of acid rain on aquatic and terrestrial systems?
- How will fish, birds, and other wildlife be affected by acid rain?
- Will the numbers of fish and wildlife species be reduced?
- How else will animals be affected? Will they be exposed to other chemicals released by acid precipitation?
- If our food supply becomes compromised, where will we find food to feed ourselves and our families?
- Will the local, provincial, or federal governments support us if our food supply becomes scarce or contaminated?
- How will we maintain our local economy if we can no longer hunt or fish?

Average citizen

- How will the pulp and paper plant contribute to our local economy?
- Will a large number of local people be employed by the plant?
- Will my property taxes increase with a large new business in the area?
- How will our local water supply be affected by any pollution from the plant?
- What effect will the plant have on the health and well being of my family?
- What does acid rain do to our buildings, roads, highways, and bridges?