% yield = \( \frac{5.1 \text{ g}}{6.11 \text{ g}} \times 100 = 83\% \)

9. (a) \( 2 \text{ K}_3\text{PO}_4(\text{aq}) + 3 \text{ Pb(NO}_3)_2(\text{aq}) \rightarrow \text{ Pb}_3(\text{PO}_4)_2(\text{s}) + 6 \text{ KNO}_3(\text{aq}) \)

\[
\begin{align*}
\text{mass of K}_3\text{PO}_4 & = 50.00 \text{ mL} \\
\text{mass of Pb(NO}_3)_2 & = V \times 0.200 \text{ mol} / 1 L
\end{align*}
\]

Potassium phosphate is intended to be the limiting reagent.

(b) 

\[
\begin{align*}
\text{n}_\text{K}_3\text{PO}_4 & = 50.00 \text{ mL} \times \frac{0.200 \text{ mol}}{1 L} = 10.0 \text{ mmol} \\
\text{n}_\text{Pb(NO}_3)_2 & = 10.0 \text{ mmol} \times \frac{3}{2} = 15.0 \text{ mmol} \\
\text{V}_\text{Pb(NO}_3)_2 & = 15.0 \text{ mmol} \times \frac{1 L}{0.120 \text{ mmol}} = 125 \text{ mL}
\end{align*}
\]

or

\[
\begin{align*}
\text{V}_\text{Pb(NO}_3)_2 & = 50.00 \text{ mL} \times \frac{0.200 \text{ mol} \text{ K}_3\text{PO}_4}{1 L \text{ K}_3\text{PO}_4} \times \frac{3 \text{ mol} \text{ Pb(NO}_3)_2}{2 \text{ mol} \text{ K}_3\text{PO}_4} \times \frac{1 L \text{ Pb(NO}_3)_2}{0.120 \text{ mol} \text{ Pb(NO}_3)_2} \times \frac{1}{0.120 \text{ mol} \text{ Pb(NO}_3)_2}
\end{align*}
\]

(c) \( 110\% \times 125 \text{ mL} = 138 \text{ mL} \)

The instructor should tell the students to use at least 138 mL of lead(II) nitrate solution.

(d) To test for completeness, students could add a few more drops of the excess reagent solution (using a medicine dropper) and allow it to run down the side of the reaction container, after the precipitate has settled. If there is any cloudiness visible when this solution reaches the solution above the precipitate then there are still phosphate ions in the solution.

8.4 TITRATION ANALYSIS

Investigation 8.3: Standardization Analysis of NaOH(aq) (Demonstration)

(Pages 331, 342)

Purpose

The purpose of this investigation is to use a titration design to standardize a solution for future chemical analysis.

Problem

What is the concentration of a stock NaOH(aq) solution?

Evidence

mass of KHP used to prepare 100 mL of 0.150 mol/L solution = 3.06 g

Table 1: Volume of NaOH(aq) Required to React with 10.00 mL of KHP Solution

<table>
<thead>
<tr>
<th>Trial</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final burette reading (mL)</td>
<td>10.7</td>
<td>21.1</td>
<td>31.5</td>
</tr>
<tr>
<td>Initial burette reading (mL)</td>
<td>0.2</td>
<td>10.7</td>
<td>21.1</td>
</tr>
<tr>
<td>Volume of NaOH(aq) added (mL)</td>
<td>10.5</td>
<td>10.4</td>
<td>10.4</td>
</tr>
</tbody>
</table>
Analysis

average volume of NaOH(aq) = \( \frac{10.5\text{mL} + 10.4\text{mL} + 10.4\text{mL}}{3} = 10.4\text{mL} \)

\[ \text{KC}_7\text{H}_4\text{O}_2\text{COOH}(aq) + \text{NaOH}(aq) \rightarrow \text{KNaC}_7\text{H}_4\text{O}_2\text{COO}(aq) + \text{H}_2\text{O} (l) \]

10.00 mL 10.4 mL

0.150 mol/L

\[ n_{\text{KHP}} = 10.00 \text{ mL} \times \frac{0.150 \text{ mol}}{1 \text{ L}} = 1.50 \text{ mmol} \]

\[ n_{\text{NaOH}} = 1.50 \text{ mmol} \times \frac{1}{1} = 1.50 \text{ mmol} \]

\[ [\text{NaOH}] = \frac{1.50 \text{ mmol}}{10.4 \text{ mL}} = 0.144 \text{ mol/L} \]

or

\[ [\text{NaOH}] = 10.00 \text{ mL} \times \frac{0.150 \text{ mol KHP}}{1 \text{ mol KHP}} \times \frac{1 \text{ mol NaOH}}{1 \text{ mol KHP}} \times \frac{1}{10.4 \text{ mL NaOH}} \]

\[ = 0.144 \text{ mol/L NaOH} \]

According to the evidence collected, the amount concentration of sodium hydroxide solution is 0.144 mol/L.

Practice

(Page 331)

1. Once the burette has been washed with distilled water, rinse the burette with a small volume of titrant. It will not matter if the inside of the burette is wet, as long as the liquid in it is the same solution that will be used to fill it.

2. Pipettes are used to ensure that equal volumes of the samples are taken. The procedure used for taking each successive sample should be identical to ensure that all samples are precisely the same.

3. Doing multiple trials and averaging the answers, increases the certainty and reliability of the result.

4. An indicator is used. This is a substance that changes colour in response to changes in pH in the reaction solution.

Investigation 8.4: Titration Analysis of Vinegar

(Pages 331, 343)

Purpose

The purpose of this investigation is to test the manufacturer’s claim of the concentration of acetic acid in a consumer sample of vinegar.

Problem

What is the amount concentration of acetic acid in a sample of vinegar?

Materials

- lab apron
- eye protection
• distilled or deionized water
• 2 - 100 mL or 150 mL beakers
• 250 mL beaker
• 2 - 250 mL Erlenmeyer flasks
• 100 mL volumetric flask with stopper
• 10 mL volumetric pipette and bulb
• 50 mL burette
• small funnel
• medicine dropper
• laboratory stand
• burette clamp
• meniscus finder
• phenolphthalein indicator
• NaOH(aq)
• vinegar

Procedure
1. Obtain about 40 mL of vinegar in a clean, dry 100 mL beaker.
2. Pipette two 10.00 mL portions into a clean 100 mL volumetric flask and dilute to the mark.
3. Stopper and invert several times to mix thoroughly.
4. Obtain about 70 mL of NaOH(aq) in a clean, dry 100 mL beaker.
5. Set up the burette to contain the NaOH(aq).
6. Pipette a 10.00 mL sample of diluted vinegar into a clean Erlenmeyer flask.
7. Add 1 or 2 drops of phenolphthalein indicator.
8. Record the initial burette reading (to a precision of 0.1 mL).
9. Titrate the sample with NaOH(aq) until a single drop produces a permanent pink colour.
10. Record the final burette reading (to 0.1 mL).
11. Repeat steps 6 to 10 until three consistent results are obtained.

Evidence

<table>
<thead>
<tr>
<th>Trial</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final burette reading (mL)</td>
<td>12.7</td>
<td>25.0</td>
<td>37.4</td>
</tr>
<tr>
<td>Initial burette reading (mL)</td>
<td>0.3</td>
<td>12.7</td>
<td>25.0</td>
</tr>
<tr>
<td>Volume of NaOH(aq) added (mL)</td>
<td>12.4</td>
<td>12.3</td>
<td>12.4</td>
</tr>
</tbody>
</table>

Analysis

average volume of NaOH(aq) = \( \frac{12.4 \text{ mL} + 12.3 \text{ mL} + 12.4 \text{ mL}}{3} = 12.4 \text{ mL} \)

\[
\text{CH}_3\text{COOH(aq)} + \text{NaOH(aq)} \rightarrow \text{NaCH}_3\text{COO(aq)} + \text{HOH(l)}
\]

\[
\begin{align*}
10.00 \text{ mL} & \quad c = 0.144 \text{ mol/L} \\
\text{12.4 mL} & \quad c_f = \frac{V_f c_i}{V_i}
\end{align*}
\]

To find the amount concentration of acetic acid in the original, undiluted vinegar,

\[
c_i = \frac{100.0 \text{ mL}}{20.0 \text{ mL}} \times \frac{0.178 \text{ mol}}{1 \text{ L}} = 0.890 \text{ mol/L}
\]

or
According to the evidence collected, the original amount concentration of the vinegar is 0.890 mol/L.

Evaluation
The titration design is judged to be adequate because the evidence was gathered and the problem was answered with no obvious problems. The design could perhaps be improved by eliminating the dilution of the vinegar and using a more concentrated standardized sodium hydroxide solution. However, this is a minor improvement and I still have great confidence in the design used. The materials and procedure were adequate because sufficient evidence was easily obtained. A new technological skill is required and titration to a precise endpoint requires practice with a burette. Both the dilution and the titration measurement steps need to be done carefully. Eliminating the dilution step would eliminate some of the experimental uncertainties because fewer measurements would be required. The technological skills were adequate, as evidenced by the consistency of the trials. On the basis of my evaluation of this experiment, I am quite confident in my results. The main sources of ambivalence with this experiment are the uncertainties in the various measurements.

The percent difference between the experimental result and the predicted value is 7%.

\[
\text{% difference} = \left( \frac{0.890 \text{ mol/L} - 0.83 \text{ mol/L}}{0.83 \text{ mol/L}} \right) \times 100 = 0.06 \times 100 = 7\%
\]

On the basis of my results, I am confident that the manufacturer’s claim on the label is acceptable.

The purpose of this Investigation was accomplished, as the manufacturer’s claim could be verified. However, more supporting analyses would increase the certainty of the conclusion that has been drawn.

Section 8.4 Questions
(Page 332)
1. Analysis
The volumes of hydrochloric acid added during trials 1–4 are 14.1 mL, 13.9 mL, and 14.0 mL, respectively. Discarding the first value, the average volume of HCl(aq) = \[\frac{14.1 \text{ mL} + 13.9 \text{ mL} + 14.0 \text{ mL}}{3} = 14.0 \text{ mL}\]

\[\text{c} \times 1.48 \text{ mol/L} \times 14.0 \text{ mL} = 20.7 \text{ mmol} \]

\[\text{c} \times 1.48 \text{ mol/L} \times 10.00 \text{ mL} = 14.8 \text{ mmol} \]

\[\text{n}_{\text{HCl}} = 14.0 \text{ mL} \times \frac{1.48 \text{ mol} \times 1}{1 \text{ mL}} = 20.7 \text{ mmol} \]

\[\text{n}_{\text{NH}_3} = 20.7 \text{ mmol} \times \frac{1}{1} = 20.7 \text{ mmol} \]
\[
[NH_3] = \frac{20.7 \text{ mol}}{10.00 \text{ L}} = 2.07 \text{ mol/L}
\]
(diluted solution)
\[
V_c c_i = V_c c_f
\]
\[
c_i = \frac{V_f}{V_i} \times c_i
= \frac{10}{1} \times 2.07 \text{ mol/L}
= 20.7 \text{ mol/L}
\]
(original solution)

or
\[
[NH_3] = \frac{14.0 \text{ mol HCl}}{1 \text{ L HCl}} \times \frac{1.48 \text{ mol HCl}}{1 \text{ L HCl}} \times \frac{1 \text{ mol NH}_3}{1 \text{ mol HCl}} \times \frac{10}{1} \times \frac{1}{10.00 \text{ mol L NH}_3}
\]
\[
= 20.7 \text{ mol/L NH}_3
\]

According to the evidence collected, the original undiluted amount concentration of ammonia is 20.7 mol/L.

2. (a) When you open a container that holds any volatile gas dissolved in water, some of the gas will escape (evaporate) due to the decrease in pressure.

(b) Each time the stock bottle is opened, some of the solute vapour will escape. This changes the ratio of solute to solvent, thereby changing (decreasing) the concentration of the solution.

3. Design
A standard solution of sodium carbonate is prepared. Successive samples of unknown hydrochloric acid are titrated with this standard solution, using methyl orange indicator, until at least three consistent volume results are obtained. The acid concentration is then calculated from the volume of sodium carbonate solution used.

Extension
4. \[
2 \text{ NaOH(aq)} + \text{ H}_2\text{SO}_3(aq) \rightarrow \text{ Na}_2\text{SO}_3(aq) + 2 \text{ H}_2\text{O(l)}
\]

12.0 mL

\[
n_{\text{NaOH}} = 12.0 \text{ mL} \times \frac{0.110 \text{ mol}}{1 \text{ L}}
= 1.32 \text{ mmol}
\]

\[
n_{\text{H}_2\text{SO}_3} = 1.32 \text{ mmol} \times \frac{1}{2}
= 0.660 \text{ mmol}
\]

Since there is one sulfur atom in each H2SO3 molecule,
\[
n_s = 0.660 \text{ mmol} \times \frac{1}{1}
= 0.660 \text{ mmol}
\]

The chemical amount of sulfur atoms present in the 100 mL acid sample is 0.660 mmol.