4. The metal is oxidized and the nonmetal is reduced.
5. The number of electrons gained and lost in a redox reaction must be equal because the electrons used to reduce one reactant are produced by the oxidation of the other reactant. In other words, the electrons transfer from one reactant to the other.

Applying Inquiry Skills

6. Because the mass of the paperclip decreased, we can assume that some of the iron in the paperclip was oxidized into ions by the chemicals in the cola.

Making Connections

7. (a) Reactant oxidized: $Al_{(s)}$ Reactant reduced: $Ag^{+}_{(aq)}$ or $Ag_2S_{(s)}$
   (b) Method in (a) is better because it returns silver that was oxidized to the silverware. Although method (b) is effective, a small amount of silver is permanently removed each time the silverware is scrubbed.
8. Photographic film has a solid base, usually made of a plastic such as celluloid or polyester, which is coated with a gel containing light-sensitive silver halide compounds (such as silver bromide, silver chloride, and silver iodide). The energy of the incoming light, particularly from the blue end of the visible spectrum, oxidizes some of the halide ions to halogen atoms:

   $X^{-}_{(aq)}$ + light energy $\rightarrow X_{(s)} + e^{-}$ where X could be Cl, Br, or I.

   Electrons, released by this process, reduce silver ions in the exposed film to grey-black silver atoms, forming a so-called "latent image":

   $Ag^{+}_{(aq)} + e^{-} \rightarrow Ag_{(s)}$

   However, the latent image is too weak to be seen, and requires amplification. This amplification stage is commonly known as "developing," and is done through the action of chemical developers such as hydroquinone, HOC_6H_4OH. The formation of silver atoms in the latent image sensitizes the neighbouring silver halide crystals, making them more susceptible to the action of the developer. When the film is dipped into a bath of developer, silver halide grains next to the latent image are also reduced to silver metal:

   $2\ AgX_{(s)} + HOC_6H_4OH_{(aq)} + 2\ OH^{-}_{(aq)}. \rightarrow 2\ Ag_{(s)} + C_6H_4O_2 + 2\ H_2O_{(l)} + 2\ X^{-}_{(aq)}.$

   The silver atoms produced in this reaction collect around the silver grains of the latent image, making them large enough to be seen. When the photographic image has developed to the desired degree, the developing reaction is "stopped" by dipping the film into an acidic solution such as acetic acid.

Extension

9. (a) The oxidation of glucose is an important biological process that releases a great deal of energy. When plenty of oxygen is available, glucose is oxidized directly into carbon dioxide and water. The energy released in the process is stored in a molecule called adenosine triphosphate or ATP. During strenuous exercise, however, sufficient oxygen may not be available. Under these conditions, glucose is oxidized into lactic acid.
   (b) Muscles used in long-distance running rely more on aerobic oxidation of glucose for their energy. When running at a comfortable pace, both systems of oxidation are used but the ratio of anaerobic: aerobic is low enough to prevent lactic acid from accumulating. As the pace increases, the anaerobic: aerobic ratio increases to the point where lactic acid begins to accumulate in the blood. This is known as the lactic acid threshold. In order to improve performance, long-distance runners try to train at the speed at which the lactic acid threshold occurs. This serves to increase the threshold and overall performance.

5.2 REDOX REACTIONS OF NONMETALS

PRACTICE

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1.

(a)	Cl	0		
(b)	S	0		
(c)	H	+1	S	−2
(d)	F	–1		
(e)	Na	+1	O	−2
(f)	C	+4	O	−2
(g)	Fe	+3	O	−2
(h)	H	+1	O	−1

2.

(a)	Cl	+3
(b)	N	+3
(c)	S	+4
(d)	C	+4
(e)	Cl	+7
(f)	Fe	+3
(g)	Pb	+2
(h)	Mn	+7

PRACTICE

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3. (a) $\overset{0}{H_{2(g)}} + \overset{0}{Cl_{2(g)}} \rightarrow 2\ \overset{+1\ -1}{HCl_{(g)}}$

   The oxidation number of hydrogen changed from 0 to +1; while the oxidation number of chlorine changed from 0 to −1. Therefore, this is a redox reaction.

   (b) $2\ \overset{0}{K_{(s)}} + \overset{0}{I_{2(g)}} \rightarrow 2\ \overset{+1\ -1}{KI_{(s)}}$

   The oxidation numbers of potassium and iodine changed from 0 to +1 and –1 respectively. Therefore, this is a redox reaction.

   (c) $\overset{+2\ +4\ -2}{CaCO_{3(s)}} \rightarrow \overset{+2\ -2}{CaO_{(s)}} + \overset{+4\ -2}{CO_{2(g)}}$

   Since there is no change in oxidation numbers for any of the atoms, the given reaction is not a redox reaction.

   (d) $2\ \overset{+1\ -2}{H_2O_{(l)}} \rightarrow 2\ \overset{0}{H_{2(g)}} + \overset{0}{O_{2(g)}}$

   The oxidation number of hydrogen changed from +1 to 0; the oxidation numbers of oxygen changed from–2 to 0. Therefore, this is a redox reaction.

   (e) $2\ \overset{0}{Li_{(s)}} + 2\ \overset{+1\ -2}{H_2O_{(l)}} \rightarrow 2\ \overset{+1\ -2\ +1}{LiOH_{(aq)}} + \overset{0}{H_{2(g)}}$

   The oxidation number of lithium changed from 0 to +1; the oxidation number of hydrogen changed from +1 to 0. Therefore, this is a redox reaction.

   (f) $\overset{+3\ -2}{Fe_2O_{3(s)}} + 3\ \overset{+2\ -2}{CO_{(g)}} \rightarrow 2\ \overset{0}{Fe_{(s)}} + 3\ \overset{+4\ -2}{CO_{2(g)}}$

   The oxidation number of iron changed from +3 to 0; the oxidation number of carbon changed from +2 to +4. Therefore, this is a redox reaction.

   (g) $\overset{-4\ +1}{CH_{4(g)}} + 2\ \overset{0}{O_{2(g)}} \rightarrow \overset{+4\ -2}{CO_{2(g)}} + 2\ \overset{+1\ -2}{H_2O_{(g)}}$

   The oxidation number of carbon changed from −4 to +4; the oxidation number of oxygen changed from 0 to −2. Therefore, this is a redox reaction.

   (h) $2\ \overset{+1\ +5\ -2}{NaNO_{3(s)}} \rightarrow 2\ \overset{+1\ +3\ -2}{NaNO_{2(s)}} + \overset{0}{O_{2(g)}}$

   The oxidation number of nitrogen changed from +5 to +3; the oxidation number of oxygen changed from −2 to 0. Therefore, this is a redox reaction.

   (i) $\overset{0}{Ca_{(s)}} + 2\ \overset{+1\ -1}{HCl_{(aq)}} \rightarrow \overset{0}{H_{2(g)}} + \overset{+2\ -1}{CaCl_{2(aq)}}$

   The oxidation number of calcium changed from 0 to +2; the oxidation number of hydrogen changed from +1 to 0. Therefore, this is a redox reaction.

   (j) $2\ \overset{+1\ +5\ -2}{HNO_{3(aq)}} + \overset{+2\ -2\ +1}{Ca(OH)_{2\ (aq)}} \rightarrow 2\ \overset{+1\ -2}{H_2O_{(l)}} + \overset{+2\ +5\ -2}{Ca(NO_3)_{2(aq)}}$

   Since there is no change in oxidation numbers for any of the atoms, the given reaction is not a redox reaction.

SECTION 5.2 QUESTIONS

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Understanding Concepts

1. **Table 2** Comparing Oxidation and Reduction

	Oxidation number increases or decreases?
Oxidation	oxidation number increases
Reduction	oxidation number decreases

2. (a) O: 0
   (b) Ag: +1
   (c) Mn: +4
   (d) Zn: +2
   (e) Cl: +5
   (f) C: +4
   (g) Mn: +7
   (h) S: +4
   (i) S: +2
3. Assigning oxidations numbers:

   0 0 +1 −2

   $2\ H_{2(g)} + O_{2(g)} \rightarrow 2\ H_2O_{(g)}$

   The oxidation number of hydrogen changed from 0 to +1; the oxidation number of oxygen changed from 0 to −2. Therefore, this is a redox reaction.
4. Assigning oxidations numbers:

   0 +1 −2 +2 −2 +1 0

   $Ca_{(s)} + 2\ H_2O_{(l)} \rightarrow Ca(OH)_{2(aq)} + H_{2(g)}$

   The oxidation number of calcium changed from 0 to +2; the oxidation number of hydrogen changed from +1 to 0. Therefore, this is a redox reaction.
5. Assigning oxidation numbers:

   +3 −2 0 0 +1 −2

   $Fe_2O_{3(s)} + 3\ H_{2(g)} \rightarrow 2\ Fe_{(s)} + 3\ H_2O_{(g)}$

   The oxidation number of iron changed from +3 to 0. Therefore, $Fe_2O_{3(s)}$, or (more specifically) Fe^{3+} is reduced. The oxidation number of hydrogen changed from 0 to +1. Therefore $H_{2(g)}$ is oxidized.
6. (a) Assigning oxidations numbers:

   +4 −2 0 +6 −2

   $2\ SO_{2(g)} + O_{2(g)} \rightarrow 2\ SO_{3(g)}$

   The oxidation number of sulfur changed from +4 to +6; the oxidation number of oxygen (in elemental form) changed from 0 to −2. Therefore, this is a redox reaction.

   (b) Assigning oxidations numbers:

   +4 −2 +1 −2 +1 +5 −2 +2 −2

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

   The oxidation number of nitrogen changed from +4 to +5 in $HNO_{3(aq)}$ and to +2 in $NO_{(g)}$. Therefore, this is a redox reaction. [This is an unusual situation in which atoms of the same element are both oxidized and reduced.]

   (c) Assigning oxidations numbers:

   +4 −2 +1 −2 +1 +4 −2

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

   Since there is no change in oxidation numbers for any of the atoms, the given reaction is not a redox reaction.

Making Connections

7. (a) The first step in the procedure is for the dentist to assess your teeth to determine the type and duration of treatment required. Not all stains can be removed through the action of a whitening agent. For example, yellow-stained teeth often respond better to bleaching agents than do brown or gray-coloured teeth. The first step in treatment is usually a thorough cleaning of the teeth to remove plaque. Then a protective gel or rubber shield is applied to the gums and other soft tissue. A peroxide-based gel is then applied directly to the teeth. The gel is generally more concentrated than those available for home use. Shining a light or laser onto the teeth decomposes the peroxide to release oxygen, which enters the tooth enamel where it oxidizes stains. This process can take up to one hour. Depending on the degree of whiteness desired, a few subsequent treatments may be required. The cost of the procedure can range between $500 and $1000, depending on the number of visits required.

   (b) There are several types of at-home products available, from either your dentist or the local drugstore. In take-home kits available from a dentist, a tray is first molded to the person’s teeth. The tray is filled with bleaching chemicals, which are usually dilute gels of carbamide peroxide or hydrogen peroxide, and placed in the mouth for a set period of time. These kits can range in cost from $200 to $500. Some “over the counter” products contain plastic strips containing bleaching agents that are “taped” onto the teeth once or twice a day for several days. “Paint-on” whitening products are also available. The cost of over-the-counter products ranges from $20 to $100.

(c)

Criteria	Dentist	At home
Cost	more expensive	less expensive
Strength of chemicals	stronger bleaching agents are used, resulting in shorter treatment time	weaker bleaching agents are used, requiring longer treatment times
Results	should give good results since the procedure is being performed by a professional	results can vary depending on the diligence of the user
Time required	less time, compared to at-home treatments	more time required: some home treatments can take up to 14 days.
Convenience	requires only a few treatments in the dentist's office; client must take time off work or school for treatment	can be tedious because of the number of treatments required; some treatments require the user to sleep with the whitening tray in the mouth can be done at home

8. Hair is made mainly of a protein called keratin. Proteins are long molecules made of smaller repeating units called amino acids. A particular amino acid called cysteine is responsible for the natural waviness of hair. Each cysteine unit along a protein chain has a –SH side-chain. In naturally wavy hair, cysteines on adjacent protein chains lose their hydrogen atoms and form sulfur-to-sulfur covalent bonds (disulfide crosslinks) between each other. Naturally wavy hair has far more disulfide cross-links than straight hair. In order to permanently reshape curly hair, these cross-links must be chemically broken. One commonly used reagent is ammonium thioglycolate. This chemical breaks the disulfide bond by reducing (in the redox sense) the sulfur atoms. Once the links between the protein chains are broken, the chains can move past each other freely, allowing the hair to be reshaped.

5.3 ACTIVITY: DEVELOPING AN ACTIVITY SERIES OF METALS

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Observations

(a) Copper and tin did not react at all with the acid. The rate of production of gas bubbles was used to order the remaining metals: iron (fewest bubbles), zinc (a moderate number of bubbles), and magnesium (most bubbles).

Analysis

(b) The metals listed in order from least to most reactive are: copper and tin, iron, zinc, and magnesium.

(c) $Fe_{(s)} + 2\ HCl_{(aq)} \rightarrow FeCl_{2(aq)} + H_{2(g)}$
$Zn_{(s)} + 2\ HCl_{(aq)} \rightarrow ZnCl_{2(aq)} + H_{2(g)}$
$Mg_{(s)} + 2\ HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_{2(g)}$

Evaluation

(d) Generally, it was not difficult to determine the order of reactivity. Most of the metals reacted at different rates with the acid. The only exceptions to this generalization were tin and copper. Neither of these metals appeared to react with the acid.

To improve the Procedure, more uniform-sized pieces of metals could be used. Furthermore, a different, or more concentrated, acid could be used to determine if there is a difference in reactivity between tin and copper.

Synthesis

(e) Copper piping is now preferred because it is much less reactive than iron.