

UNIT 5 ELECTROCHEMISTRY

5.1

EXTENSION EXERCISE

(Pages 270–271)

OXIDATION AND REDUCTION—ADDITIONAL PRACTICE

- Group 1
 - 1
 - 1
- Group 17
 - 7
 - 1
- 1
 - 1
- $2 \text{K}_{(s)} + \text{Cl}_{2(g)} \rightarrow 2 \text{KCl}_{(s)}$
 - 2 electrons gained
 - 2 electrons lost
- The potassium ion is significantly smaller than the atom because the ion has fewer occupied energy levels than the atom.
 - Chloride ions are significantly larger than chlorine atoms. This difference arises because of the increased electron–electron repulsions that occur in the chloride due to the extra electron.
- Group 2
 - 2
 - 2
- 16
 - 6
 - 2
- 2
 - 2
- $2 \text{Ca}_{(s)} + \text{O}_{2(g)} \rightarrow 2 \text{CaO}_{(s)}$
 - 4 electrons gained
 - 4 electrons lost

5.1

EXTENSION EXERCISE

(Pages 272–273)

ANTIOXIDANTS: ANTIDOTE FOR OXYGEN POISONING—EXTRA CHALLENGE

Questions

- The reactivity of free radicals makes them dangerous. In an effort to pair up their unpaired electrons, free radicals oxidize molecules with which they come into contact. In the process, they damage the molecules and tissues that they oxidize.
- Free radicals become reduced as they gain electrons from surrounding molecules, which lose electrons and become oxidized.
- Antioxidants easily give up electrons to free radicals. This transfer of electrons means a redox reaction occurs.
- A well-balanced diet provides a natural source of dietary anti-oxidants useful to combat the effects of free radicals.
- BHT is used to preserve the odour, colour, and flavour of foods. BHT oxidizes more readily than the fats and oils in food, thus preventing spoilage. In addition to food products, BHT is also used as a preservative in drugs and cosmetics.

(Pages 274–276)

OXIDATION NUMBERS—ADDITIONAL PRACTICE

1. (a) +3 (f) +1
 (b) +2 (g) +2
 (c) +4 (h) +2
 (d) +1 (i) +2
 (e) +3 (j) +3
2. (a) +2 (g) +2
 (b) +4 (h) +5
 (c) 0 (i) +7
 (d) +1 (j) +6
 (e) -2 (k) +4
 (f) +4
3. (a) decreases
 (b) stays the same
 (c) increases
 (d) decreases
 (e) stays the same
4. (a), (c), and (d)
5. (a) $\begin{matrix} +2 & -2 & 0 & 0 & +2 & -2 \\ \text{PbO}_{(s)} & + & \text{C}_{(s)} & \rightarrow & \text{Pb}_{(s)} & + & \text{CO}_{(g)} \end{matrix}$
 redox
 (b) $\begin{matrix} +1 & -2 & 0 & 0 \\ 2 \text{H}_2\text{O}_{(l)} & \rightarrow & 2 \text{H}_{2(g)} & + & \text{O}_{2(g)} \end{matrix}$
 redox
 (c) $\begin{matrix} +1 & -1 & -3 & +1 & -3 & +1 & -1 \\ \text{HCl}_{(g)} & + & \text{NH}_{3(g)} & \rightarrow & \text{NH}_4\text{Cl}_{(s)} \end{matrix}$
 not redox
 (d) $\begin{matrix} 0 & +4 & -2 & +2 & -2 & +3 & -2 \\ \text{Zn}_{(s)} & + & 2 \text{MnO}_{2(s)} & \rightarrow & \text{ZnO}_{(s)} & + & \text{Mn}_2\text{O}_{3(s)} \end{matrix}$
 redox
 (e) $\begin{matrix} 0 & +1 & -2 & +2 & -2 & +1 & 0 \\ \text{Ca}_{(s)} & + & 2 \text{H}_2\text{O}_{(l)} & \rightarrow & \text{Ca(OH)}_{2(aq)} & + & \text{H}_{2(g)} \end{matrix}$
 redox
 (f) $\begin{matrix} 0 & +1 & +5 & -2 & +4 & -2 & +1 & -1 \\ 3 \text{S}_{(s)} & + & 2 \text{KClO}_{3(s)} & \rightarrow & 3 \text{SO}_{2(g)} & + & 2 \text{KCl}_{(s)} \end{matrix}$
 redox
 (g) $\begin{matrix} +1 & -2 & 0 & +4 & -2 & +1 & -2 \\ 2 \text{H}_2\text{S}_{(g)} & + & 3 \text{O}_{2(g)} & \rightarrow & 2 \text{SO}_{2(g)} & + & 2 \text{H}_2\text{O}_{(g)} \end{matrix}$
 redox
 (h) $\begin{matrix} -4 & +1 & 0 & -2 & +1 & -1 & +1 & -1 \\ \text{CH}_{4(g)} & + & \text{Cl}_{2(g)} & \rightarrow & \text{CH}_3\text{Cl}_{(g)} & + & \text{HCl}_{(g)} \end{matrix}$
 redox
6. (a) $\begin{matrix} 0 & 0 & +3 & -2 \\ 4 \text{Al}_{(s)} & + & 3 \text{O}_{2(s)} & \rightarrow & 2 \text{Al}_2\text{O}_{3(s)} \end{matrix}$
 reactant oxidized: $\text{Al}_{(s)}$ reactant reduced: $\text{O}_{2(g)}$
 (b) $\begin{matrix} 0 & +1 & 0 & +2 \\ \text{Mg}_{(s)} & + & 2 \text{Ag}^+_{(aq)} & \rightarrow & 2 \text{Ag}_{(s)} & + & \text{Mg}^{2+}_{(aq)} \end{matrix}$
 reactant oxidized: $\text{Mg}_{(s)}$ reactant reduced: $\text{Ag}^+_{(aq)}$
 (c) $\begin{matrix} 0 & +1 & +3 & 0 \\ 2 \text{Al}_{(s)} & + & 6 \text{H}^+_{(aq)} & \rightarrow & 2 \text{Al}^{3+}_{(aq)} & + & 3 \text{H}_{2(g)} \end{matrix}$
 reactant oxidized: $\text{Al}_{(s)}$ reactant reduced: $\text{H}^+_{(aq)}$

- (d)
$$\overset{0}{\text{Cl}}_{2(\text{g})} + 2 \overset{+1}{\text{Na}} \overset{-1}{\text{I}}_{(\text{aq})} \rightarrow \overset{0}{\text{I}}_{2(\text{aq})} + 2 \overset{+1}{\text{Na}} \overset{-1}{\text{Cl}}_{(\text{aq})}$$

 reactant oxidized: $\text{I}^-_{(\text{aq})}$ or $\text{NaI}_{(\text{aq})}$ reactant reduced: $\text{Cl}_{2(\text{g})}$
- (e)
$$\overset{+4}{\text{Mn}} \overset{-2}{\text{O}}_{2(\text{s})} + 4 \overset{+1}{\text{H}} \overset{-1}{\text{Cl}}_{(\text{aq})} \rightarrow \overset{0}{\text{Cl}}_{2(\text{g})} + \overset{+2}{\text{Mn}} \overset{-1}{\text{Cl}}_{2(\text{aq})} + 2 \overset{+1}{\text{H}} \overset{-2}{\text{O}}_{(\text{l})}$$

 reactant oxidized: $\text{Cl}^-_{(\text{aq})}$ or $\text{HCl}_{(\text{aq})}$ reactant reduced: $\text{Mn}^{4+}_{(\text{s})}$ or $\text{MnO}_{2(\text{s})}$
- (f)
$$\overset{0}{2 \text{ Fe}}_{(\text{s})} + \overset{0}{\text{O}}_{2(\text{g})} + 2 \overset{+1}{\text{H}} \overset{-2}{\text{O}}_{(\text{l})} \rightarrow 2 \overset{+2}{\text{Fe}} \overset{-2}{\text{O}} \overset{+1}{\text{H}}_{2(\text{s})}$$

 reactant oxidized: $\text{Fe}_{(\text{s})}$ reactant reduced: $\text{O}_{2(\text{g})}$

5.1–5.2 SELF QUIZ

(Page 277)

Completion

1. redox
2. oxidized
3. Simple (monatomic)
4. Reduction
5. Redox reaction
6. reduced
7. single displacement
8. activity series
9. Oxidation–reduction
10. element
11. Oxidation numbers
12. oxidation

(Pages 280–282)

ACTIVITY: DEVELOPING AN ACTIVITY SERIES OF CATIONS

[Sample answer]

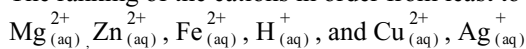
Observations**Table 1** Reactivity of Five Metals with Six Solutions

Metals	Cation in solution					
	$\text{Ag}^+_{(\text{aq})}$	$\text{Cu}^{2+}_{(\text{aq})}$	$\text{Fe}^{2+}_{(\text{aq})}$	$\text{H}^+_{(\text{aq})}$	$\text{Zn}^{2+}_{(\text{aq})}$	$\text{Mg}^{2+}_{(\text{aq})}$
$\text{Ag}_{(\text{s})}$	NR	NR	NR	NR	NR	NR
$\text{Cu}_{(\text{s})}$	gray fuzz forms on the metal; solution becomes blue	NR	NR	NR	NR	NR
$\text{Fe}_{(\text{s})}$	gray fuzz forms on the metal	reddish-brown coat forms on the metal	NR	some bubbles on the metal	NR	NR
$\text{Zn}_{(\text{s})}$	gray fuzz forms on the metal	reddish coat forms on the metal	metal becomes darker	more bubbles on the metal	NR	NR
$\text{Mg}_{(\text{s})}$	gray fuzz forms on the metal	black coating forms that turns red after 5 to 10 min.	metal becomes darker	bubbles form quickly on the metal	tiny black spots formed on the metal	NR

Note: “NR” means that no evidence of a reaction was observed.

Analysis

- (a) The ranking of the cations in order from least to most reactive is



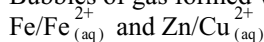
Least reactive \longrightarrow Most reactive

Solutions of H^+ and Cu^{2+} both reacted with three metals so it was impossible to determine which of the two is more reactive.

Evaluation

- (b) The magnesium in $\text{Zn}^{2+}_{(\text{aq})}$, appeared to darken slightly. However, only half the groups in the class noticed this subtle change.

Bubbles of gas formed very slowly in these metal/solution combinations:



- (c) The changes would be more definite and would occur quicker if more concentrated solutions were used.
 (d) Removing the oxide coating by sanding exposes fresh metal that can react with the solution. Without this step, the reactions would have occurred more slowly, if at all.

Synthesis

- (e) $\text{Mg}^{2+}_{(\text{aq})}, \text{Zn}^{2+}_{(\text{aq})}, \text{Fe}^{2+}_{(\text{aq})}, \text{H}^+_{(\text{aq})}$ and $\text{Cu}^{2+}_{(\text{aq})}, \text{Ag}^+_{(\text{aq})}$

Least reactive \longrightarrow Most reactive

- (f) Ag, Cu, Fe, Zn, Mg
Least reactive —————→ Most reactive
- (g) The order of the metal and ion reactivity is opposite.
- (h) The metals that would react in a $\text{Sn}^{2+}_{(\text{aq})}$ solution are Mg, Zn, and Fe because these metals are above tin on the activity series.

5.3–5.6 SELF QUIZ

(Page 287)

Completion

- The metals toward the top are most likely to be oxidized.
 - The metals toward the bottom are least likely to be oxidized.
- Hydrogen is included because, like the metals, it forms positive ions.
- $\text{Ni}_{(\text{s})} + \text{CuSO}_{4(\text{aq})} \rightarrow \text{Cu}_{(\text{s})} + \text{NiSO}_{4(\text{aq})}$
 - no reaction
 - $\text{Ca}_{(\text{s})} + \text{H}_2\text{SO}_{4(\text{aq})} \rightarrow \text{H}_{2(\text{g})} + \text{CaSO}_{4(\text{aq})}$
 - $\text{Mg}_{(\text{s})} + 2 \text{HNO}_{3(\text{aq})} \rightarrow \text{H}_{2(\text{g})} + \text{Mg}(\text{NO}_3)_{2(\text{aq})}$
- $\text{TiCl}_{4(\text{s})} + 2 \text{Mg}_{(\text{s})} \rightarrow \text{Ti}_{(\text{s})} + 2 \text{MgCl}_{2(\text{s})}$
 - Since titanium(IV) chloride reacted with magnesium, it can be concluded that Mg is more reactive than Ti. Therefore, Ti must be below Mg on the activity series.

Table 1 Classification by Ability to Conduct

Conductors	Nonconductors
$\text{Cu}_{(\text{s})}$ $\text{NaOH}_{(\text{aq})}$ $\text{KCl}_{(\text{aq})}$ $\text{Ca}(\text{OH})_{2(\text{aq})}$	$\text{C}_6\text{H}_{12}\text{O}_{6(\text{aq})}$ $\text{H}_2\text{O}_{(\text{l})}$ $\text{KCl}_{(\text{s})}$

5.8

EXTENSION EXERCISE

(Pages 291–292)

INVESTIGATION: MEASURING CELL POTENTIALS—EXTRA CHALLENGE

Part 1: Measuring Cell Potentials of Cells Involving Magnesium

Observations

- (a) **Observations of Cell Potentials** [Students' observations may vary.]

Cell	Anode	Cathode	Observed maximum cell potential (V)
Mg/Cu	Mg	Cu	1.45
Mg/Fe	Mg	Fe	1.00
Mg/Zn	Mg	Zn	0.60

Part 2: Predicting Other Cell Potentials

Prediction

(b) Cell	Predicted cell potential (V)
Zn/Fe	0.40
Zn/Cu	0.85
Fe/Cu	0.45

Part 3: Verifying the Predicted Cell Potentials

Procedure

(c)

1. Connect the zinc and iron half-cells with a salt bridge.
2. Measure the cell potential between the electrodes.
3. Note which half-cells are the anode and cathode of each cell.
4. Discard the salt bridge.
5. Repeat steps 1 to 4 for the other two cells.
6. Dispose of the metals and their solutions as directed by your teacher.

Caution: Some of the solutions used in this investigation are toxic and/or irritants. Wear eye protection and a laboratory apron. Avoid skin contact.

Observations

Cell	Observed cell potential (V)
Zn/Fe	0.36
Zn/Cu	0.87
Fe/Cu	0.47

Evaluation

- (d) The predicted and observed cell potentials were very similar.
- (e) The procedure was relatively easy to follow and gave reliable results. Using larger half-cells, more concentrated solutions, and electrodes that were similar in size would have produced more consistent results. Possible sources of error are:
- the cell potential fluctuates so it is sometimes difficult to read
 - some of the fluid in the salt bridge may have evaporated
 - the metal strips were different in size

5.11

EXTENSION EXERCISE

(Pages 293–296)

EXPLORE AN ISSUE: HYDROGEN POWER—EXTRA CHALLENGE

Understanding the Issue

1. Three limitations of the internal combustion engine are:
 - the internal combustion is inefficient, converting only about 25% of the energy stored in gasoline to mechanical energy;
 - automobile emissions are a major source of air pollution; and
 - gasoline is a fossil fuel, of which there is limited supply.
2. Three reasons why hydrogen appears to be the ideal fuel of the future include:
 - hydrogen burns cleanly
 - hydrogen fuel cells are far more efficient than the internal combustion engine
 - there appears to be an endless supply of hydrogen-containing molecules on Earth

3. The technological problems that must be overcome include the following issues.
- How will hydrogen fuel be distributed? Will there be network of hydrogen-refuelling stations, similar to gasoline stations, or will hydrogen be produced in the car on demand?
 - How will hydrogen be stored?
 - Can on-board hydrogen tanks be made safe enough to withstand a minor collision, yet still be lightweight and not too bulky?
 - Will it be possible to build a tank that can store sufficient hydrogen to give a car a good driving range?

Debate

(a) and (b)

Table 1 Pros and Cons of Hydrogen Power

Pros	Cons
<ul style="list-style-type: none"> • Hydrogen is clean. • There is an endless supply. • Hydrogen fuel cells are energy efficient. • Our supply of fossil fuels is limited. • Our society is more environmentally conscious than ever before. • Development of new technologies is good for the economy in general. • Switching to hydrogen reduces our dependence on oil and the global political tensions associated with maintaining oil supplies. 	<ul style="list-style-type: none"> • Hydrogen is only as clean as the fuel used to produce it. • Energy is required to produce hydrogen. Unless a clean renewable resource is used to produce hydrogen, there is no environmental advantage to using hydrogen. • Billions of dollars have already been invested in the development of hydrogen fuel cells and we are still many years away from mass production of hydrogen-powered cars. • Many technological hurdles still need to be overcome. • A hydrogen distribution infrastructure needs to develop before mass production of fuel cell-powered vehicles is possible.

[Sample references]

Vehicle of Change; October 2002; *Scientific American*. by Lawrence D. Burns, J. Byron McCormick and Christopher E. Borroni-Bird

<http://science.howstuffworks.com/fuel-cell.htm>

- (c) [Sample answer] Hydrogen is likely to become more popular as we start running out of gas, but it will take a long time. The hurdles are more social than technological, and would be overcome more quickly if municipal governments supported the hydrogen fuel cell industry by purchasing hydrogen-powered vehicles. This would help subsidize the cost to the private consumer.
- (d) [Sample answer] Arguments supporting the proposition “All cars will be powered by hydrogen by the year 2050”:
- We will start to run out of petroleum, and will have to save it for manufacturing, not burn it as fuel.
 - Pollution emissions regulations will make it less socially acceptable to drive gas-powered cars.
 - The technological hurdles blocking the wide-scale adoption of hydrogen-powered vehicles will be overcome.
 - Not wanting to lose any income, the oil companies will start providing hydrogen refuelling facilities at their gas stations.

(e), (f)

[Sample answer] The side opposing the proposition won. They put forward some good arguments, but I don't think they should have won because our side had collected more information. We would have done better if we had presented our information in a more focussed way that really supported the proposition.

5.7–5.11 SELF QUIZ

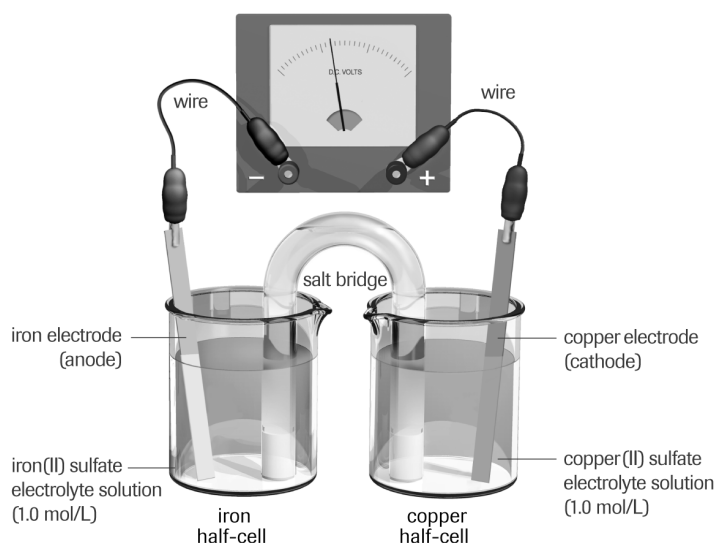
(Pages 297–298)

Modified True or False

- True
- False; In a galvanic cell, oxidation occurs at the anode.
- False; In a galvanic cell involving two metal electrodes, the metal that is higher on the activity series loses electrons.
- True
- False; Electrons always flow from the anode to the cathode.
- True
- False; The size of the cell potential depends on the electrodes and the solutions used to construct the galvanic cell.
- True
- False; The electrolyte in an alkaline dry cell is basic.
- False; Secondary cells can be recharged OR Primary cells cannot be recharged.
- True

Completion

12. (a)



- Sodium sulfate, $\text{Na}_2\text{SO}_{4(\text{aq})}$ would be a suitable electrolyte for the salt bridge in this cell because sulfate is already present in each half-cell and the sodium ion will not react with the cell contents.
 - Iron is oxidized because it is higher on the activity series than copper.
 - anode: iron cathode: copper
 - cathode: copper
 - anode half-reaction: $\text{Fe}_{(\text{s})} \rightarrow \text{Fe}_{(\text{aq})}^{2+} + 2\text{e}^-$
 - cathode half-reaction: $\text{Cu}_{(\text{aq})}^{2+} + 2\text{e}^- \rightarrow \text{Cu}_{(\text{s})}^{2+}$
 - overall cell reaction: $\text{Fe}_{(\text{s})} + \text{Cu}_{(\text{aq})}^{2+} \rightarrow \text{Fe}_{(\text{aq})}^{2+} + \text{Cu}_{(\text{s})}$
- The chemicals are put in two beakers.
 - The chemicals are separated by a porous fabric.
 - The Mg/Ag cell has the largest cell potential because magnesium and silver are the farthest apart, of the given pairs, on the activity series.
 - The Cu/Ag cell has the smallest cell potential because copper and silver are closest to each other, of the given pairs, on the activity series.
 - A clean point of contact ensures the best possible conductor-to-conductor electrical connection.
 - The cell potential would drop rapidly.
 - As the cell operates, the aluminum becomes thinner.
 - Fuel cells, in principle, can operate indefinitely because they are continually supplied with chemicals. Primary cells, on the other hand, stop operating once their chemical supply runs out.

(Pages 299–300)

GALVANIC CELLS AND CORROSION—ADDITIONAL PRACTICE

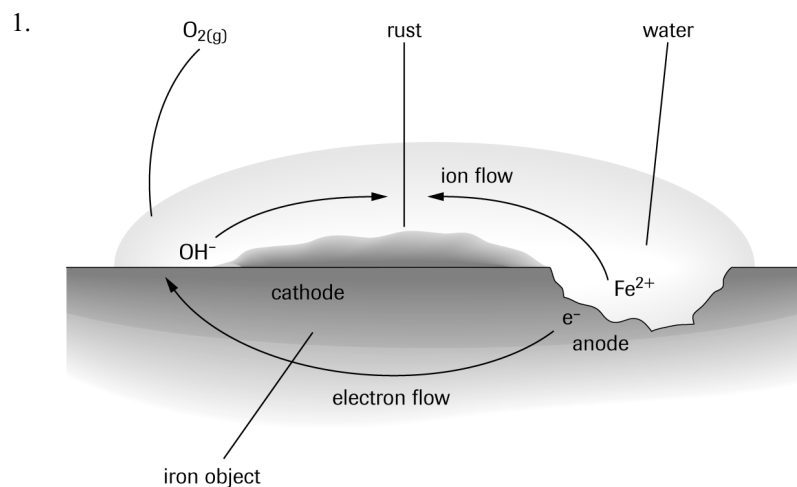


Figure 1
Corroding iron

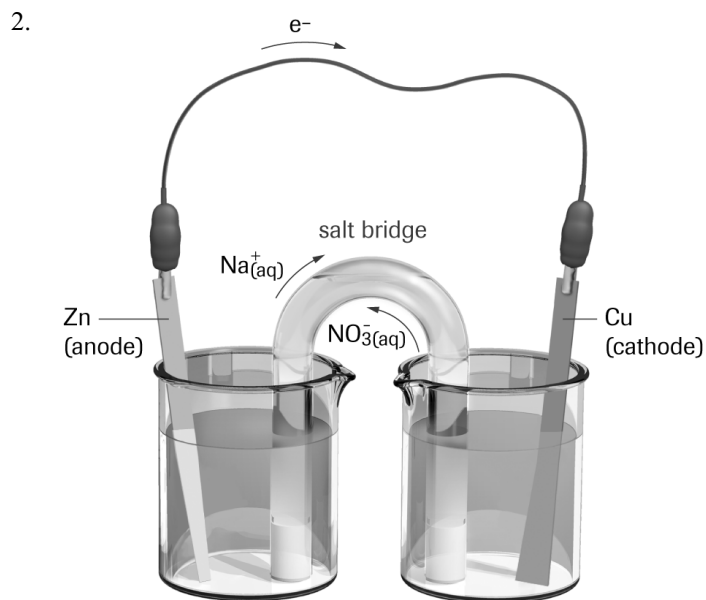


Figure 2
A zinc–copper galvanic cell

3. (a)

Cell	Zinc–copper cell	Corrosion cell
Anode half-reaction	$\text{Zn}_{(s)} \rightarrow \text{Zn}_{(aq)}^{2+} + 2 e^{-}$	$\text{Fe}_{(s)} \rightarrow \text{Fe}_{(aq)}^{2+} + 2 e^{-}$
Cathode half-reaction	$\text{Cu}_{(aq)}^{2+} + 2 e^{-} \rightarrow \text{Cu}_{(s)}$	$\frac{1}{2} \text{O}_{2(g)} + \text{H}_2\text{O}_{(l)} + 2 e^{-} \rightarrow 2 \text{OH}_{(aq)}^{-}$
Anode	$\text{Zn}_{(s)}$	$\text{Fe}_{(s)}$
Cathode	$\text{Cu}_{(s)}$	$\text{Fe}_{(s)}$
Path of electrons	anode to cathode ($\text{Zn}_{(s)}$ to $\text{Cu}_{(s)}$)	anode to cathode
Direction of ion flow	anions to anode cations to cathode	anions to anode cations to cathode
Electrode that loses mass	anode ($\text{Zn}_{(s)}$)	anode (site of corrosion)

- (b) In the Zn/Cu cell, the anode and cathode are in separate beakers. The anode and cathode of a corroding nail are on the same metal.
4. Electrolytes speed up the rate of corrosion by acting as a salt bridge between the anode and cathode sites.
5. (a) Removing the salt bridge breaks the circuit in the Zn/Cu cell, resulting in the cell potential dropping to 0.00 V.
(b) Keeping the iron nail dry would have the same effect as removing the salt bridge in the Zn/Cu cell.
6. Oxygen oxidizes $\text{Fe}_{(aq)}^{2+}$ to $\text{Fe}_{(aq)}^{3+}$.

5.13

ALTERNATIVE EXERCISE

(Pages 301–302)

CASE STUDY: THE LEAD DILEMMA

Questions

- (a) Having sat in the pipes all summer long, hydrogen ions in water had plenty of time to oxidize lead from the solder.
(b) Lead levels were high in the morning because lead had accumulated overnight. During the day the water supply is used frequently, thus preventing lead from accumulating.
(c) Lead levels dropped in the first week of school because the taps were used frequently.
- [Sample answer] If I were principal, I would recommend that the custodians flush the water through the pipes every day, and that the water be repeatedly tested to make sure that its lead content is not too high.
- Pregnant students and staff members should be supplied with bottled water as a precaution.
- [Sample answer] In addition to drinking water, there are a variety of ways in which we encounter lead in the environment. Lead dust generated from industrial operations, such as smelting and refining, can be carried by the wind and deposited in local neighbourhoods or farmland. Furthermore, workers at smelting and refining operations can accidentally transport lead dust home on their skin or clothing. It is not uncommon for the soil near some lead–acid battery manufacturing facilities to have unusually high lead levels. Airborne lead dust enters our food supply by falling directly onto crops or into the soil where it is absorbed by plants. Lead dust can also be generated during home renovation projects. Most household paints produced before 1950 contained high concentrations of lead. Knocking down a wall in an old house can release a significant amount of lead dust. This is of particular concern if the household has young children. Lead can also enter food in a variety of ways. For example, serving acidic beverages, such as citric juices and wine, in leaded crystal can cause some lead to leach from the glass into the beverage. Serving or preparing food in pottery coated with lead-based glazes can have a similar effect.

(Pages 307–308)

INVESTIGATION: SACRIFICIAL ANODES—EXTRA CHALLENGE**Prediction**

- (a) Magnesium is a more likely sacrificial anode for iron because it is above both iron and copper on the activity series.

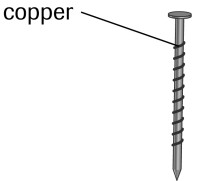


Observations**Table 1** Observations of Nails at the End of Class

Nail wrapped with copper	Nail wrapped with magnesium	Unwrapped nail
faint pink beginning to form	no noticeable changes	no noticeable changes

Table 2 Observations for Chemical Tests

Ion	Chemical test	Observation
$\text{Fe}^{2+}_{(\text{aq})}$	potassium hexacyanoferrate(III) indicator	blue
$\text{OH}^{-}_{(\text{aq})}$	phenolphthalein	pink
$\text{Mg}^{2+}_{(\text{aq})}$	sodium hydroxide	white precipitate

Sketches of Final Observations

Nail wrapped with copper	Nail wrapped with magnesium	Unwrapped nail
 <p>pink around the nail; surface of the nail is blue</p>	 <p>bubbles around the nail; no blue colour; pink near the nail; some white cloudiness near the magnesium</p>	 <p>pink near the nail</p>

Analysis

- (b) The blue colour indicates places where iron is being oxidized to $\text{Fe}^{2+}_{(\text{aq})}$ (anode sites), and pink indicates the presence of $\text{OH}^{-}_{(\text{aq})}$ (cathode sites).
- (c) Because the nail wrapped with copper had a significant coating of blue (indicating the production of $\text{Fe}^{2+}_{(\text{aq})}$), we can conclude that this nail corroded the most.
- (d) Magnesium also corroded during the experiment. The evidence for magnesium corrosion is the formation of a white precipitate around the magnesium-wrapped nail.
- (e) Based on the evidence from this experiment, magnesium protected the iron nail from corrosion. It is, therefore, the best sacrificial anode. Copper, on the other hand, promoted the corrosion of iron.

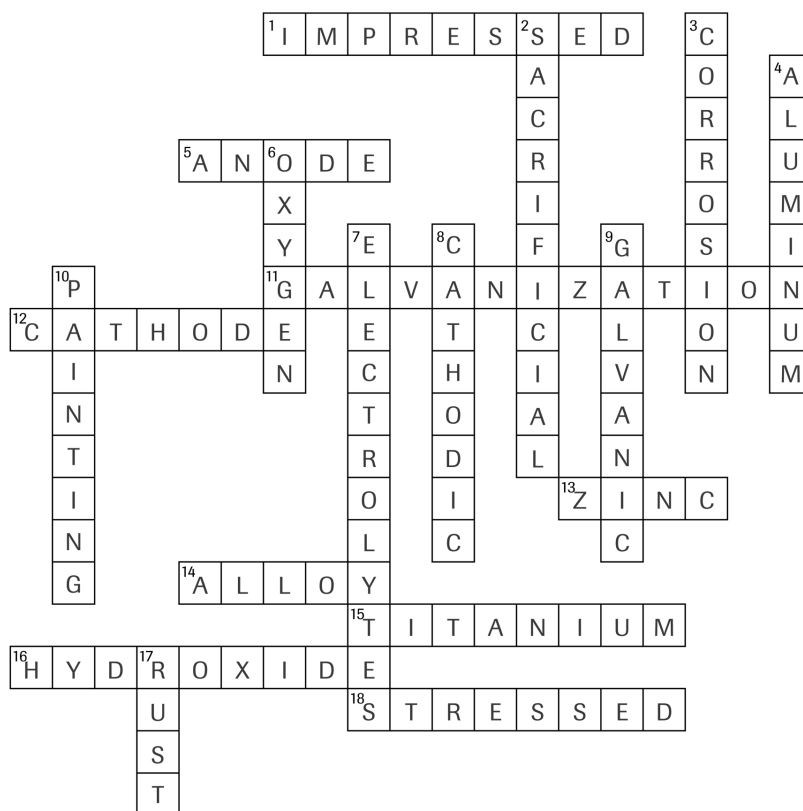
Synthesis

- (f) According to the activity series, metals above iron could be used as sacrificial anodes. Another suitable sacrificial anode could be zinc.
- (g) Because gold is below iron on the activity series, contact with gold would accelerate the corrosion of iron.

5.12–5.16 SELF QUIZ

(Page 310)

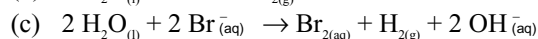
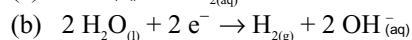
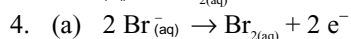
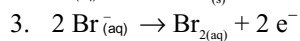
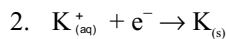
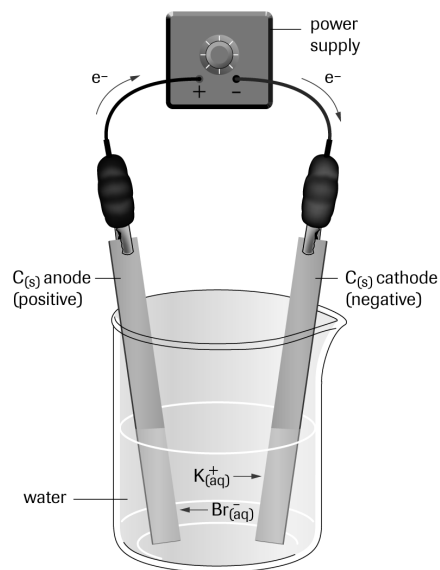
Completion



(Pages 312–313)

ELECTROLYSIS REVIEW—ADDITIONAL PRACTICE

1.



5.

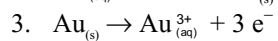
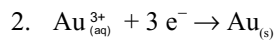
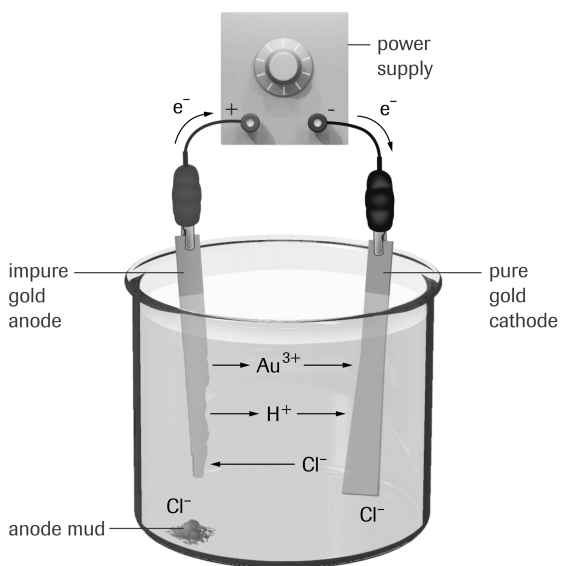
Table 1 Comparison of Galvanic and Electrolytic Cells

Cell	Galvanic cell	Electrolytic cell
Spontaneous or non-spontaneous?	spontaneous	nonspontaneous
Energy produced or required?	energy produced	energy required
Type of energy change that occurs	chemical energy to electrical energy	electrical energy to chemical energy
Where reduction occurs	cathode	cathode
Where oxidation occurs	anode	anode
Direction of electron flow	anode to cathode	anode to cathode
Direction of ion flow	cations to cathode anions to anode	cations to cathode anions to anode

(Page 314)

ELECTROREFINING REVIEW—ADDITIONAL PRACTICE

1.



4. Silver impurities are oxidized to silver ions.

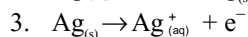
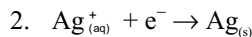
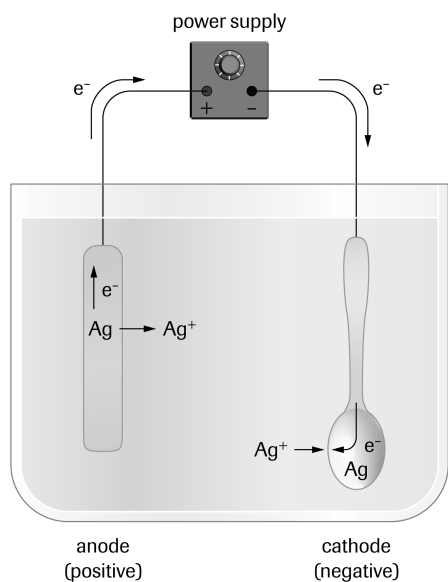
5. Platinum impurities drop to the bottom of the cell.

6. The sludge at the bottom of the tank often contains valuable metals that can be reprocessed and sold to recover costs.

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ELECTROPLATING REVIEW—ADDITIONAL PRACTICE

1.



4. (a) The mass of the silver bar decreases while the mass of the spoon increases as the cell operates.
 (b) The silver bar replenishes the silver ion content of the plating solution.

UNIT 5**ALTERNATIVE EXERCISE**

(Pages 316–317)

PERFORMANCE TASK: ELECTROPLATING**Question**

- (a) How much applied current produces the best electroplating results?

Prediction

- (b) [Sample Answer] Applying a high current will provide the best electroplating results.

Experimental Design

- (c) [Sample Answer] Identical metal objects are electroplated in a copper(II) sulfate solution using three different current settings (0.20 A, 0.50 A, and 0.75 A) for the same length of time (3 min) to see which gives the best electroplating results. The independent variable was the current; the dependent variable was quality of plating, and the fixed variables were the concentration, composition, and temperature of solutions and length of electroplating time.

Observations

(d) Comparison of the Three Objects

Object 1 0.20 A for 3.0 min	Object 2 0.50 A for 3.0 min	Object 3 0.75 A for 3.0 min
<ul style="list-style-type: none">• somewhat shiny, smooth, light copper finish• does not rub off with paper or finger• when buffed with paper towel, became more shiny and did not rub off• plating can be removed by scraping with a sharp object	<ul style="list-style-type: none">• darker, dull copper finish• rubs off easily with paper towel or finger	<ul style="list-style-type: none">• darkest of the three finishes• appears thicker and quite grainy• rubs off very easily with paper towel or finger

The following are criteria for a successful electroplating procedure:

- The metal surface should be smooth, attractive, and uniform, as opposed to rough and grainy.
- The electroplating should adhere well to the metal beneath.

Analysis

- (e) The lowest current setting resulted in the best finish. This setting resulted in a smooth finish that adhered well even when buffed. Of the three currents tested, 0.30 A gave the best finish.

Evaluation

- (f) Cleaning the metals removes any materials from the surface that may interfere with the plating process.
- (g) At times it was difficult to maintain the current at precisely the same setting for the entire 3-min plating period. Also, the object was plated more on the side facing the anode. Ideally, the thickness of the plating should be uniform. Otherwise, few difficulties were encountered.
- (h) Rotating the object during the plating procedure would perhaps improve the uniformity of the finish. Alternatively, we could use a cylindrical anode that surrounds the cathode. Also the plating procedure could be operated for a longer time to produce a thicker coating. Using a better power supply would make it easier to maintain a consistent current during the plating process.
- (i) The quality of the plated surface on the first metal object shows that my prediction was incorrect: a low current is better than a high one, for electroplating.

Synthesis

- (j) [Sample answer] I predict that operating the plating cell at low current for a longer period of time should give optimum results. The use of low currents apparently ensures that copper is deposited slowly, giving it time to adhere well. A longer plating time would allow the plate to thicken and become more uniform.

UNIT 5 SELF QUIZ

(Pages 318–319)

Modified True or False

1. False; Reduction refers to the gain of electrons.
2. True
3. True
4. True
5. False; In a galvanic cell, oxidation occurs at the anode.
6. False; The cell potential measures the electric potential difference between the electrodes of a galvanic cell.
7. False; The three minimum requirements for a galvanic cell are two different metals and an electrolyte.
8. False; Corrosion will eat a hole through iron faster than through aluminum because aluminum forms a protective oxide layer that protects the underlying metal.
9. False; In cathodic protection, the metal to be protected is made the cathode of the corrosion cell.
10. False; Zinc would make a suitable sacrificial anode for iron.
11. False; In a battery, the anode and cathode chemicals must remain separate for the cell to produce electricity.

- 12. False; Electrons leave the anode of a battery and return through the cathode.
- 13. True
- 14. True
- 15. True

Multiple Choice

- 16. (d)
- 17. (a)
- 18. (c)
- 19. (d)
- 20. (a)
- 21. (d)
- 22. (b)
- 23. (c)
- 24. (d)
- 25. (a)

