CHAPTER 9 ELECTRIC CELLS

Reflect On Your Learning

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1. [*Likely initial answer*] Chemical reactions occur that produce electricity.
   [*More complete answer*] The substance with the greatest tendency to gain electrons (i.e., with the most positive reduction potential) pulls electrons via the external circuit from another substance with the greatest tendency to lose electrons (i.e., with the most negative reduction potential). Ions transfer electric charge within the electrolyte to complete the internal circuit.
2. [*Likely initial answer*] The ability to transfer electrons is the key scientific concept.
   [*More complete answer*] The relative strengths of oxidizing and reducing agents as measured by reduction potentials is a key concept to explain why electrons are transferred. Oxidation states help to understand and describe the chemical changes that accompany the gain and loss of electrons. Other concepts such as electronegativities and ion mobility are also part of the explanation.
3. [*Likely initial answer*] Cells come in a variety of sizes; some cells are rechargeable and some are not. There are also different chemicals that are used such as nickel–cadmium (NiCad) and lead acid. Cells have a great impact because of their use in cars and portable electronic devices such as CD and DVD players.
   [*More complete answer*] Cells generally fall into three categories: primary, secondary, and fuel cells. Each has different characteristics and uses. Primary cells are not rechargeable, are relatively inexpensive, and are used in flashlights and small electronic devices. Secondary cells are rechargeable and are very useful for mobile phones, laptop computers, and small electronic devices. Fuel cells use a continuously supplied fuel and can be used for small power-generating stations and probably (in the near future) in cars. All of these cells significantly affect our lives in terms of convenience, new opportunities, and environmental effects.

Try This Activity: A Simple Electric Cell

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(a) The copper strip was momentarily connected to the positive (red) terminal of the voltmeter and the zinc strip to the negative (black) terminal. The needle of the voltmeter deflected briefly from zero to positive values (or the digital meter briefly registered a positive value). When the leads were reversed, the needle tried to go backwards below zero (or the digital meter briefly registered a negative value).
(b) Yes. (Depending on the fruit or vegetable, two may be needed, connected in series.)
(c) The orange with the two metal strips acted like a cell or battery. There must be some chemical reactions occurring that produce electricity.
(d) Yes.
(e) All fruits and vegetables contain some kind of juice as long as they are relatively fresh and not dried out.
(f) The electric cell could be improved with a more compact and convenient design. Instead of using some fruit or vegetable, use the essential chemicals inside the fruit or vegetable and put them in some kind of container.

9.1 OXIDATION AND REDUCTION

PRACTICE

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Understanding Concepts

1. (a) Reduction was used to describe a reaction producing a metal from its naturally occurring compound.
   (b) Oxidation was used to describe reactions of substances such as metals or fuels with oxygen.
   (c) An oxidizing agent is a substance that causes or promotes the oxidation of another substance.
   (d) A reducing agent is a substance that causes or promotes the reduction of another substance.
   (e) Metallurgy is the science and technology of extracting metals from their naturally occurring compounds and adapting these metals for useful purposes.
   (f) Corrosion is the adverse reaction of human-made items with chemicals in the envrionment, usually metals reacting to form oxides, carbonates, or sulfides.

2. (a) oxidaton of iron; oxygen is the oxidizing agent
   (b) reduction of lead(II) oxide; carbon is the reducing agent
   (c) reduction of nickel(II) oxide; hydrogen is the reducing agent
   (d) oxidation of tin; bromine is the oxidizing agent
   (e) reduction of iron(III) oxide; carbon monoxide is the reducing agent
   (f) oxidation of copper; nitric acid is the oxidizing agent
3. Three reducing agents used in metallurgy are carbon, carbon monoxide, and hydrogen.
4. Nonmetals serve as oxidizing agents for metals.

Making Connections

5. In the history of metallurgy, technological applications came before scientific understanding. Methods for refining and alloying gold, copper, silver, lead, mercury, tin, and iron were developed over 3000 years ago, long before atomic theory.

Extension

6. Archaeometallurgists are concerned with what metals are present in metallic objects, where the metal ores were mined, and where the metals were reduced from the ore. The metals most studied are copper, tin, and lead, as found in bronze objects made during the time period from 3000 B.C. to 1000 B.C. (the "Bronze Age"). Samples of the same metal from different mines can be distinguished from each other by the ratios of the lead isotopes that are present. Establishing the place where a metal was mined helps archaeologists to reconstruct the trade patterns of ancient societies.

PRACTICE

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Understanding Concepts

7. (a) A redox reaction is a chemical reaction involving a transfer of electrons.
   (b) Reduction is a chemical process involving a gain of electrons.
   (c) Oxidation is a chemical process involving a loss of electrons.
8. (a) $Zn_{(s)} \rightarrow Zn^{2+}_{(aq)} + 2\ e^-$

   $Cu^{2+}_{(aq)} + 2\ e^- \rightarrow Cu_{(s)}$

   (b) $Mg_{(s)} \rightarrow Mg^{2+}_{(aq)} + 2\ e^-$

   $2\ H^+_{(aq)} + 2\ e^- \rightarrow H_{2(g)}$

9. (a) $Ni_{(s)} \rightarrow Ni^{2+}_{(aq)} + 2\ e^-$ oxidation

   $Cu^{2+}_{(aq)} + 2\ e^- \rightarrow Cu_{(s)}$ reduction

   (b) $Pb_{(s)} \rightarrow Pb^{2+}_{(aq)} + 2\ e^-$ oxidation

   $Cu^{2+}_{(aq)} + 2\ e^- \rightarrow Cu_{(s)}$ reduction

   (c) $2\ H^+_{(aq)} + 2\ e^- \rightarrow H_{2(g)}$ reduction

   $Ca_{(s)} \rightarrow Ca^{2+}_{(aq)} + 2\ e^-$ oxidation

   (d) $Fe^{3+}_{(s)} + 3\ e^- \rightarrow Fe_{(l)}$ reduction

   $Al_{(s)} \rightarrow Al^{3+}_{(s)} + 3\ e^-$ oxidation

10. $Cl_{2(aq)} + 2\ e^- \rightarrow 2\ Cl^-_{(aq)}$

    $2\ I_{(aq)} \rightarrow I_{2(s)} + 2\ e^-$

11. The presence of the same ions in the reactants and products indicates that no electrons have been transferred. Therefore, a redox reaction has not taken place.

PRACTICE

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Understanding Concepts

12. (a) +4
    (b) +7
    (c) +6
    (d) +6
    (e) –1
    (f) –1
13. (a) +1
    (b) +2
    (c) +4
    (d) –3
    (e) –2
    (f) +5
    (g) 0
    (h) –3
14. (a) 0
    (b) 0
    (c) +4
    (d) +2
15. (a) $16\ H^{+}_{(aq)} + 2\ Cr_2O^{2-}_{7(aq)} + 3\ C_2H_5OH_{(aq)} \rightarrow 4\ Cr^{3+}_{(aq)} + 3\ HC_2H_3O_{2(aq)} + H_2O_{(l)}$

    +1 +6 –2 –2 +1 –2 +1 +3 0 +1 0 –2 +1 +1 –2

    (b) The orange colour of the $Cr_2O^{2-}_{7(aq)}$ should be replaced by the green colour of the $Cr^{3+}_{(aq)}$.

16.

methane →	methanol →	methanal →	methanoic acid →	carbon dioxide
CH_4	CH_3OH	CH_2O	$HCHO_2$	CO_2
–4	–2	0	+2	+4

Extension

17. (a) The oxidation number of iron in Fe_3O_4 is calculated to be $+\frac{8}{3}$.
    (b) The fractional value of the answer is unusual because it would involve a fractional number of electrons which is not possible.
    (c) The formula, Fe_3O_4, might represent a compound involving a combination of iron(II) oxide and iron(III) oxide, which could be written $FeO \cdot Fe_2O_3$.

PRACTICE

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Understanding Concepts

18. (a) $5\ CH_3OH_{(l)} + 2\ MnO^{-}_{4(aq)} + 6\ H^{+}_{(aq)} \rightarrow 5\ CH_2O_{(l)} + 2\ Mn^{2+}_{(aq)} + 8\ H_2O_{(l)}$
    –2 +1 –2 +1 +7 –2 +1 0 +1 –2 +2 +1 –2

    (b) Carbon is oxidized from –2 to 0; $CH_3OH \xrightarrow{\text{oxidation}} CH_2O$

    (c) Manganese is reduced from +7 to +2; $MnO_4^{-} \xrightarrow{\text{reduction}} Mn^{2+}$

19. (a) $Cu_{(s)} + 2\ AgNO_{3(aq)} \rightarrow 2\ Ag_{(s)} + Cu(NO_3)_{2(aq)}$
    0 +1 +5 –2 0 +2 +5 –2 reaction is redox
    oxidation: $Cu \rightarrow Cu^{2+}$; reduction: $Ag^{+} \rightarrow Ag$

    (b) $Pb(NO_3)_{2(aq)} + 2\ KI_{(aq)} \rightarrow PbI_{2(s)} + 2\ KNO_{3(aq)}$
    +2 +5 –2 +1 –1 +2 –1 +1 +5 –2 reaction is **not** redox

    (c) $Cl_{2(aq)} + 2\ KI_{(aq)} \rightarrow I_{2(s)} + 2\ KCl_{(aq)}$
    0 +1 –1 0 +1 –1 reaction is redox
    oxidation: $I^{-} \rightarrow$ I in I_2; reduction: Cl in $Cl_2 \rightarrow Cl^{-}$

(d) $2\ NaCl_{(l)} \rightarrow 2\ Na_{(l)} + Cl_{2(g)}$
+1 –1 0 0 reaction is redox
oxidation: $Cl^- \rightarrow Cl$ in Cl_2; reduction: $Na^+ \rightarrow Na$

(e) $HCl_{(aq)} + NaOH_{(aq)} \rightarrow HOH_{(l)} + NaCl_{(aq)}$
+1 –1 +1 –2 +1 +1 –2 +1 +1 –1 reaction is **not** redox

(f) $2\ Al_{(s)} + 3\ Cl_{2(g)} \rightarrow 2\ AlCl_{3(s)}$
0 0 +3 –1 reaction is redox
oxidation: $Al \rightarrow Al^{3+}$; reduction: Cl in $Cl_2 \rightarrow Cl^-$

(g) $2\ C_4H_{10(g)} + 13\ O_{2(g)} \rightarrow 8\ CO_{2(g)} + 10\ H_2O_{(l)}$
–2.5 +1 0 +4 –2 +1 –2 reaction is redox
oxidation: C in $C_4H_{10} \rightarrow$ C in CO_2; reduction: O in $O_2 \rightarrow$ O in CO_2 and H_2O

(h) $2\ H_2O_{2(l)} \rightarrow 2\ H_2O_{(l)} + O_{2(g)}$
+1 –1 +1 –2 0 reaction is redox
oxidation: O in H_2O_2 to O in O_2; reduction: O in H_2O_2 to O in H_2O

20. (a) single displacement
(b) double displacement
(c) single displacement
(d) decomposition
(e) double displacement
(f) formation
(g) combustion
(h) decomposition
Double displacement reactions do not appear to be redox reactions.

21. The oxygen atoms in hydrogen peroxide, $H_2O_{2(l)}$, have an oxidation number of –1, and can be either oxidized to $O_{2(g)}$, (oxidation number of 0), or reduced to an oxidation state of –2 (as in $H_2O_{(l)}$ or metallic oxides).

Making Connections

22. On Earth, carbon is easily oxidized to carbon dioxide by a combustion reaction.
$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$
0 +4
On Saturn, carbon would likely undergo the following reduction reaction.
$C_{(s)} + H_{2(g)} \rightarrow CH_{4(g)}$
0 –4

SECTION 9.1 QUESTIONS

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Understanding Concepts

1.

	Electron transfer	Oxidation states
oxidation	loss of electrons	increases (becomes more positive)
reduction	gain of electrons	decreases (becomes more negative)

2. (a) $Cu^{2+}_{(aq)} + 2\ e^- \rightarrow Cu_{(s)}$ reduction
$Pb_{(s)} \rightarrow Pb^{2+}_{(aq)} + 2\ e^-$ oxidation
(b) $Cl_{2(aq)} + 2\ e^- \rightarrow 2\ Cl^-_{(aq)}$ reduction
$2\ Br^-_{(aq)} \rightarrow Br_{2(l)} + 2\ e^-$ oxidation

3. An oxidation number is a positive or negative number corresponding to the apparent charge that an atom in a molecule or ion would have if the electron pairs in covalent bonds belonged entirely to the more electronegative atom.

4. A redox reaction can be recognized using a chemical reaction equation by
- looking for examples of formation, decomposition, single displacement, and combustion reactions;

- 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) $\underset{+7\ -2}{MnO_{4(aq)}^{-}} + \underset{+3\ -2}{C_2O_{4(aq)}^{2-}} + \underset{+1}{H^{+}_{(aq)}} \rightarrow \underset{+2}{Mn^{2+}_{(aq)}} + \underset{+1\ -2}{H_2O_{(l)}} + \underset{+4\ -2}{CO_{2(g)}}$
   (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) $Cr_2O_{7(aq)}^{2-} + 6\ Cl^{-}_{(aq)} + 14\ H^{+}_{(aq)} \rightarrow 2\ Cr^{3+}_{(aq)} + 3\ Cl_{2(aq)} + 7\ H_2O_{(l)}$
   (b) $2\ IO_{3\ (aq)}^{-} + 5\ HSO_{3\ (aq)}^{-} \rightarrow 5\ SO_{4(aq)}^{2-} + I_{2(s)} + 3\ H^{+}_{(aq)} + H_2O_{(l)}$
   (c) $2\ HBr_{(aq)} + H_2SO_{4(aq)} \rightarrow SO_{2(g)} + Br_{2(l)} + 2\ H_2O_{(l)}$
3. (a) $2\ MnO_{4\ (aq)}^{-} + 3\ SO_{3(aq)}^{2-} + H_2O_{(l)} \rightarrow 3\ SO_{4(aq)}^{2-} + 2\ MnO_{2(s)} + 2\ OH^{-}_{(aq)}$
   (b) $4\ ClO_{3\ (aq)}^{-} + 3\ N_2H_{4(aq)} \rightarrow 6\ NO_{(g)} + 4\ Cl^{-}_{(aq)} + 6\ H_2O_{(l)}$
4. $4\ NH_{3(g)} + 7\ O_{2(g)} \rightarrow 4\ NO_{2(g)} + 6\ H_2O_{(g)}$