- comparing the oxidation states of atoms/ions on the reactant side of the equation with those of atoms/ions of the same elements on the product side.

5. (a) When an atom is oxidized, its oxidation number increases, i.e., becomes more positive.
   (b) When an atom is reduced, its oxidation number decreases, i.e., becomes more negative.
6. (a) carbon +2; oxygen –2
   (b) oxygen 0
   (c) nitrogen –3; hydrogen +1; chloride –1
   (d) hydrogen +1; phosphorus +5; oxygen –2
   (e) sodium +1; sulfur +2; oxygen –2
   (f) sodium +1; phosphorus +5; oxygen –2
7. (a) $\underset{+7\ -2}{MnO^{-}_{4(aq)}} + \underset{+3\ -2}{C_2O^{2-}_{4(aq)}} + \underset{+1}{H^{+}_{(aq)}} \rightarrow \underset{+2}{Mn^{2+}_{(aq)}} + \underset{+1\ -2}{H_2O_{(l)}} + \underset{+4\ -2}{CO_{2(g)}}$
   (b) Carbon is oxidized. Its oxidation number changes from +3 to +4.
   (c) Manganese is reduced. Its oxidation number changes from +7 to +2.
8. (a) $H_2O_{(l)} + CO_{2(g)} \rightarrow H_2CO_{3(aq)}$
   (b) This is not a redox reaction. The oxidation numbers of all of the atoms remain unchanged.

Applying Inquiry Skills

9. Clean the surface of the copper and zinc strips thoroughly using steel wool. Rinse, dry, and measure the mass of each metal strip. Then insert the strips into an orange (or other fruit) and connect the strips directly with a wire. Let the cell operate for a period of time. Remove electrodes, rinse and dry, and measure the mass of each electrode.

Making Connections

10. (a) $3\ Ag_2S_{(s)} + 2\ Al_{(s)} \rightarrow Al_2S_{3(s)} + 6\ Ag_{(s)}$
    (b) Aluminum is oxidized (0 to +3) and silver is reduced (+1 to 0).
    (c) This is a better method of cleaning silver than polishing or scrubbing because it does not remove silver from the object the way that polishing and scrubbing do.
11. The Breathalyzer measures the alcohol content of exhaled breath, which is assumed to be proportional to the blood alcohol content. Inside the device, the alcohol in the breath sample is oxidized by acidic potassium dichromate, a process that produces a colour change that is measured by a colorimeter.

    The Intoxilyzer uses infrared absorption spectroscopy to pass infrared light through the breath sample, and then measures how much absorption is caused by the presence of alcohol.

    The technology of the Breathalyzer is based on the redox reaction between ethanol and acidic potassium dichromate, while the Intoxilyzer is based on infrared absorption spectroscopy, which does not involve a redox reaction.

9.2 BALANCING REDOX EQUATIONS

PRACTICE

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Understanding Concepts

1. The oxidation number of an atom is calculated by counting shared electrons as belonging to the more electronegative atom. Therefore, the gain or loss of electrons by an atom is reflected by a change in the oxidation number equal to the number of electrons transferred.
2. (a) $Cr_2O^{2-}_{7(aq)} + 6\ Cl^{-}_{(aq)} + 14\ H^{+}_{(aq)} \rightarrow 2\ Cr^{3+}_{(aq)} + 3\ Cl_{2(aq)} + 7\ H_2O_{(l)}$
   (b) $2\ IO^{-}_{3\,(aq)} + 5\ HSO^{-}_{3\,(aq)} \rightarrow 5\ SO^{2-}_{4(aq)} + I_{2(s)} + 3\ H^{+}_{(aq)} + H_2O_{(l)}$
   (c) $2\ HBr_{(aq)} + H_2SO_{4(aq)} \rightarrow SO_{2(g)} + Br_{2(l)} + 2\ H_2O_{(l)}$
3. (a) $2\ MnO^{-}_{4\,(aq)} + 3\ SO^{2-}_{3(aq)} + H_2O_{(l)} \rightarrow 3\ SO^{2-}_{4(aq)} + 2\ MnO_{2(s)} + 2\ OH^{-}_{(aq)}$
   (b) $4\ ClO^{-}_{3\,(aq)} + 3\ N_2H_{4(aq)} \rightarrow 6\ NO_{(g)} + 4\ Cl^{-}_{(aq)} + 6\ H_2O_{(l)}$
4. $4\ NH_{3(g)} + 7\ O_{2(g)} \rightarrow 4\ NO_{2(g)} + 6\ H_2O_{(g)}$

PRACTICE

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Understanding Concepts

5. (a) $N_2O_{(g)} + 2\ H^+_{(aq)} + 2\ e^- \rightarrow N_{2(g)} + H_2O_{(l)}$ reduction

 (b) $NO_{2\ (aq)}^- + 2\ OH^-_{(aq)} \rightarrow NO_{3\ (aq)}^- + H_2O_{(l)} + 2\ e^-$ oxidation

 (c) $Ag_2O_{(s)} + H_2O_{(l)} + 2\ e^- \rightarrow 2\ Ag_{(s)} + 2\ OH^-_{(aq)}$ reduction

 (d) $NO_{3\ (aq)}^- + 3\ H^+_{(aq)} + 2\ e^- \rightarrow HNO_{2(aq)} + H_2O_{(l)}$ reduction

 (e) $H_{2(g)} + 2\ OH^-_{(aq)} \rightarrow 2\ H_2O_{(l)} + 2\ e^-$ oxidation

PRACTICE

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Understanding Concepts

6. (a)

$$4\ [Zn_{(s)} \rightarrow Zn^{2+}_{(aq)} + 2\ e^-]$$
$$NO^-_{3(aq)} + 10\ H^+_{(aq)} + 8\ e^- \rightarrow NH^+_{4(aq)} + 3\ H_2O_{(l)}$$
$$\overline{4\ Zn_{(s)} + NO^-_{3(aq)} + 10\ H^+_{(aq)} \rightarrow 4\ Zn^{2+}_{(aq)} + NH^+_{4(aq)} + 3\ H_2O_{(l)}}$$

 (b)

$$Cl_{2(aq)} + 2\ e^- \rightarrow 2\ Cl^-_{(aq)}$$
$$SO_{2(g)} + 2\ H_2O_{(l)} \rightarrow SO^{2-}_{4(aq)} + 4\ H^+_{(aq)} + 2\ e^-$$
$$\overline{Cl_{2(aq)} + SO_{2(g)} + 2\ H_2O_{(l)} \rightarrow 2\ Cl^-_{(aq)} + SO^{2-}_{4(aq)} + 4\ H^+_{(aq)}}$$

7. (a)

$$2\ [MnO^-_{4(aq)} + 2\ H_2O_{(l)} + 3\ e^- \rightarrow MnO_{2(s)} + 4\ OH^-_{(aq)}]$$
$$3\ [2\ I^-_{(aq)} \rightarrow I_{2(s)} + 2\ e^-]$$
$$\overline{2\ MnO^-_{4(aq)} + 4\ H_2O_{(l)} + 6\ I^-_{(aq)} \rightarrow 2\ MnO_{2(s)} + 8\ OH^-_{(aq)} + 3\ I_{2(s)}}$$

 (b)

$$3\ [CN^-_{(aq)} + 2\ OH^-_{(aq)} \rightarrow CNO^-_{(aq)} + H_2O_{(l)} + 2\ e^-]$$
$$IO^-_{3(aq)} + 3\ H_2O_{(l)} + 6\ e^- \rightarrow I^-_{(aq)} + 6\ OH^-_{(aq)}$$
$$\overline{3\ CN^-_{(aq)} + IO^-_{3(aq)} \rightarrow 3\ CNO^-_{(aq)} + I^-_{(aq)}}$$

 (c)

$$2\ [OCl^-_{(aq)} + H_2O_{(l)} + 2\ e^- \rightarrow Cl^-_{(aq)} + 2\ OH^-_{(aq)}]$$
$$OCl^-_{(aq)} + 4\ OH^-_{(aq)} \rightarrow ClO^-_{3(aq)} + 2\ H_2O_{(l)} + 4\ e^-$$
$$\overline{3\ OCl^-_{(aq)} \rightarrow 2\ Cl^-_{(aq)} + ClO^-_{3(aq)}}$$

Extension

8. $2\ KMnO_{4(aq)} + 5\ H_2S_{(aq)} + 3\ H_2SO_{4(aq)} \rightarrow K_2SO_{4(aq)} + 2\ MnSO_{4(aq)} + 5\ S_{(s)} + 8\ H_2O_{(l)}$

SECTION 9.2 QUESTIONS

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Understanding Concepts

1. Both methods of balancing redox equations are based on the conservation of electrons, i.e., the number of electrons gained by the oxidizing agent must equal the number of electrons lost by the reducing agent.
2. Oxidation: increase in oxidation number; loss of electrons
 Reduction: decrease in oxidation number; gain of electrons

3. (a)

$$Cu_{(s)} \rightarrow Cu^{2+}_{(aq)} + 2\ e^-$$
$$2\ [NO^-_{3(aq)} + 2\ H^+_{(aq)} + e^- \rightarrow NO_{2(g)} + H_2O_{(l)}\ ]$$
$$Cu_{(s)} + 2\ NO^-_{3(aq)} + 4\ H^+_{(aq)} \rightarrow Cu^{2+}_{(aq)} + 2\ NO_{2(g)} + 2\ H_2O_{(l)}$$

(b)

$$2\ [Mn^{2+}_{(aq)} + 4\ H_2O_{(aq)} \rightarrow MnO^-_{4(aq)} + 8\ H^+_{(aq)} + 5\ e^-]$$
$$5\ [HBiO_{3(aq)} + 5\ H^+_{(aq)} + 2\ e^- \rightarrow Bi^{3+}_{(aq)} + 3\ H_2O_{(l)}]$$
$$2\ Mn^{2+}_{(aq)} + 5\ HBiO_{3(aq)} + 9\ H^+_{(aq)} \rightarrow 5\ Bi^{3+}_{(aq)} + 2\ MnO^-_{4(aq)} + 7\ H_2O_{(aq)}$$

(c)

$$3\ [H_2O_{2(aq)} \rightarrow O_{2(g)} + 2\ H^+_{(aq)} + 2\ e^-]$$
$$Cr_2O^{2-}_{7(aq)} + 14\ H^+_{(aq)} + 6\ e^- \rightarrow 2\ Cr^{3+}_{(aq)} + 7\ H_2O_{(l)}$$
$$3\ H_2O_{2(aq)} + Cr_2O^{2-}_{7(aq)} + 8\ H^+_{(aq)} \rightarrow 2\ Cr^{3+}_{(aq)} + 3\ O_{2(g)} + 7\ H_2O_{(l)}$$

4. (a)

$$2\ [Cr(OH)_{3(s)} + 5\ OH^-_{(aq)} \rightarrow CrO^{2-}_{4(aq)} + 4\ H_2O_{(l)} + 3\ e^-\ ]$$
$$IO^-_{3(aq)} + 3\ H_2O_{(l)} + 6\ e^- \rightarrow I^-_{(aq)} + 6\ OH^-_{(aq)}$$
$$2\ Cr(OH)_{3(s)} + 4\ OH^-_{(aq)} + IO^-_{3(aq)} \rightarrow 2\ CrO^{2-}_{4(aq)} + 5\ H_2O_{(l)} + I^-_{(aq)}$$

(b)

$$Ag_2O_{(s)} + H_2O_{(l)} + 2\ e^- \rightarrow 2\ Ag_{(s)} + 2\ OH^-_{(aq)}$$
$$CH_2O_{(aq)} + 3\ OH^-_{(aq)} \rightarrow CHO^-_{2(aq)} + 2\ H_2O_{(l)} + 2\ e^-$$
$$Ag_2O_{(s)} + OH^-_{(aq)} + CH_2O_{(aq)} \rightarrow 2\ Ag_{(s)} + CHO^-_{2(aq)} + H_2O_{(l)}$$

(c)

$$2\ [S_2O^{2-}_{4(aq)} + 8\ OH^-_{(aq)} \rightarrow 2\ SO^{2-}_{4(aq)} + 4\ H_2O_{(l)} + 6\ e^-\ ]$$
$$3\ [O_{2(g)} + 2\ H_2O_{(l)} + 4\ e^- \rightarrow 4\ OH^-_{(aq)}]$$
$$2\ S_2O^{2-}_{4(aq)} + 3\ O_{2(g)} + 4\ OH^-_{(aq)} \rightarrow 4\ SO^{2-}_{4(aq)} + 2\ H_2O_{(l)}$$

Applying Inquiry Skills

5. Two general experimental designs that could help determine the balancing of the main species in a redox reaction are gravimetric stoichiometry (mass measurement) and volumetric stoichiometry (titration).

Making Connections

6. (a)

$$2\ [Al_{(s)} + 4\ OH^-_{(aq)} \rightarrow Al(OH)^-_{4(aq)} + 3\ e^-\ ]$$
$$3\ [2\ H_2O_{(l)} + 2\ e^- \rightarrow H_{2(g)} + 2\ OH^-_{(aq)}]$$
$$2\ Al_{(s)} + 2\ OH^-_{(aq)} + 6\ H_2O_{(l)} \rightarrow 2\ Al(OH)^-_{4(aq)} + 3\ H_{2(g)}$$

(b) Some possible health and safety issues associated with the use of solid drain cleaners are:
- Sodium hydroxide is very caustic and should be handled with gloves and eye protection.
- Flushing aluminum compounds down the drain has an impact on the environment because aluminum ions are toxic to fish and other aquatic organisms.

Extension

7.

$$Ce^{4+}_{(aq)} + e^- \rightarrow Ce^{3+}_{(aq)}$$
$$Fe^{2+}_{(aq)} \rightarrow Fe^{3+}_{(aq)} + e^-$$
$$Ce^{4+}_{(aq)} + Fe^{2+}_{(aq)} \rightarrow Ce^{3+}_{(aq)} + Fe^{3+}_{(aq)}$$

15.1 mL	25.0 mL
0.125 mol/L	*C*

$$n_{Ce^{4+}} = 15.1 \cancel{\text{mL}} \times 0.125 \frac{\text{mol}}{\cancel{\text{L}}}$$

$$n_{Ce^{4+}} = 1.89 \text{ mmol}$$

$$n_{Fe^{2+}} = 1.89 \text{ m}\cancel{\text{mol}} \text{ Ce}^{4+} \times \frac{1 \text{ mol Fe}^{2+}}{1 \cancel{\text{mol}} \text{ Ce}^{4+}}$$

$$n_{Fe^{2+}} = 1.89 \text{ mmol}$$

$$C_{Fe^{2+}} = \frac{1.89 \cancel{\text{m}}\text{mol}}{25.0 \cancel{\text{m}}\text{L}}$$

$$= 0.0755 \text{ mol/L}$$

$$C_{Fe^{2+}} = 75.5 \text{ mmol/L}$$

The concentration of iron(II) ions in the sample is 75.5 mmol/L.

9.3 PREDICTING REDOX REACTIONS

PRACTICE

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Understanding Concepts

1. Oxidation and reduction are processes that work together in the transfer of electrons that takes place in many chemical reactions. Oxidation is the process of losing electrons while reduction is the process of gaining electrons. Oxidizing agents and reducing agents are the substances directly involved in the transfer of electrons in a redox reaction. Oxidizing agents remove electrons from reducing agents, causing the reducing agent to be oxidized (loss of electrons) and the oxidizing agent to be reduced (gain of electrons).
2. If a substance is a very strong oxidizing agent it has a very strong attraction for electrons.
3. If a substance is a very strong reducing agent, its electrons are weakly attracted, and are easily removed.
4. According to Table 1, lead and zinc react spontaneously with a copper(II) ion solution.
5. According to Table 1, silver and copper did not appear to react with a copper(II) ion solution.
6. The metals, $Pb_{(s)}$ and $Zn_{(s)}$, which react spontaneously with $Cu^{2+}_{(aq)}$, both appear below the $Cu^{2+}_{(aq)}$ line in a table of reduction half-reactions.
7. Only zinc metal reacts spontaneously with lead(II) ions; silver, copper, and lead metals did not react with lead(II) ions. The metal, $Zn_{(s)}$, which reacts spontaneously with $Pb^{2+}_{(aq)}$, appears below the $Pb^{2+}_{(aq)}$ line in a table of reduction half-reactions.

Applying Inquiry Skills

8. Metal ions react spontaneously with metals listed below them in a table of reduction half-reactions. According to Table 3, the predictions are correct and the hypothesis is verified.
9. The following table of reduction half-reaction equations is based on the evidence presented in Table 4.

Relative Strengths of Oxidizing and Reducing Agents

decreasing	SOA	$Cl_{2(aq)}$ + 2 e^-	$\rightleftharpoons$ 2 $Cl^-_{(aq)}$	↑	decreasing
reactivity of	↓	$Br_{2(aq)}$ + 2 e^-	$\rightleftharpoons$ 2 $Br^-_{(aq)}$	↑	reactivity of
oxidizing agents	↓	$I_{2(aq)}$ + 2 e^-	$\rightleftharpoons$ 2 $I^-_{(aq)}$	SRA	reducing agents