(d) In a double-blind study, randomly selected control and experimental groups of 500 volunteers are studied for changes which affect their circulatory system. The control group gets an ordinary bracelet (placebo) identical in appearance to the titanium bracelet that the experimental group receives. Both groups undergo a thorough physical exam by a team of doctors to determine their health and in particular, the characteristics of their circulatory system. The physical exam is conducted before the test, at the mid-point of the test period, and at the end of the test period.

13.4 REDOX STOICHIOMETRY

Lab Exercise 13.C: Analyzing for Tin

(Page 598)

Purpose
The purpose of this lab exercise is to use the stoichiometric method in a redox chemical analysis.

Problem
What is the amount concentration of tin(II) ions in a solution prepared for research on toothpaste?

Analysis

\[ \text{OA} \quad \text{SOA} \quad \text{OA} \quad \text{OA} \quad \text{OA} \]

\[
\begin{align*}
K^+(aq), & \quad \text{MnO}_4^-(aq), & \quad H^+(aq), & \quad \text{Sn}^{2+}(aq), & \quad H_2O(l) \\
SRA & \quad RA & \\
2 [\text{MnO}_4^-(aq) + 8 H^+(aq) + 5 e^- & \rightarrow \text{Mn}^{2+}(aq) + 4 H_2O(l)] \\
5 [\text{Sn}^{2+}(aq) & \rightarrow \text{Sn}^{4+}(aq) + 2 e^-] \\
2 \text{MnO}_4^-(aq) + 16 H^+(aq) + 5 \text{Sn}^{2+}(aq) & \rightarrow 2 \text{Mn}^{2+}(aq) + 8 H_2O(l) + 5 \text{Sn}^{4+}(aq) \\
12.4 \text{ mL} & \quad 10.00 \text{ mL} & \\
0.0832 \text{ mol/L} & \quad c & \\
n_{\text{MnO}_4^-} = 12.4 \text{ mL} \times \frac{0.0832 \text{ mol}}{1 \text{ L}} = 1.03 \text{ mmol} \\
n_{\text{Sn}^{2+}} = 1.03 \text{ mmol} \times \frac{5}{2} = 2.58 \text{ mmol} \\
[\text{Sn}^{2+}(aq)] = \frac{2.58 \text{ mmol}}{10.00 \text{ mL}} = 0.258 \text{ mol/L} \\
or [\text{Sn}^{2+}(aq)] = 12.4 \text{ mL MnO}_4^- \times \frac{0.0832 \text{ mol MnO}_4^-}{1 \text{ L MnO}_4^-} \times \frac{5 \text{ mol Sn}^{2+}}{2 \text{ mol MnO}_4^-} \times \frac{1}{10.00 \text{ mL Sn}^{2+}} \\
= 0.258 \text{ mol/L} \\
\]

According to the evidence and the stoichiometric analysis, the amount concentration of tin(II) ions in the solution is 0.258 mol/L.

Web Activity: Canadian Achievers—Imants Lauks

(Page 598)

1. The FlexCard™ technology functions as an entire blood diagnostic laboratory on a credit card-sized device. FlexCard is a card format similar to smart cards that are used in ATM, cheque, and phone cards. It can hold large amounts of information on a small chip. The device on the FlexCard contains a silicon chip with biosensor circuits and only a small sample needs to be used, in order for the results to be read by a wireless card reader. This technology provides a low-cost, accurate, and complete blood diagnostic system that can be used quickly and easily by
anyone. It is a point-of-care blood analysis system, so samples do not have to be sent to a lab. Comparable quantitative systems require much more complex and expensive instrumentation.

**Practice**

(Page 598)

1. Four requirements for titration experiments are that the reactions be spontaneous, fast, quantitative, and stoichiometric.

2. Alternative designs include crystallization, filtration, gas collection, colorimetry, and a variety of electrical methods.

3. 

\[
\begin{align*}
\text{Ni(s), } & \quad \text{Ag}^+(aq), \quad \text{H}_2\text{O(l)} \\
\text{SRA} & \quad \text{RA} \\
2 \ [\text{Ag}^+(aq) + e^- \rightarrow \text{Ag(s)}] & \quad \text{Ni(s)} \rightarrow \text{Ni}^{2+}(aq) + 2 \ e^- \\
2 \ \text{Ag}^+(aq) + \text{Ni(s)} \rightarrow 2 \ \text{Ag(s)} + \text{Ni}^{2+}(aq) & \\
0.10 \ \text{mol/L} & \quad 25.0 \ \text{g} \\
V & \quad 58.69 \ \text{g/mol} \\
n_{\text{Ni}} & = 25.0 \ \text{g} \times \frac{1 \ \text{mol}}{58.69 \ \text{g}} = 0.426 \ \text{mol} \\
n_{\text{Ag}^+} & = 0.426 \ \text{mol} \times \frac{2}{1} = 0.852 \ \text{mol} \\
\frac{V_{\text{Ag}^+}}{V} & = 0.852 \ \text{mol} \times \frac{1 \ \text{L}}{0.10 \ \text{mol}} = 8.5 \ \text{L} \\
or \ V_{\text{Ag}^+} & = 25.0 \ \text{g Ni} \times \frac{1 \ \text{mol Ni}}{58.69 \ \text{g Ni}} \times \frac{2 \ \text{mol Ag}^+}{1 \ \text{mol Ni}} \times \frac{1 \ \text{L Ag}^+}{0.10 \ \text{mol Ag}^+} = 8.5 \ \text{L} \\
\end{align*}
\]

According to the stoichiometric method, the volume of silver ion solution required is 8.5 L.

4. 

\[
\begin{align*}
+6 & \quad +4 & \quad +3 & \quad +2 & \quad +6 & \quad +2 \\
2 \ \text{CrO}_4^{2-}(aq) & \quad + 3 \ \text{SO}_3^{2-}(aq) & \quad + 5 \ \text{H}_2\text{O(l)} & \rightarrow \quad 2 \ \text{Cr(OH)}_3(s) & \quad + 3 \ \text{SO}_4^{2-}(aq) & \quad + 4 \ \text{OH}^-(aq) \\
3 \ \text{e}^-/\text{Cr} & \quad 2 \ \text{e}^-/\text{S} \\
3 \ \text{e}^-/\text{CrO}_4^{2-} & \quad 2 \ \text{e}^-/\text{SO}_3^{2-} \\
\times 2 & \quad \times 3 \\
50.0 \ \text{mL} & \quad 22.6 \ \text{mL} \\
c & \quad 1.08 \ \text{mol/L} \\
\frac{n_{\text{SO}_3^{2-}}}{c} & = 22.6 \ \text{mL} \times \frac{1.08 \ \text{mL}}{1 \ \text{L}} = 24.4 \ \text{mmol} \\
\frac{n_{\text{CrO}_4^{2-}}}{c} & = 24.4 \ \text{mmol} \times \frac{2}{3} = 16.3 \ \text{mmol} \\
[\text{CrO}_4^{2-}(aq)] & = \frac{16.3 \ \text{mmol}}{50.0 \ \text{mL}} = 0.325 \ \text{mol/L} \\
or \ [\text{CrO}_4^{2-}(aq)] & = 22.6 \ \text{mL SO}_3^{2-} \times \frac{1.08 \ \text{mol SO}_3^{2-}}{1 \ \text{L SO}_3^{2-}} \times \frac{2 \ \text{mol CrO}_4^{2-}}{3 \ \text{mol SO}_3^{2-}} \times \frac{1}{50.0 \ \text{mL CrO}_4^{2-}} \\
& = 0.325 \ \text{mol/L} \\
\end{align*}
\]

According to the stoichiometric method, the amount concentration of chromate ions is 0.325 mol/L.
5. \( n_{Fe} = 1.08 \text{ g} \times \frac{1 \text{ mol}}{55.85 \text{ g}} = 0.0193 \text{ mol}; n_{Fe} = n_{Fe^{2+}} \)

\[
[Fe^{2+}(aq)] = \frac{0.0193 \text{ mol}}{0.2500 \text{ L}} = 0.0774 \text{ mol/L}
\]

or \( [Fe^{2+}(aq)] = 1.08 \frac{\text{ g} \text{ Fe}}{55.85 \text{ g} \text{ Fe}} \times \frac{1 \text{ mol} \text{ Fe}}{1 \text{ mol} \text{ Fe}} \times \frac{1}{0.2500 \text{ L} \text{ Fe}^{2+}} = 0.0774 \text{ mol/L} \)

\[
\left[ \text{MnO}_4^{-}(aq) + 8 \text{ H}^{+}(aq) + 5 \text{ e}^{-} \rightarrow \text{Mn}^{2+}(aq) + 4 \text{ H}_2\text{O}(l) \right]
\]

\[
5 \left[ \text{Fe}^{2+}(aq) \rightarrow \text{Fe}^{3+}(aq) + \text{ e}^{-} \right]
\]

\[
\text{MnO}_4^{-}(aq) + 8 \text{ H}^{+}(aq) + 5 \text{ Fe}^{2+}(aq) \rightarrow \text{Mn}^{2+}(aq) + 4 \text{ H}_2\text{O}(l) + 5 \text{ Fe}^{3+}(aq)
\]

13.6 mL \( c \) 0.0774 mol/L

\[
n_{Fe^{2+}} = 10.0 \text{ mL} \times \frac{0.0774 \text{ mol}}{1 \text{ L}} = 0.774 \text{ mmol}
\]

\[
n_{\text{MnO}_4^{-}} = 0.774 \text{ mmol} \times \frac{1}{5} = 0.155 \text{ mmol}
\]

\[
[\text{MnO}_4^{-}(aq)] = \frac{0.155 \text{ mmol}}{13.6 \text{ mmol}} = 0.0114 \text{ mol/L or } 11.4 \text{ mmol/L}
\]

or \( [\text{MnO}_4^{-}(aq)] = 10.0 \text{ mL} \text{ Fe}^{2+} \times \frac{0.774 \text{ mol Fe}^{2+}}{1 \text{ L Fe}^{2+}} \times \frac{1 \text{ mol MnO}_4^{-}}{5 \text{ mol Fe}^{2+}} \times \frac{1}{0.0136 \text{ L MnO}_4^{-}} = 11.4 \text{ mmol/L} \)

According to the stoichiometric method, the amount concentration of the permanganate solution is 11.4 mmol/L.

**Lab Exercise 13.3D: Analyzing for Chromium in Steel**

*(Page 599)*

**Purpose**

The purpose of this lab exercise is to use the stoichiometric method in a redox chemical analysis.

**Problem**

What is the amount concentration of chromium(II) ions in a solution obtained in the analysis of a stainless steel alloy?

**Analysis**

\[
\left[ \text{Cr}_2\text{O}_7^{2-}(aq) + 14 \text{ H}^+(aq) + 6 \text{ e}^- \rightarrow 2 \text{ Cr}^{3+}(aq) + 7 \text{ H}_2\text{O}(l) \right]
\]

\[
6 \left[ \text{Cr}^{2+}(aq) \rightarrow \text{Cr}^{3+}(aq) + \text{ e}^- \right]
\]

\[
\text{Cr}_2\text{O}_7^{2-}(aq) + 14 \text{ H}^+(aq) + 6 \text{ Cr}^{2+}(aq) \rightarrow 8 \text{ Cr}^{3+}(aq) + 7 \text{ H}_2\text{O}(l)
\]

17.4 mL \( c \) 0.125 mol/L

\[
n_{\text{Cr}_2\text{O}_7^{2-}} = 17.4 \text{ mL} \times \frac{0.125 \text{ mol}}{1 \text{ L}} = 2.18 \text{ mmol}
\]
\[ n_{\text{Cr}^{2+}} = 2.18 \text{ mmol} \times \frac{6}{1} = 13.1 \text{ mmol} \]

\[ [\text{Cr}^{2+} (\text{aq})] = \frac{13.1 \text{ mmol}}{10.00 \text{ mL}} = 1.31 \text{ mol/L} \]

or \[ [\text{Cr}^{2+} (\text{aq})] = 17.4 \text{ m}\text{L} \cdot \text{Cr}_2\text{O}_7^{2-} \times \frac{0.125 \text{ mol} \cdot \text{Cr}_2\text{O}_7^{2-}}{1 \text{ L} \cdot \text{Cr}_2\text{O}_7^{2-}} \times \frac{6 \text{ mol} \cdot \text{Cr}^{2+}}{1 \text{ mol} \cdot \text{Cr}_2\text{O}_7^{2-}} \times \frac{1}{10.00 \text{ mL} \cdot \text{Cr}^{2+}} \]

= 1.31 \text{ mol/L}

According to the evidence and the stoichiometric analysis, the amount concentration of chromium(II) ions is 1.31 mol/L.

**Investigation 13.4: Analyzing a Hydrogen Peroxide Solution**

(Pages 599, 603)

**Purpose**
The technological purpose of this investigation is to test and evaluate the percent concentration of the consumer solution of hydrogen peroxide.

**Problem**
What is the percent concentration of hydrogen peroxide in a consumer product?

**Prediction**
According to the manufacturer’s label, the concentration of hydrogen peroxide is 3%.

**Materials**
- lab apron
- eye protection
- FeSO₄·(NH₄)₂SO₄·6H₂O(s)
- 2 mol/L H₂SO₄(aq)
- diluted H₂O₂(aq)
- KMnO₄(aq)
- wash bottle
- 50 mL burette and clamp
- 10 mL graduated cylinder
- two 100 mL beakers
- medicine dropper
- stirring rod
- centigram balance
- small funnel
- laboratory stand
- laboratory scoop

**Evidence**

\[ \text{mass of FeSO}_4\cdot(\text{NH}_4)_2\text{SO}_4\cdot6\text{H}_2\text{O(s)} \text{ to prepare 100.0 mL of solution} = 1.96 \text{ g} \]

**Titration of 10.00 mL of Acidic Iron(II) Standard with KMnO₄(aq)**

<table>
<thead>
<tr>
<th>Trial</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>final burette reading (mL)</td>
<td>13.6</td>
<td>26.6</td>
<td>39.6</td>
<td>13.9</td>
</tr>
<tr>
<td>initial burette reading (mL)</td>
<td>0.2</td>
<td>13.6</td>
<td>26.6</td>
<td>0.8</td>
</tr>
<tr>
<td>volume of KMnO₄(aq) (mL)</td>
<td>13.4</td>
<td>13.0</td>
<td>13.0</td>
<td>13.1</td>
</tr>
<tr>
<td>endpoint colour</td>
<td>red</td>
<td>pink</td>
<td>pink</td>
<td>pink</td>
</tr>
</tbody>
</table>

- dilution of consumer H₂O₂(aq), 25.0 mL to 1.00 L
- 5 mL of H₂SO₄(aq) added to H₂O₂(aq) in each trial

**Titration of 10.00 mL of Acidified, Diluted H₂O₂(aq) with KMnO₄(aq)**

<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>11.5</td>
<td>22.7</td>
<td>33.9</td>
</tr>
<tr>
<td>initial burette reading (mL)</td>
<td>0.2</td>
<td>11.5</td>
<td>22.7</td>
</tr>
<tr>
<td>volume of KMnO₄(aq) (mL)</td>
<td>11.3</td>
<td>11.2</td>
<td>11.2</td>
</tr>
<tr>
<td>endpoint colour</td>
<td>pink</td>
<td>pink</td>
<td>pink</td>
</tr>
</tbody>
</table>
Analysis

Standardization of the potassium permanganate solution:

average volume of \( \text{KMnO}_4 \) (aq) = \( \frac{13.0 \text{ mL} + 13.0 \text{ mL} + 13.1 \text{ mL}}{3} \) = 13.0 mL

\[
\begin{align*}
\text{OA} & \quad \text{SOA} & \quad \text{OA} & \quad \text{OA} & \quad \text{OA} & \quad \text{OA} \\
K^+(aq) & \quad \text{MnO}_4^-(aq), & \quad H^+(aq), & \quad Fe^{2+}(aq), & \quad H_2O(l), & \quad SO_4^{2-}(aq), & \quad NH_4^+(aq)
\end{align*}
\]

\[
\begin{align*}
\text{MnO}_4^-(aq) + 8 H^+(aq) + 5 e^- & \rightarrow \text{Mn}^{2+}(aq) + 4 H_2O(l) \\
5 [\text{Fe}^{2+}(aq) \rightarrow \text{Fe}^{3+}(aq) + e^-]
\end{align*}
\]

\[
\begin{align*}
\text{MnO}_4^-(aq) + 8 H^+(aq) + 5 \text{Fe}^{2+}(aq) & \rightarrow \text{Mn}^{2+}(aq) + 4 H_2O(l) + 5 \text{Fe}^{3+}(aq) \\
13.0 \text{ mL} & \quad 10.00 \text{ mL} \\
c & \quad 0.0500 \text{ mol/L} \\
n_{\text{Fe}^{2+}} & = 10.00 \text{ mL} \times \frac{0.0500 \text{ mol}}{1 \text{ L}} = 0.500 \text{ mmol} \\
n_{\text{MnO}_4^-} & = 0.500 \text{ mmol} \times \frac{1}{5} = 0.100 \text{ mmol} \\
[\text{MnO}_4^- (aq)] & = \frac{0.100 \text{ mmol}}{13.0 \text{ mL}} = 0.00767 \text{ mol/L} \\
\text{or } [\text{MnO}_4^- (aq)] & = 10.0 \text{ mL} \times \frac{0.0500 \text{ mol} \text{Fe}^{2+}}{1 \text{ L} \text{Fe}^{2+}} \times \frac{1 \text{ mol} \text{MnO}_4^-}{5 \text{ mol} \text{Fe}^{2+}} \times \frac{1}{13.0 \mu \text{L} \text{MnO}_4^-} \\
& = 0.00767 \text{ mol/L}
\end{align*}
\]

Analysis of the hydrogen peroxide solution:

average volume of \( \text{KMnO}_4 \) (aq) = \( \frac{11.3 \text{ mL} + 11.2 \text{ mL} + 11.2 \text{ mL}}{3} \) = 11.2 mL

\[
\begin{align*}
\text{OA} & \quad \text{SOA} & \quad \text{OA} & \quad \text{OA} & \quad \text{OA} & \quad \text{OA} \\
K^+(aq) & \quad \text{MnO}_4^-(aq), & \quad H^+(aq), & \quad H_2O_2(aq), & \quad H_2O(l), & \quad SO_4^{2-}(aq)
\end{align*}
\]

\[
\begin{align*}
2 \text{ [MnO}_4^- \text{(aq)} + 8 \text{H}^+(aq) + 5 \text{ e}^- & \rightarrow \text{Mn}^{2+}(aq) + 4 \text{H}_2\text{O}(l)] \\
5 \text{ [H}_2\text{O}_2(aq) \rightarrow \text{O}_2(g) + 2 \text{H}^+(aq) + 2 \text{ e}^-] \\
2 \text{ MnO}_4^- \text{(aq)} + 6 \text{H}^+(aq) + 5 \text{H}_2\text{O}_2(aq) & \rightarrow 2 \text{Mn}^{2+}(aq) + 8 \text{H}_2\text{O}(l) + 5 \text{O}_2(g) \\
11.2 \text{ mL} & \quad 10.00 \text{ mL} \\
c & \quad 0.00767 \text{ mol/L} \\
n_{\text{MnO}_4^-} & = 11.2 \text{ mL} \times \frac{0.00767 \text{ mol}}{1 \text{ L}} = 0.0862 \text{ mmol} \\
n_{\text{H}_2\text{O}_2} & = 0.0862 \text{ mmol} \times \frac{5}{2} = 0.215 \text{ mmol} \\
[\text{H}_2\text{O}_2(aq)] & = \frac{0.215 \text{ mmol}}{10.00 \text{ mL}} = 0.0215 \text{ mol/L} \text{ (diluted sample)} \\
\text{or } [\text{H}_2\text{O}_2(aq)] & = 11.2 \text{ mL} \times \frac{0.00767 \text{ mol} \text{MnO}_4^-}{1 \text{ L} \text{MnO}_4^-} \times \frac{5 \text{ mol} \text{H}_2\text{O}_2}{2 \text{ mol} \text{MnO}_4^-} \times \frac{1}{10.00 \mu \text{L} \text{H}_2\text{O}_2} \\
& = 0.0215 \text{ mol/L}
\end{align*}
\]

Since the original hydrogen peroxide was diluted by a factor of 40, the amount concentration of the original solution was 0.0215 \text{ mol/L} \times 40 = 0.860 \text{ mol/L}. This corresponds to a percent concentration of 2.94% according to the graph.
According to the evidence and the stoichiometric analysis, the percent concentration of hydrogen peroxide is 2.94%.

**Evaluation**
The titration design is judged to be adequate and is the best design for this type of chemical analysis. On the basis of previous experience, I am quite confident in this design. The materials were adequate because they were of reasonable quality. The procedure allowed sufficient evidence to be collected and was, therefore, adequate. Technological skills were routine and adequate, as shown by the consistent results among the trials. Preparation of the iron(II) solution and judgment of the endpoint colour, if not done correctly, are parts that could have a noticeable effect on the results. On the basis of my evaluation of this experiment, I am very certain of the results and I would expect only a small percent difference. This difference would be due to small measurement uncertainties and perhaps a small uncertainty in the judgment of the endpoint colour.

The prediction was verified with a percent difference of 2%.

\[
\text{% difference} = \frac{|2.94\% - 3\%|}{3\%} \times 100\% = 2\%
\]

The prediction clearly agrees with the experimental result taking into account expected uncertainties. The claim by the manufacturer is judged to be acceptable because the prediction was verified. I am very confident in this judgment.

The purpose was accomplished although it would be better to test several bottles obtained from different stores.

**Section 13.4 Questions**

(File 600)
1. The similarities between the method for redox stoichiometry and other examples of stoichiometry are that both are methods of determining an unknown quantity or concentration from a known quantity or concentration following basically the same steps. The differences are that redox stoichiometry involves a different procedure for obtaining the balanced chemical reaction equation and uses net ionic equations rather than the non-ionic chemical equations that are common with other types of stoichiometry.
2. (a) Two common strong oxidizing agents used in a redox titration are acidified dichromate solution and acidified permanganate.
   (b) An example of a strong reducing agent is basic sulfite ion solution.
(c) Other examples of strong reducing agents include \( \text{Se}^{2-}(\text{aq}) \), \( \text{Cr}^{2+}(\text{aq}) \), and \( \text{H}_2\text{Te}(\text{aq}) \), which can all be used in a titration design. A variety of active metals such as \( \text{Zn}(\text{s}) \), \( \text{Al}(\text{s}) \) and \( \text{Mg}(\text{s}) \) can also be used as strong reducing agents using a gravimetric design such as precipitation and filtration.

3. It is necessary to standardize a potassium permanganate solution because the solution cannot be prepared with an accurate concentration due to reactions with organic and inorganic impurities in water and even with water itself.

4. \[ \text{ClO}_4^-(\text{aq}) + 8 \text{H}^+(\text{aq}) + 8 \text{e}^- \rightarrow \text{Cl}^- (\text{aq}) + 4 \text{H}_2\text{O}(\text{l}) \]
\[ 4 \left[ \text{H}_2\text{O}_2(\text{l}) \rightarrow \text{O}_2(\text{g}) + 2 \text{H}^+(\text{aq}) + 2 \text{e}^- \right] \]
\[ \text{ClO}_4^-(\text{aq}) + 4 \text{H}_2\text{O}_2(\text{l}) \rightarrow \text{Cl}^- (\text{aq}) + 4 \text{O}_2(\text{g}) + 4 \text{H}_2\text{O}(\text{l}) \]

\[ n_{\text{ClO}_4^-} = 24.0 \text{ mL} \times \frac{0.200 \text{ mol}}{1 \text{ L}} = 4.80 \text{ mmol} \]

\[ n_{\text{H}_2\text{O}_2} = 4.80 \text{ mmol} \times \frac{4}{1} = 19.2 \text{ mmol/L} \]

\[ [\text{H}_2\text{O}_2(\text{aq})] = \frac{19.2 \text{ mmol}}{10.00 \text{ mL}} = 1.92 \text{ mol/L} \]

or \[ [\text{H}_2\text{O}_2(\text{aq})] = 24.0 \text{ mL} \times \frac{0.200 \text{ mol} \text{ClO}_4^-}{1 \text{ L} \text{ClO}_4^-} \times \frac{4 \text{ mol} \text{H}_2\text{O}_2}{1 \text{ mol} \text{ClO}_4^-} \times \frac{1}{10.00 \text{ mL} \text{H}_2\text{O}_2} \]

\[ = 1.92 \text{ mol/L} \]

On the basis of the evidence and stoichiometry, the calculated concentration of the hydrogen peroxide solution is 1.92 mol/L.

5. **Purpose**

The purpose of this lab exercise is to use redox stoichiometry to evaluate a technological process.

**Problem**

What is the amount concentration of iron(II) ions in a solution obtained in an iron ore analysis?

**Analysis**

\[ \text{SOA OA OA} \]

\[ \text{Ce}^{4+}(\text{aq}), \text{Fe}^{2+}(\text{aq}), \text{H}_2\text{O}(\text{l}) \]

\[ \text{SRA RA} \]

\[ \text{Ce}^{4+}(\text{aq}) + \text{e}^- \rightarrow \text{Ce}^{3+}(\text{aq}) \]

\[ \text{Fe}^{2+}(\text{aq}) \rightarrow \text{Fe}^{3+} + \text{e}^- \]

\[ \text{Ce}^{4+}(\text{aq}) + \text{Fe}^{2+}(\text{aq}) \rightarrow \text{Ce}^{3+}(\text{aq}) + \text{Fe}^{3+}(\text{aq}) \]

\[ 15.0 \text{ mL} \quad 25.0 \text{ mL} \]

\[ 0.125 \text{ mol/L} \quad c \]

\[ n_{\text{Ce}^{4+}} = 15.0 \text{ mL} \times \frac{0.125 \text{ mol}}{1 \text{ L}} = 1.88 \text{ mmol} \]

\[ n_{\text{Fe}^{2+}} = 1.88 \text{ mmol} \times \frac{1}{1} = 1.88 \text{ mmol} \]

\[ [\text{Fe}^{2+}(\text{aq})] = \frac{1.88 \text{ mmol}}{25.0 \text{ mL}} = 0.0749 \text{ mol/L} \]

or \[ [\text{Fe}^{2+}(\text{aq})] = 15.0 \text{ mL} \times \frac{0.125 \text{ mol} \text{Ce}^{4+}}{1 \text{ L} \text{Ce}^{4+}} \times \frac{1 \text{ mol} \text{Fe}^{2+}}{1 \text{ mol} \text{Ce}^{4+}} \times \frac{1}{25.0 \text{ mL} \text{Fe}^{2+}} \]

\[ = 0.0749 \text{ mol/L} \]
According to the evidence of the four trials and the stoichiometric method, the concentration of Fe\(^{2+}\)(aq) in the sample is 0.0749 mol/L or 74.9 mmol/L.

**Evaluation**

\[
\% \text{ difference} = \frac{0.0749 \text{ mol/L} - 0.0800 \text{ mol/L}}{0.0800 \text{ mol/L}} \times 100 = 6.4\%
\]

The experimentally derived concentration of Fe\(^{2+}\)(aq) ions in the sample is 6.4% less than predicted. This difference appears slightly larger than would be expected from typical experimental uncertainties and the acceptable tolerance of the metallurgical process is not known. Therefore, the prediction is judged to be inconclusive. Further testing and information are required. The process remains acceptable until shown to be otherwise.

6. **Problem**

What is the amount concentration of a tin(II) chloride solution prepared from a sample of tin ore?

**Analysis**

The first endpoint was overshot and the result was discarded. The average volume of K\(_2\)Cr\(_2\)O\(_7\)(aq) used in trials 2 to 4 was 10.7 mL.

\[
\begin{align*}
\text{OA} & \quad \text{OA} \quad \text{SOA} \quad \text{OA} \quad \text{OA} \quad \text{OA} \\
\text{Fe}^{2+}(aq), & \quad K^{+}(aq), \quad \text{Cr}_2\text{O}_7^{2-}(aq), \quad H^{+}(aq), \quad H_2O(l) \quad \text{SO}_4^{2-}(aq), \quad \text{NH}_4^{+}(aq) \\
\text{SRA} & \quad \text{RA} \\
\text{Cr}_2\text{O}_7^{2-}(aq) + 14 H^{+}(aq) + 6 e^- & \rightarrow 2 \text{Cr}^{3+}(aq) + 7 H_2O(l) \\
10.7 \text{ mL} & \quad 10.00 \text{ mL} \\
c & \quad 0.0500 \text{ mol/L} \\
n_{\text{Fe}^{2+}} & = 10.00 \text{ mL} \times \frac{0.0500 \text{ mol}}{1 \text{ L}} = 0.500 \text{ mmol} \\
n_{\text{Cr}_2\text{O}_7^{2-}} & = 0.500 \text{ mmol} \times \frac{1}{6} = 0.0833 \text{ mmol} \\
[\text{Cr}_2\text{O}_7^{2-}(aq)] & = \frac{0.0833 \text{ mmol}}{10.7 \text{ mL}} = 0.00779 \text{ mol/L} \\
or [\text{Cr}_2\text{O}_7^{2-}(aq)] & = 10.00 \text{ mL} \times \frac{0.0500 \text{ mol} \text{ Fe}^{2+}}{1 \text{ mol} \text{ Fe}^{2+}} \times \frac{1 \text{ mol} \text{ Cr}_2\text{O}_7^{2-}}{6 \text{ mol} \text{ Fe}^{2+}} \times \frac{1}{10.7 \text{ mL} \text{ Cr}_2\text{O}_7^{2-}} \\
& = 0.00779 \text{ mol/L}
\end{align*}
\]

The average volume of K\(_2\)Cr\(_2\)O\(_7\)(aq) used in the second titration was 11.1 mL, based on trials 2 to 4.

\[
\begin{align*}
\text{OA} & \quad \text{OA} \quad \text{SOA} \quad \text{OA} \quad \text{OA} \quad \text{OA} \\
\text{Sn}^{2+}(aq), & \quad K^{+}(aq), \quad \text{Cr}_2\text{O}_7^{2-}(aq), \quad H^{+}(aq), \quad H_2O(l) \quad \text{Cl}^{-}(aq) \\
\text{SRA} & \quad \text{RA} \quad \text{RA} \quad \text{RA} \\
\text{Cr}_2\text{O}_7^{2-}(aq) + 14 H^{+}(aq) + 6 e^- & \rightarrow 2 \text{Cr}^{3+}(aq) + 7 H_2O(l) \\
11.1 \text{ mL} & \quad 10.00 \text{ mL} \\
0.00779 \text{ mol/L} & \quad c
\end{align*}
\]
\[ n_{\text{CrO}_7^{2-}} = 11.1 \text{ mL} \times \frac{0.00779 \text{ mol}}{1 \text{ L}} = 0.0862 \text{ mmol} \]
\[ n_{\text{Sn}^2+} = 0.0862 \text{ mmol} \times \frac{3}{1} = 0.259 \text{ mmol} \]
\[ [\text{Sn}^2+(aq)] = \frac{0.259 \text{ mmol}}{10.00 \text{ mL}} = 0.0259 \text{ mol/L} \]
\[ \text{or } [\text{Sn}^2+(aq)] = 11.1 \text{ mL} \times \frac{0.00779 \text{ mol} \cdot \text{CrO}_7^{2-}}{1 \text{ L} \cdot \text{CrO}_7^{2-}} \times \frac{1 \text{ mol Sn}^2+}{6 \text{ mol CrO}_7^{2-}} \times \frac{1}{10.00 \text{ mL} \cdot \text{Sn}^2+} \]
\[ = 0.0259 \text{ mol/L} \]

According to the evidence and the stoichiometric analysis, the concentration of tin(II) chloride is 25.9 mmol/L.

**Extension**

7. [In the following calculations, \( P \) represents both the percentage of iron in the iron ore sample and the volume of potassium dichromate used in the titration. Alternatively, a specific percentage and volume (e.g., 5% and 5 mL) could be chosen and the concentration of the potassium dichromate calculated stoichiometrically from these values. The same concentration should be predicted, regardless of the values chosen.]

\[ \text{OA OA OA OA OA} \]
\[ \text{Fe}^{2+}(aq), \text{K}^+(aq), \text{ Cr}_2\text{O}_7^{2-}(aq), \text{H}^+(aq), \text{H}_2\text{O}(l) \]
\[ \text{SRA RA} \]
\[ \text{Cr}_2\text{O}_7^{2-}(aq) + 14 \text{ H}^+(aq) + 6 e^- \rightarrow 2 \text{ Cr}^{3+}(aq) + 7 \text{ H}_2\text{O}(l) \]
\[ \text{or } \text{Cr}_2\text{O}_7^{2-}(aq) + 14 \text{ H}^+(aq) + 6 \text{ Fe}^{2+}(aq) \rightarrow 2 \text{ Cr}^{3+}(aq) + 7 \text{ H}_2\text{O}(l) + 6 \text{ Fe}^{3+}(aq) \]

\[ P \text{ mL} \quad P\% \text{ of 1.00 g} \]
\[ c = 55.85 \text{ g/mol} \]
\[ n_{\text{Fe}^{2+}} = \frac{P}{100} \times 1.00 \text{ g} \times \frac{1 \text{ mol}}{55.85 \text{ g}} = 0.179P \text{ mmol} \]
\[ n_{\text{Fe}^{3+}} = 0.179P \text{ mmol} \times \frac{1}{6} = 0.0298P \text{ mmol} \]
\[ [\text{Cr}_2\text{O}_7^{2-}(aq)] = \frac{0.0298P \text{ mmol}}{P \text{ mL}} = 0.0298 \text{ mol/L or 29.8 mmol/L} \]
\[ \text{or } [\text{Cr}_2\text{O}_7^{2-}(aq)] = \frac{P}{100} \times 1.00 \frac{\text{Fe}^{2+}}{\text{Fe}^{2+}} \times \frac{1 \text{ mol Fe}^{2+}}{55.85 \text{ g Fe}^{2+}} \times \frac{1 \text{ mol Cr}_2\text{O}_7^{2-}}{6 \text{ mol Fe}^{2+}} \times \frac{1}{0.001P \text{ L Cr}_2\text{O}_7^{2-}} \]
\[ = 29.8 \text{ mmol/L} \]

According to the stoichiometric method, the required concentration of potassium dichromate is 29.8 mmol/L.