Chapter 2: The Reduction and Oxidation of Metals

Practice, page 61

1. A colour change is evidence of a chemical change or chemical reaction.

2. In ancient times, the First Nations people had extensive trading networks that moved goods and materials across the North American continent.

3. a. European settlers had been in North America for only hundreds of years. If these settlers were assumed to be the only source of the copper, the artifacts could then be only hundreds of years old.

b. If an artifact was crafted from copper that was 99.9% pure, the source of the copper for that artifact would then be from the Lake Superior area and not from Europe.

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4. $n_{Ag} = 0.533 \text{ mol}$

$n_{O_2} = ?$

First, determine the mole ratio.

Balanced chemical equation: $4\ Ag(s) + 2\ H_2S(g) + O_2(g) \rightarrow 2\ Ag_2S(s) + 2\ H_2O(l)$

Mole ratio:
$$\frac{n_{O_2}}{n_{Ag}} = \frac{coefficient_{O_2}}{coefficient_{Ag}} = \frac{1}{4}$$

Now, calculate the number of moles of $O_2(g)$ required.

$$\frac{n_{O_2}}{n_{Ag}} = \frac{1}{4}$$

$$\begin{aligned} n_{O_2} &= \frac{1}{4} \times n_{Ag} \\ &= \frac{1}{4} \times 0.533 \text{ mol} \\ &= 0.133 \text{ mol} \end{aligned}$$

The amount of oxygen required is 0.133 mol.

5. $n_{Ag_2S} = 1.45 \text{ mol}$

$n_{H_2S} = ?$

First, determine the mole ratio.

Balanced chemical equation: $4 \text{ Ag(s)} + 2 \text{ H}_2\text{S(g)} + \text{O}_2\text{(g)} \rightarrow 2 \text{ Ag}_2\text{S(s)} + 2 \text{ H}_2\text{O(l)}$

Mole ratio:
$$\frac{n_{H_2S}}{n_{Ag_2S}} = \frac{coefficient_{H_2S}}{coefficient_{Ag_2S}} = \frac{2}{2}$$

Now, calculate the number of moles of H_2S required.

$$\frac{n_{H_2S}}{n_{Ag_2S}} = \frac{2}{2}$$
$$n_{A_2S} = \frac{2}{2} \times n_{Ag_2S}$$
$$= \frac{2}{2} \times 1.45 \text{ mol}$$
$$= 1.45 \text{ mol}$$

Note: When the mole ratio is 1:1, the number of moles will be equal.

The amount of hydrogen sulfide required is 1.45 mol.

6. Eggs naturally contain sulfur compounds. (The odour from rotten eggs is due to hydrogen sulfide. This is why many people describe hydrogen sulfide as having a rotten-egg odour.) The presence of sulfur compounds in the eggs encourages the formation of the black tarnish (silver sulfide) on the spoon.

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7. a. Since the mole ratio is 1:1, there will be 3.87 mol of carbonic acid produced.

b. The first step in the process of copper obtaining its outer coating of basic copper carbonate is the formation of carbonic acid. This step depends on a chemical reaction between carbon dioxide and water in the atmosphere. The burning of fossil fuels ensures a rich supply of carbon dioxide, and the humid environment means there is lots of water in the atmosphere for this first step to occur.

8. a. $n_{Cu} = 3.89 \text{ mol}$

$n_{H_2CO_3} = ?$

$$\frac{n_{H_2CO_3}}{n_{Cu}} = \frac{coefficient_{H_2CO_3}}{coefficient_{Cu}}$$
$$\frac{n_{H_2CO_3}}{n_{Cu}} = \frac{1}{2}$$
$$n_{H_2CO_3} = \frac{1}{2} \times n_{Cu}$$
$$= \frac{1}{2} \times 3.89 \text{ mol}$$
$$= 1.95 \text{ mol}$$

The reaction will use 1.95 mol of carbonic acid.

b. $n_{Cu} = 3.89 \text{ mol}$

$n_{Cu_2(OH)_2CO_3} = ?$

$$\frac{n_{Cu_2(OH)_2CO_3}}{n_{Cu}} = \frac{coefficient_{Cu_2(OH)_2CO_3}}{coefficient_{Cu}}$$

$$\frac{n_{Cu_2(OH)_2CO_3}}{n_{Cu}} = \frac{1}{2}$$

$$\begin{aligned} n_{Cu_2(OH)_2CO_3} &= \frac{1}{2} \times n_{Cu} \\ &= \frac{1}{2} \times 3.89 \text{ mol} \\ &= 1.95 \text{ mol} \end{aligned}$$

The reaction will produce 1.95 mol of basic copper carbonate.

9. a. $n_{Ag_2S} = 4.29 \times 10^{-3} \text{ mol}$

$n_{Al} = ?$

$$\frac{n_{Al}}{n_{Ag_2S}} = \frac{coefficient_{Al}}{coefficient_{Ag_2S}}$$

$$\frac{n_{Al}}{n_{Ag_2S}} = \frac{2}{3}$$

$$\begin{aligned} n_{Al} &= \frac{2}{3} \times n_{Ag_2S} \\ &= \frac{2}{3} \times \left(4.29 \times 10^{-3} \text{ mol}\right) \\ &= 2.86 \times 10^{-3} \text{ mol} \end{aligned}$$

The reaction requires 2.86×10^{-3} mol of aluminium.

b. $n_{Ag_2S} = 4.29 \times 10^{-3} \text{ mol}$

$n_{H_2O} = ?$

$$\frac{n_{H_2O}}{n_{Ag_2S}} = \frac{coefficient_{H_2O}}{coefficient_{Ag_2S}}$$

$$\frac{n_{H_2O}}{n_{Ag_2S}} = \frac{3}{3}$$

Since the mole ratio is equal to 1, this reaction will require 4.29×10^{-3} mol of water.

c. $n_{Ag_2S} = 4.29 \times 10^{-3} \text{ mol}$

$n_{Ag} = ?$

$$\frac{n_{Ag}}{n_{Ag_2S}} = \frac{coefficient_{Ag}}{coefficient_{Ag_2S}}$$

$$\frac{n_{Ag}}{n_{Ag_2S}} = \frac{6}{3}$$

$$\begin{aligned} n_{Ag} &= \frac{6}{3} \times n_{Ag_2S} \\ &= \frac{6}{3} \times \left(4.29 \times 10^{-3} \text{ mol}\right) \\ &= 8.58 \times 10^{-3} \text{ mol} \end{aligned}$$

This reaction will produce 8.58×10^{-3} mol of silver.

d. $n_{Ag_2S} = 4.29 \times 10^{-3}$ mol
$n_{Al_2O_3} = ?$

$$\frac{n_{Al_2O_3}}{n_{Ag_2S}} = \frac{coefficient_{Al_2O_3}}{coefficient_{Ag_2S}}$$
$$\frac{n_{Al_2O_3}}{n_{Ag_2S}} = \frac{1}{3}$$
$$n_{Al_2O_3} = \frac{1}{3} \times n_{Ag_2S}$$
$$= \frac{1}{3} \times \left(4.29 \times 10^{-3}\text{ mol}\right)$$
$$= 1.43 \times 10^{-3}\text{ mol}$$

The reaction will produce 1.43×10^{-3} mol of aluminium oxide.

10. a. $n_{H_2S} = 5.76 \times 10^{-3}$ mol
$n_{NaHCO_3} = ?$

$$\frac{n_{NaHCO_3}}{n_{H_2S}} = \frac{coefficient_{NaHCO_3}}{coefficient_{H_2S}}$$
$$\frac{n_{NaHCO_3}}{n_{H_2S}} = \frac{3}{3}$$

Since the mole ratio is 1:1, this reaction will require 5.76×10^{-3} mol of baking soda.

b. $n_{H_2S} = 5.76 \times 10^{-3}$ mol
$n_{NaHS} = ?$

$$\frac{n_{NaHS}}{n_{H_2S}} = \frac{coefficient_{NaHS}}{coefficient_{H_2S}}$$
$$\frac{n_{NaHS}}{n_{H_2S}} = \frac{3}{3}$$

Since the mole ratio is 1:1, this reaction will require 5.76×10^{-3} mol of sodium hydrosulfide.

c. If the mole ratio is 1:1, the number of moles must be equal. This eliminates the need for calculations because the number of moles of the unknown substance must equal the number of moles of the given substance.

11. a. The odour of hydrogen sulfide isn't noticeable because the baking soda reacts with the hydrogen sulfide to produce sodium hydrosulfide, NaHS(aq), water, H_2O(l), and carbon dioxide CO_2(g).

b. According to the second equation, the gas liberated by these reactions is carbon dioxide.

2.1 Questions, page 68

Knowledge

1. Mole ratio is the ratio of the coefficients in a balanced chemical equation.

Mass is the amount of matter, usually measured in grams or kilograms.

2. a. step 1: List the knowns and unknowns.

$$\frac{n_{\text{reactant}}}{n_{\text{product}}} = \frac{coefficient_{\text{reactant}}}{coefficient_{\text{product}}}$$

$$n_{\text{product}} = \boxed{\qquad}$$

$$n_{\text{reactant}} = ?$$

step 2: Use the balanced chemical equation to set up the mole ratio with the unknown in the numerator.

$$\frac{n_{\text{reactant}}}{n_{\text{product}}} = \frac{coefficient_{\text{reactant}}}{coefficient_{\text{product}}}$$

$$\frac{n_{\text{reactant}}}{n_{\text{product}}} = \frac{\boxed{}}{\boxed{}}$$

step 3: Rearrange, substitute, and solve.

$$\begin{aligned} n_{\text{reactant}} &= \frac{\boxed{}}{\boxed{}} \times n_{\text{product}} \\ &= \frac{\boxed{}}{\boxed{}} \times \boxed{\qquad} \\ &= \boxed{\qquad} \end{aligned}$$

b. step 1: List the knowns and unknowns.

$$n_{\text{reactant}} = \boxed{\qquad}$$

$$n_{\text{product}} = ?$$

step 2: Use the balanced chemical equation to set up the mole ratio with the unknown in the numerator.

$$\frac{n_{\text{product}}}{n_{\text{reactant}}} = \frac{coefficient_{\text{product}}}{coefficient_{\text{reactant}}}$$

$$\frac{n_{\text{product}}}{n_{\text{reactant}}} = \frac{\boxed{}}{\boxed{}}$$

step 3: Rearrange, substitute, and solve.

$$\begin{aligned} n_{\text{product}} &= \frac{\boxed{}}{\boxed{}} \times n_{\text{reactant}} \\ &= \frac{\boxed{}}{\boxed{}} \times \boxed{\qquad} \\ &= \boxed{\qquad} \end{aligned}$$

3. Answers will vary. One example could be refining a precious metal from its ore. In the case of processing pure gold from ore, the amount of pure gold produced each day is a direct reflection of the amount of raw ore that must be processed to keep the operation profitable.

4. Answers will vary. One example is neutralizing an acid spill with a base to protect the environment. Care must be taken not to add too much of the base. An excess amount of base could also be hazardous to the environment.

Applying Concepts

5. a. $n_{Fe_2O_3} = 1.5 \times 10^3$ mol

$n_{Fe} = ?$

$$\frac{n_{Fe}}{n_{Fe_2O_3}} = \frac{coefficient_{Fe}}{coefficient_{Fe_2O_3}}$$

$$\frac{n_{Fe}}{n_{Fe_2O_3}} = \frac{2}{1}$$

$$\begin{aligned} n_{Fe} &= \frac{2}{1} \times n_{Fe_2O_3} \\ &= \frac{2}{1} \times \left(1.5 \times 10^3 \text{ mol}\right) \\ &= 3.0 \times 10^3 \text{ mol} \end{aligned}$$

This process will produce 3.0×10^3 mol of pure iron metal.

b. $n_{Fe_2O_3} = 1.5 \times 10^3$ mol

$n_{CO_2} = ?$

$$\frac{n_{CO_2}}{n_{Fe_2O_3}} = \frac{coefficient_{CO_2}}{coefficient_{Fe_2O_3}}$$

$$\frac{n_{CO_2}}{n_{Fe_2O_3}} = \frac{3}{1}$$

$$\begin{aligned} n_{CO_2} &= \frac{3}{1} \times n_{Fe_2O_3} \\ &= \frac{3}{1} \times \left(1.5 \times 10^3 \text{ mol}\right) \\ &= 4.5 \times 10^3 \text{ mol} \end{aligned}$$

This process will release 4.5×10^3 mol of carbon dioxide into the air.

c. $n_{Fe_2O_3} = 1.5 \times 10^3$ mol

$n_{CO} = ?$

$$\frac{n_{CO}}{n_{Fe_2O_3}} = \frac{coefficient_{CO}}{coefficient_{Fe_2O_3}}$$

$$\frac{n_{CO}}{n_{Fe_2O_3}} = \frac{3}{1}$$

$$\begin{aligned} n_{CO} &= \frac{3}{1} \times n_{Fe_2O_3} \\ &= \frac{3}{1} \times \left(1.5 \times 10^3 \text{ mol}\right) \\ &= 4.5 \times 10^3 \text{ mol} \end{aligned}$$

To fully change the ore, 4.5×10^3 mol of carbon monoxide will be required.

6. **a.** $n_{NO} = 2.8 \times 10^3$ mol

$n_{NH_3} = ?$

$$\frac{n_{NH_3}}{n_{NO}} = \frac{coefficient_{NH_3}}{coefficient_{NO}}$$

$$\frac{n_{NH_3}}{n_{NO}} = \frac{4}{4}$$

Since the mole ratio is 1:1, you will need 2.8×10^3 mol of ammonia.

b. $n_{NO} = 2.8 \times 10^3$ mol

$n_{O_2} = ?$

$$\frac{n_{O_2}}{n_{NO}} = \frac{coefficient_{O_2}}{coefficient_{NO}}$$

$$\frac{n_{O_2}}{n_{NO}} = \frac{5}{4}$$

$$\begin{aligned} n_{O_2} &= \frac{5}{4} \times n_{NO} \\ &= \frac{5}{4} \times \left(2.8 \times 10^3 \text{ mol}\right) \\ &= 3.5 \times 10^3 \text{ mol} \end{aligned}$$

You will need 3.5×10^3 mol of oxygen.

c. $n_{NO} = 2.8 \times 10^3$ mol

$n_{H_2O} = ?$

$$\frac{n_{H_2O}}{n_{NO}} = \frac{coefficient_{H_2O}}{coefficient_{NO}}$$

$$\frac{n_{H_2O}}{n_{NO}} = \frac{6}{4}$$

$$\begin{aligned} n_{H_2O} &= \frac{6}{4} \times n_{NO} \\ &= \frac{6}{4} \times \left(2.8 \times 10^3 \text{ mol}\right) \\ &= 4.2 \times 10^3 \text{ mol} \end{aligned}$$

This reaction will produce 4.2×10^3 mol of water.

7. **a.** $n_{C_6H_{12}O_6} = 9.00$ mol

$n_{H_2O} = ?$

$$\frac{n_{H_2O}}{n_{C_6H_{12}O_6}} = \frac{coefficient_{H_2O}}{coefficient_{C_6H_{12}O_6}}$$

$$\frac{n_{H_2O}}{n_{C_6H_{12}O_6}} = \frac{6}{1}$$

$$\begin{aligned} n_{H_2O} &= \frac{6}{1} \times n_{C_6H_{12}O_6} \\ &= \frac{6}{1} \times 9.00 \text{ mol} \\ &= 54.0 \text{ mol} \end{aligned}$$

This reaction required 54.0 mol of water.

b. $n_{C_6H_{12}O_6} = 9.00 \text{ mol}$

$n_{O_2} = ?$

$$\frac{n_{O_2}}{n_{C_6H_{12}O_6}} = \frac{coefficient_{O_2}}{coefficient_{C_6H_{12}O_6}}$$

$$\frac{n_{O_2}}{n_{C_6H_{12}O_6}} = \frac{6}{1}$$

$$\begin{aligned} n_{O_2} &= \frac{6}{1} \times n_{C_6H_{12}O_6} \\ &= \frac{6}{1} \times 9.00 \text{ mol} \\ &= 54.0 \text{ mol} \end{aligned}$$

This reaction produced 54.0 mol of oxygen.

c. The number of moles of carbon dioxide needed were 54.0 mol. Carbon dioxide, water, and oxygen each have a coefficient of 6; and glucose has a coefficient of 1. Since the mole ratios of each substance to glucose is 6 to 1, each substance requires six times as many moles as glucose to balance the equation.

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12. a. The processes of mining, crushing, and grinding the rock require large amounts of energy.

b. $m_{blister} = 150\ 000 \text{ t}$

$m_{waste} = ?$

$$\frac{m_{waste}}{m_{blister}} = \frac{98\%}{2\%}$$

$$\begin{aligned} m_{waste} &= \frac{98\%}{2\%} \times m_{blister} \\ &= \frac{98\%}{2\%} \times 150\ 000 \text{ t} \\ &= 7\ 350\ 000 \text{ t} \end{aligned}$$

c. As ores continue to be depleted, they will become more expensive to mine. Mine sites will have to be located in places that are much more remote to mine ore that has lower concentrations of copper. Given this trend, recycled copper will become a source that increases in value.

13. a. $n_{Cu} = 74.8 \text{ mol}$

$n_{Cu_2S} = ?$

$$\frac{n_{Cu_2S}}{n_{Cu}} = \frac{coefficient_{Cu_2S}}{coefficient_{Cu}}$$

$$\frac{n_{Cu_2S}}{n_{Cu}} = \frac{1}{6}$$

$$\begin{aligned} n_{Cu_2S} &= \frac{1}{6} \times n_{Cu} \\ &= \frac{1}{6} \times 74.8 \text{ mol} \\ &= 12.5 \text{ mol} \end{aligned}$$

Every second, 12.5 mol of copper(I) sulfide is required.

b. $n_{Cu} = 74.8 \text{ mol}$

$n_{Cu_2S} = ?$

$$\frac{n_{Cu_2S}}{n_{Cu}} = \frac{coefficient_{Cu_2S}}{coefficient_{Cu}}$$

$$\frac{n_{Cu_2S}}{n_{Cu}} = \frac{1}{6}$$

$$n_{Cu_2S} = \frac{1}{6} \times n_{Cu}$$

$$= \frac{1}{6} \times 74.8 \text{ mol}$$

$$= 12.5 \text{ mol}$$

Every second, 12.5 mol of sulfur dioxide is produced.

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14. **METAL IONS**

Ore Compound	Chemical Formula	Metal Ion	Number of Electrons Lost by Metal Ion
aluminium oxide	$Al_2O_3(s)$	$Al^{3+}(aq)$	3
iron(III) oxide	$Fe_2O_3(s)$	$Fe^{3+}(aq)$	3
silver oxide	$Ag_2O(s)$	$Ag^{+}(aq)$	1
silver sulfide	$Ag_2S(s)$	$Ag^{+}(aq)$	1
iron(II) sulfide	$FeS(s)$	$Fe^{2+}(aq)$	2
zinc nitrate	$Zn(NO_3)_2(s)$	$Zn^{2+}(aq)$	2
calcium carbonate	$CaCO_3(s)$	$Ca^{2+}(aq)$	2
potassium phosphate	$K_3PO_4(s)$	$K^{+}(aq)$	1

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15. **a.** Silver was the substance oxidized.

b. This is called oxidation because the silver lost electrons.

c. The liquid magma allows the copper to settle into a concentrated layer within the magma chamber. Many years later, these volcanoes become places that contain valuable copper ore.

16. **a.** The right side of each reaction shows electrons being released.

b. The term *oxidation* tends to imply that oxygen is involved. As the three examples of oxidation indicate, this is not always the case.

Practice, page 73

17. **a.** Silver is the substance that is reduced because it gains electrons.

b. The process of chemically removing the tarnish is an example of reduction. In this case, the silver ions gain electrons to become pure silver atoms.

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18.
a. reduction, gained 1 electron
b. oxidation, lost 3 electrons
c. reduction, gained 2 electrons
d. reduction, gained 3 electrons
e. oxidation, lost 4 electrons
f. oxidation, lost 2 electrons
g. oxidation, lost 1 electron
h. reduction, gained 4 electrons
i. reduction, gained 2 electrons
j. reduction, gained 1 electron

19. Since pure silver metal was produced from silver ions in the solution, the silver was reduced.

Practice, page 75

charge changes from 0 to 2+ (more positive) = oxidation

20. **a.** $\overset{0}{Zn}(s) + 2\,\overset{+\;-}{HCl}(aq) \longrightarrow \overset{2+\;-}{ZnCl_2}(aq) + \overset{0}{H_2}(g)$

charge changes from 1+ to 0 (less positive) = reduction

oxidized = Zn, zinc
reduced = H^+, hydrogen ion
spectator = Cl^-, chloride ion

charge changes from 4+ to 0 (less positive) = reduction

b. $3\,\overset{4+\;2-}{MnO_2}(s) + 4\,\overset{0}{Al}(s) \longrightarrow 3\,\overset{0}{Mn}(s) + 2\,\overset{3+\;2-}{Al_2O_3}(s)$

charge changes from 0 to 3+ (more positive) = oxidation

oxidized = Al, aluminium
reduced = Mn^{4+}, manganese ion
spectator = O^{2-}, oxide ion

charge changes from 0 to 3+ (more positive) = oxidation

c. $2\,\overset{0}{Al}(s) + 3\,\overset{0}{I_2}(s) \longrightarrow 2\,\overset{3+\,-}{AlI_3}(s)$

charge changes from 0 to 1– (less positive) = reduction

oxidized = Al, aluminium
reduced = I_2, iodine
spectator = none

charge changes from 0 to 1+ (more positive) = oxidation

d. $$2\,\overset{0}{\mathrm{Na}}(s) + \overset{0}{\mathrm{Cl}}_2(g) \longrightarrow 2\,\overset{+}{\mathrm{Na}}\overset{-}{\mathrm{Cl}}(g)$$

charge changes from 0 to 1– (less positive) = reduction

oxidized = Na, sodium
reduced = Cl_2, chlorine
spectator = none

charge changes from 0 to 2+ (more positive) = oxidation

e. $$\overset{0}{\mathrm{Ca}}(s) + 2\,\overset{+}{\mathrm{H}}\overset{-}{\mathrm{OH}}(l) \longrightarrow \overset{2+}{\mathrm{Ca}}\overset{-}{\mathrm{(OH)}}_2(s) + \overset{0}{\mathrm{H}}_2(g)$$

charge changes from 1+ to 0 (less positive) = reduction

oxidized = Ca, calcium
reduced = H^+, hydrogen ion
spectator = OH^-, hydroxide ion

21. a. The zinc atom loses two electrons.
The hydrogen ion gains one electron.
The chloride ion is a spectator.

b. The manganese ion gains four electrons.
The oxide ion is a spectator.
The aluminium atom loses three electrons.

c. The aluminium atom loses three electrons.
The iodine atom gains one electron.

d. The sodium atom loses one electron.
The chlorine atom gains one electron.

e. The calcium atom loses two electrons.
The hydrogen ion gains one electron.
The hydroxide ion is a spectator.

2.2 Questions, page 75

Knowledge

1. Oxidation is the loss of electrons by a chemical substance when it reacts.
Reduction is the gain of electrons by a chemical substance when it reacts.
A spectator ion is an ion that does not gain or lose electrons during a reaction.

2. Two reactants in a single replacement reaction undergo a change in charge. The one which loses one or more electrons becomes more positive, so it is being oxidized; the one which gains one or more electrons becomes more negative, so it is being reduced.

3. a. An oxygen molecule could undergo reduction, changing to form two oxide ions, $O^{2-}(aq)$.

b. An iron(III) ion could undergo reduction, changing to form an iron(II) ion, $Fe^{2+}(aq)$, or an iron atom, Fe(s).

c. An iron(II) ion could undergo reduction to form an iron atom, Fe(s).
An iron(II) ion could also undergo oxidation to form an iron(III) ion, $Fe^{3+}(aq)$.

d. An iron atom could undergo oxidation, changing to form an iron(II) ion, $Fe^{2+}(aq)$, or an iron(III) ion, $Fe^{3+}(aq)$.

e. A chloride ion could undergo oxidation, changing to form a chlorine atom, Cl(g), or a chlorine molecule, $Cl_2(g)$, if two are oxidizing.

f. A nitrogen molecule could undergo reduction, changing to form two nitride ions, $N^{3-}(aq)$.

Applying Concepts

4. a. The silver ion is gaining electrons because its charge changes from 1+ (as an ion) to 0.

b. The zinc is losing electrons because its charge changes from 0 to 2+.

c. The nitrate ion does not change its charge; it is a spectator.

d. The zinc metal, Zn(s), is oxidized since it loses electrons.

e. The silver ion, $Ag^{+}(aq)$, is reduced since it gains an electron.

f. The nitrate ion, $NO_3^{-}(aq)$, is a spectator since its charge does not change.

g. Two electrons are transferred in this reaction.

h. $n_{Zn} = 35.0 \text{ mol}$

$n_{Ag} = ?$

$$\frac{n_{Ag}}{n_{Zn}} = \frac{coefficient_{Ag}}{coefficient_{Zn}}$$

$$\frac{n_{Ag}}{n_{Zn}} = \frac{2}{1}$$

$$\begin{aligned} n_{Ag} &= \frac{2}{1} \times n_{Zn} \\ &= \frac{2}{1} \times 35.0 \text{ mol} \\ &= 70.0 \text{ mol} \end{aligned}$$

For this reaction, 70.0 mol of silver metal will form.

5. a. The iron metal, Fe(s), is oxidized.

b. The oxygen molecule, $O_2(g)$, is reduced.

c. There are 12 electrons transferred.

d. $n_{Fe} = 127$ mol

$n_{O_2} = ?$

$$\frac{n_{O_2}}{n_{Fe}} = \frac{coefficient_{O_2}}{coefficient_{Fe}}$$

$$\frac{n_{O_2}}{n_{Fe}} = \frac{3}{4}$$

$$\begin{aligned} n_{O_2} &= \frac{3}{4} \times n_{Fe} \\ &= \frac{3}{4} \times 127 \text{ mol} \\ &= 95.3 \text{ mol} \end{aligned}$$

It would take 95.3 mol of oxygen.

6. The silver is oxidized, and the oxygen is reduced. The number of electrons transferred is 4.

Practice, page 77

22. a. Gold atoms have a strong tendency to keep their electrons. So, they tend not to react with other metals.

b. Since gold does not react readily with other substances, it would be relatively easy to identify due to its brilliant yellow colour.

23. Coins need to be able to resist the effects of corrosion. They also should contain a valuable metal so they can represent true value in trade. Gold meets these criteria as a metal to manufacture coins.

Practice, page 79

24. a. A headphone jack made from iron atoms would tend to corrode easily because iron atoms are very reactive. The layer of corrosion that would form on the surface of the jack would not allow a smooth contact between the jack and the connecting surfaces. This would reduce the effectiveness of the jack as a conductor.

b. Both copper and silver are susceptible to corrosion, whereas gold is not. Even though these pure metals are better conductors, the layer of corrosion that would eventually form would make these metals less effective than gold.

25. The more stable a metal atom is, the more reactive it is as an ion. The more stable a metal ion is, the more reactive it is as a metal.

Practice, pages 82 and 83

26. List the metals in order of increasing reactivity with the acids—the least reactive metals at the top of the list and the most reactive at the bottom.

A listing of the reactivity of metal ions could be obtained from the first list. The difference is that the most reactive ions correspond to the metals at the top of the list and the least reactive metal ions correspond to the metals at the bottom of the list. Metal ions are listed on the left side of the series, and metals are listed on the right side. The two lists could be combined with redox half-reactions to produce an activity series similar to the one on page 556 of the textbook and in the Science 20 Data Booklet.

27. The activity series can be used to determine the relative reactivity of metals and metal ions. They can also be used to predict whether a combination of a metal and a metal ion will result in a spontaneous or non-spontaneous reaction.

28. $Ag^{+}(aq)$, $Sn^{2+}(aq)$, $Ni^{2+}(aq)$, $Cr^{2+}(aq)$, $Mg^{2+}(aq)$, $Li^{+}(aq)$

29. Ca(s), Zn(s), Fe(s), Cd(s), Sn(s), Pb(s), Cu(s)

30.

Reduction Half-Reaction	Oxidation Half-Reaction	Half-Reaction That First Appears in Activity Series	Reaction Type
$Ag^{+}(aq) + e^{-} \rightarrow Ag(s)$	$Au(s) \rightarrow Au^{3+}(aq) + 3e^{-}$	oxidation	non-spontaneous
$Cu^{2+}(aq) + 2e^{-} \rightarrow Cu(s)$	$Fe(s) \rightarrow Fe^{2+}(aq) + 2e^{-}$	reduction	spontaneous
$Na^{+}(aq) + e^{-} \rightarrow Na(s)$	$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^{-}$	oxidation	non-spontaneous
$Fe^{2+}(aq) + 2e^{-} \rightarrow Fe(s)$	$Al(s) \rightarrow Al^{3+}(aq) + 3e^{-}$	reduction	spontaneous
$Pb^{2+}(aq) + 2e^{-} \rightarrow Pb(s)$	$Ni(s) \rightarrow Ni^{2+}(aq) + 2e^{-}$	reduction	spontaneous
$2\ H^{+}(aq) + 2e^{-} \rightarrow H_2(g)$	$Fe(s) \rightarrow Fe^{2+}(aq) + 2e^{-}$	reduction	spontaneous
$Zn^{2+}(aq) + 2e^{-} \rightarrow Zn(s)$	$Ag(s) \rightarrow Ag^{+}(aq) + e^{-}$	oxidation	non-spontaneous
$Au^{3+}(aq) + 3e^{-} \rightarrow Au(s)$	$H_2(g) \rightarrow 2\ H^{+}(aq) + 2e^{-}$	reduction	spontaneous
$Hg^{2+}(aq) + 2e^{-} \rightarrow Hg(l)$	$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^{-}$	reduction	spontaneous

Practice, page 83

31. **a.** The aluminium is oxidized.

$$Al(s) \rightarrow Al^{3+}(aq) + 3e^{-}$$

b. The silver is reduced.

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

c. This is a spontaneous reaction because the reduction half-reaction appears above the oxidation half-reaction in the activity series.

d. The oxidizing agent is the silver since it promotes the oxidation of the aluminium.

e. The reducing agent is the aluminium since it promotes the reduction of the silver.

32. **a.** Lithium metal, Li(s), is the strongest reducing agent in the table because it has the greatest tendency to donate electrons. This enables other substances to gain electrons and be reduced.

b. The gold ion, $Au^{3+}(aq)$, is the strongest oxidizing agent in the table because it has the greatest tendency to accept electrons from other ions or atoms. This enables other substances to lose electrons and be oxidized.

2.3 Questions, page 85

Knowledge

1. a. A metal atom is the basic unit of structure for materials with metallic properties, such as malleability, ductility, and lustre. Metal atoms are neutral with respect to charge, having an equal number of protons and electrons.

   b. A metal ion is the form of a metal atom that has fewer electrons than protons, thereby having a net positive charge.

   c. An activity series is a listing of metals and metal ions based on their reactivity relative to one another.

   d. A spontaneous reaction is a chemical process that occurs without the addition of external energy.

   e. A non-spontaneous reaction is a chemical process that does not occur without the addition of external energy.

2. More reactive metal atoms tend to be poorly reactive as metal ions. Metals that readily donate electrons (oxidize easily) do so to become more stable. If they are more stable as ions, it will be more difficult to convert them into a less stable form.

3. Evidence of a spontaneous chemical reaction would include a colour change, the formation of a precipitate, the production of a gas (bubbles form), or a temperature change.

4. Evidence of a non-spontaneous chemical reaction would include constant intensity and colour, no formation of a gas or a precipitate, no change in temperature, and no detectable change in odour.

Applying Concepts

5. A metal container could be constructed with any metal that appears above lead in the activity series. Possible metals include copper, silver, and gold. Copper is the best choice because it is the least expensive. Ideally, the container could be made of plastic or glass as long as there would be no substances in the container materials that could react with lead (II) ions.

6. Gold does not corrode or oxidize under normal conditions, thereby maintaining its properties. Not only is gold appreciated for its lustre and used to make jewellery, it is also used in electronics—especially circuit boards—because its lack of reactivity ensures that it acts for a long time as a reliable conductor for the electric current. The fact that it is rare makes it even more precious.

7. Silver is slightly more reactive than gold (as indicated by its lower position in the activity series). One indication of silver's more reactive nature is its tendency to react with sulfur atoms in the atmosphere to form the black tarnish (silver sulfide, $Ag_2S(s)$).

Practice, page 87

33. Individual voltaic cells are loaded into this flashlight. This particular model requires a battery of two voltaic cells.

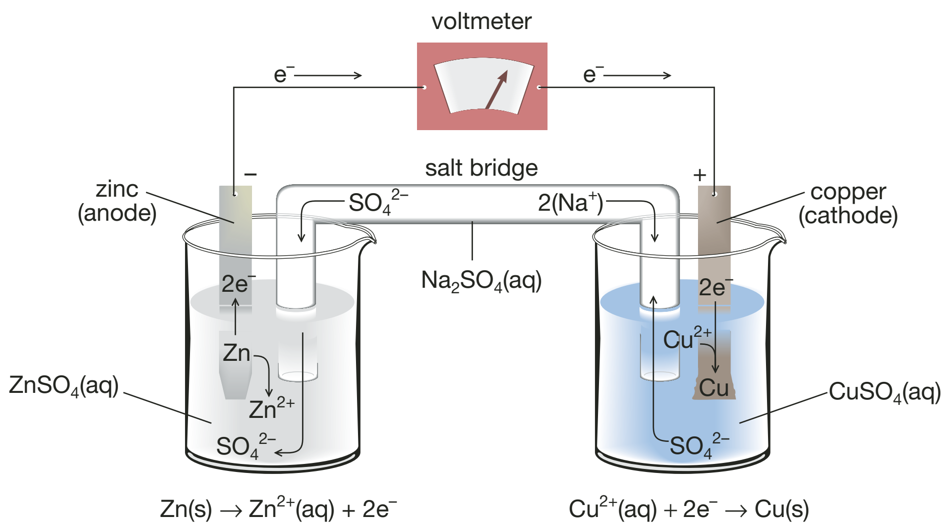
34. chemical energy → electrical energy → light energy

35. A battery of cannons act as a unit to achieve a military objective. A battery of voltaic cells work together to provide electrical energy to operate some device.

If you have an interest in military history, you may find this historical connection to be a helpful way of remembering the difference between a voltaic cell and a battery, particularly since a cylindrical consumer cell has the same shape as the barrel of a cannon.

Practice, page 91

36.



37. a. The two metals involved in this voltaic cell are copper and silver. Copper is the most reactive metal. The silver ions are the most reactive metal ion. Therefore, the copper metal is oxidized and the silver ions are reduced. This means that the copper electrode is the anode and the silver electrode is the cathode.

b. The oxidation half-reaction of copper at the anode is

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

c. The reduction half-reaction of silver ions at the cathode is

$$Ag^+(aq) + 1e^- \rightarrow Ag(s)$$

d. The salt bridge completes the circuit by allowing the transfer of nitrate ions from the beaker containing silver nitrate to the beaker containing copper(II) nitrate. It also allows the transfer of potassium ions in the opposite direction.

38. The copper metal atoms have a greater tendency to donate electrons than do the silver metal atoms. The silver metal ions have a greater tendency to accept electrons than do the copper metal ions. The result is that the electrons are moved from the copper electrode to the silver electrode. Since the only way this can happen is through the external wires, it is as if the electrons were pumped through the wires like water is pumped through a pipe.

39. A voltaic cell is a closed chemical system that needs reactants for the reaction to continue. Therefore, this reaction would stop if there wasn't an adequate supply of copper metal at the anode and silver ions in solution.

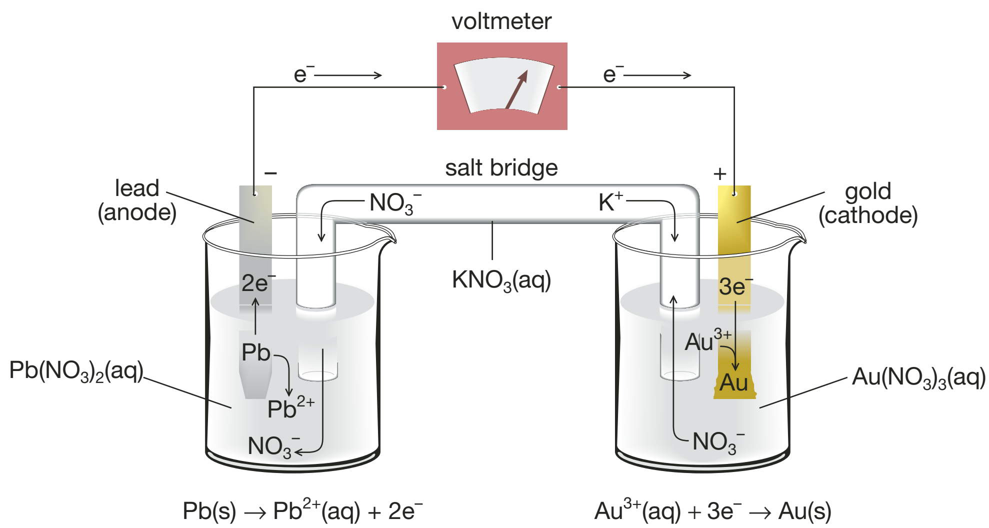
Practice, page 92

40. **a.** According to the activity series, the lead is the most reactive metal atom and the gold is the most reactive metal ion. This means that the lead is oxidized and the gold ions are reduced.

b. Since oxidation always occurs at the anode, the lead forms the anode in this cell. Reduction always occurs at the cathode, so the gold forms the cathode in this cell.

c. **Oxidation:** $Pb(s) \rightarrow Pb^{2+}(aq) + 2e^-$ **Reduction:** $Au^{3+}(aq) + 3e^- \rightarrow Au(s)$

d.

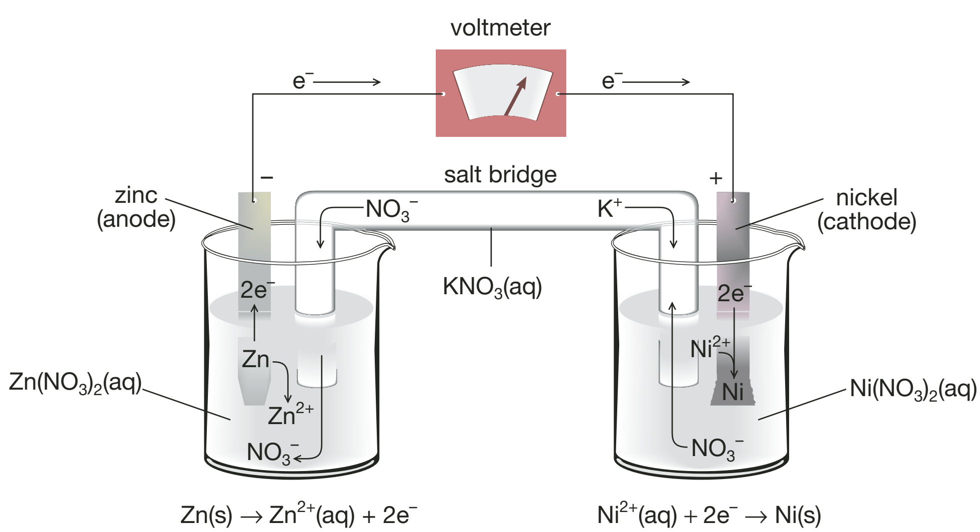


41. **a.** According to the activity series, zinc is the most reactive metal and nickel is the most reactive metal ion. This means the zinc is oxidized and the nickel ions are reduced.

b. Since oxidation occurs at the anode, the zinc forms the anode in this cell. Reduction always occurs at the cathode, so the nickel forms the cathode in this cell.

c. **Oxidation:** $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$ **Reduction:** $Ni^{2+}(aq) + 2e^- \rightarrow Ni(s)$

d.



Practice, page 94

42. **a.** This reaction indicates that the zinc electrode is the anode because this is an oxidation reaction, and oxidation always occurs at the anode.

b. The diagram shows that the zinc electrode is connected to the negative terminal of the battery. This confirms the answer to question 42.a. because electrons flow from the negative terminal—the anode.

43. **a.** As a reactant, the manganese ion has a charge of 4+; but as a product, it has a charge of 3+. This indicates that manganese gained an electron, proving that reduction occurred.

Prior to the reaction, the ammonium ion had a charge of 1+. After the reaction, ammonia became neutral. This indicates that ammonium gained an electron, proving that reduction occurred.

b. The reaction within a consumer cell is a spontaneous reaction that generates a flow of electrons. Spontaneous reactions always involve the reduction half-reaction being placed above the oxidation half-reaction in the activity series. So, the reduction half-reaction of manganese dioxide should be placed above the oxidation half-reaction for zinc.

2.4 Questions, page 94

Knowledge

1. **a.** A battery is a set of voltaic cells joined to produce an electric current.

b. A voltaic cell is a device constructed from chemical reactants that will undergo a spontaneous reduction-oxidation reaction.

c. An electrode is the metal, or conductive material, in a voltaic cell that connects to an external circuit.

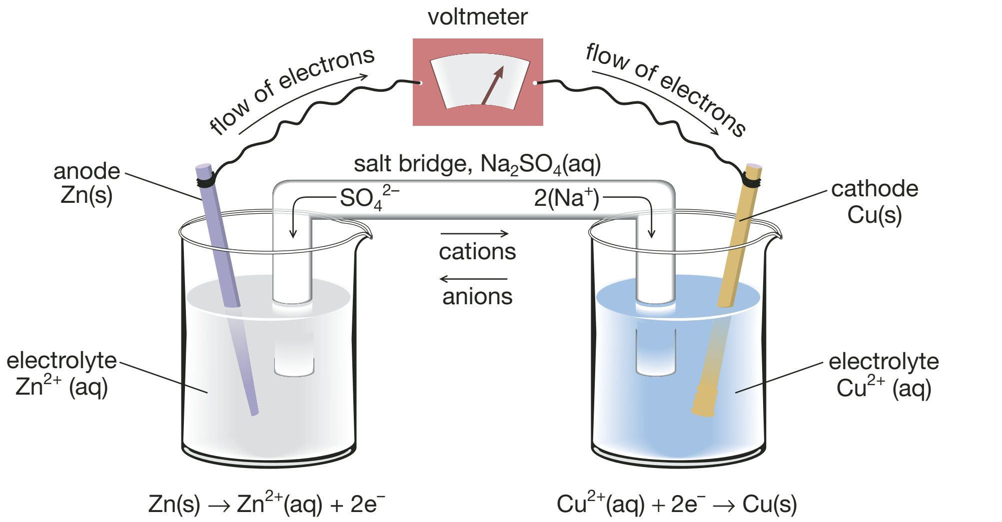
d. An anode is the negative electrode—the electrode where an oxidation reaction occurs.

e. A cathode is the positive electrode—the electrode where a reduction reaction occurs.

f. An anion is a negatively charged ion in the electrolyte of a voltaic cell. An anion will diffuse toward the anode as the cell operates to equalize charges in the system.

g. A cation is a positively charged ion in the electrolyte of a voltaic cell. A cation will diffuse toward the cathode as the cell operates to equalize charges in the system.

2.



3. The salt bridge allows for the movement of anions and cations as the redox reaction occurs. Since the cell is a circuit, the flow of electrons (negative charge) along the wire between the electrodes must be balanced with a movement of charge in the solution. The salt bridge provides a means for the flow of charged ions between the electrolyte solutions.

4. The electrons move from the anode, through the external circuit, to the cathode.

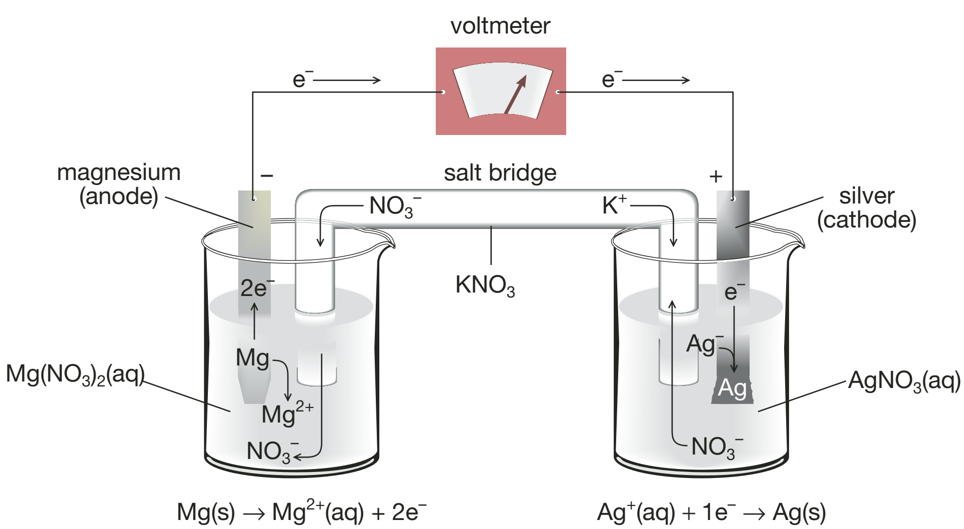
Applying Concepts

5. **a.** The magnesium is the metal that is oxidized. It appears below silver in the activity series. The silver is the metal ion that is reduced. It appears above magnesium in the activity series.

b. The magnesium is the anode, since this is the electrode where oxidation occurs. The silver is the cathode, since this is the electrode in the part of the cell where reduction occurs.

c. **Oxidation:** $Mg(s) \rightarrow Mg^{2+}(aq) + 2e^-$ **Reduction:** $Ag^+(aq) + 1e^- \rightarrow Ag(s)$

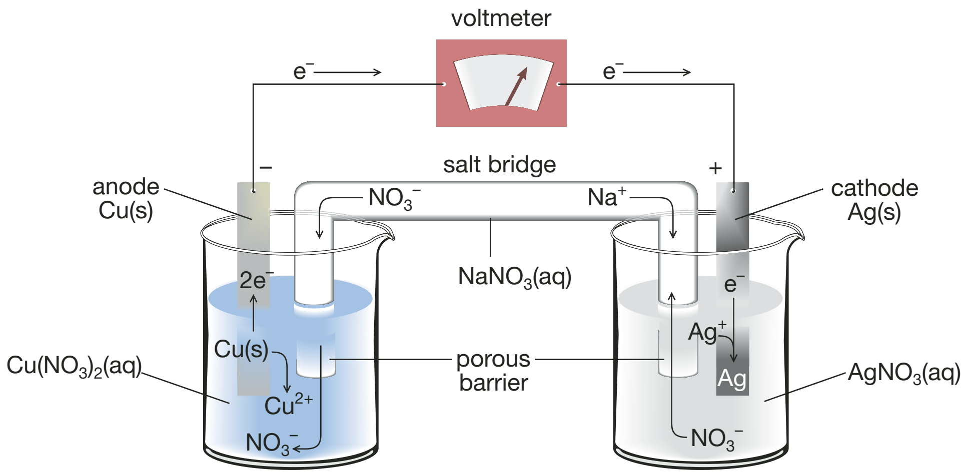
d.



6. Lithium metal appears at the bottom of the activity series, indicating that lithium atoms are the most reactive on the list. Since these atoms have the strongest tendency to donate electrons, they can form a working voltaic cell with any other metal on the list. If the other metal ion happens to be near the top of the list, the lithium would be paired with a strong tendency to accept electrons. This combination would produce a voltaic cell that could generate a large voltage.

7. In a "dead" cell, one or more of the reactants have been depleted and no matter is available for oxidation or reduction. This could be the metal ion at the cathode or the metal atoms at the anode.

8. a.



Oxidation

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

Reduction

$Ag^+(aq) + 1e^- \rightarrow Ag(s)$

$Cu(s) \,|\, Cu^{2+}(aq) \,||\, Ag^+(aq) \,|\, Ag(s)$

b. The applet should confirm the main ideas summarized by your equations and labels in the illustration.

Practice, page 99

44. It would be important to know the karat value stamped on the piece or whether the bracelet was gold-filled or gold-plated. It is very unlikely the bracelet was made from solid gold given how expensive it is to make things from 24-karat or pure gold.

Another question worth asking is whether or not this item is new. Items that are gold-filled or gold-plated have a very thin coating that can be worn off by daily use.

A final question is the mass of the bracelet. Even if the bracelet has a low percentage of gold content, if it were massive, this could still amount to a significant amount of gold that could make the bracelet quite valuable.

45. Electroplating gold requires positive gold ions in solution, $Au^{3+}(aq)$, to be attracted to the surface of the object to be plated. Since the gold ions will be reduced by combining with electrons, the object to be plated should be attached to the cathode. Reduction always occurs at the cathode.

46. Once the surface becomes scratched, the metal layer beneath the protective gold surface may be exposed to the atmosphere. Corrosion of the non-precious metal under the protective gold layer is now a possibility. This would detract from the attractive appearance of a uniform gold outer surface. The initial corrosion at the site of the scratch could also further corrode below the adjoining gold surface.

2.5 Questions, page 101

Knowledge

1. **a.** An electrolytic cell is a device in which electrical energy forces non-spontaneous reduction-oxidation reactions to occur.

b. Electroplating is the process of depositing a metal at the cathode of an electrolytic cell.

c. Electrolysis is the decomposition of a substance by means of an electric current.

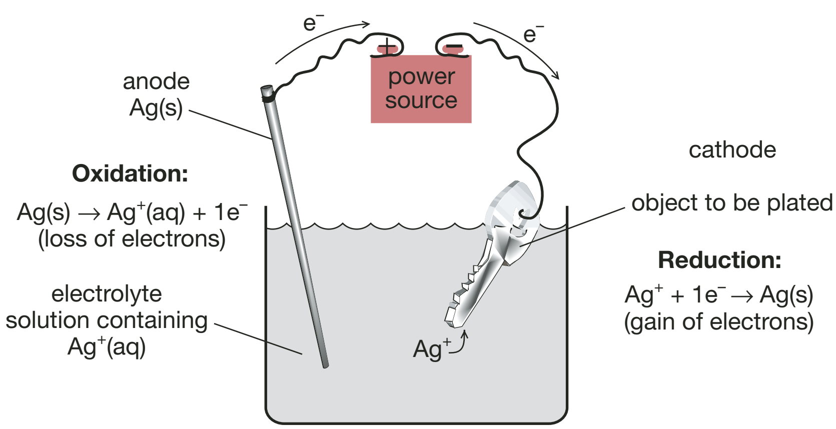
2. **ELECTROLYTIC CELLS AND VOLTAIC CELLS**

Similarities	Differences
• Both cells have aqueous and solid components. • Both cells involve reduction-oxidation reactions.	• Voltaic cells involve spontaneous reactions, whereas electrolytic cells involve non-spontaneous reactions. • Electrolytic cells have fewer components (only 1 electrolyte). • A power source is needed to operate an electrolytic cell.

3. Plating one metal over the other may be done for esthetic reasons or to provide a barrier to prevent the corrosion of the metal underneath. It is often less expensive than making the whole item from precious metal.

Applying Concepts

4.

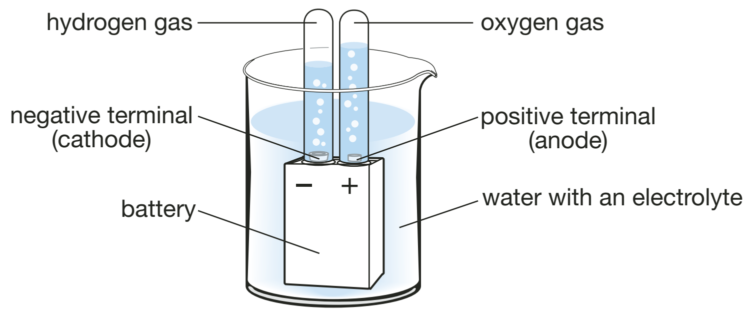


Products of cell: Ag(s) plated on the key at the cathode

5. As shown with the purification of blister copper, the impure metal is placed on the anode and thin plates of an already purified metal are attached to the cathode. As the impure metal is oxidized, the positive metal ions enter the solution and diffuse toward the cathode. When they are close to the cathode, they are attracted to the electrons made available at the cathode. As the metal ions combine with these electrons, the pure metal is deposited on the cathode.

6. Regular batteries do not contain chemicals that can be re-formed into the initial reactants by the application of an electrical current.

7. a.



b. The electrolyte is added to improve the water's ability to conduct electricity.

c. As shown by the following equation, a water molecule can be decomposed into hydrogen and oxygen.

$$2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$$