$$\text{(cathode)}\quad Zn^{2+}_{(aq)} + 2\,e^- \rightarrow Zn_{(s)} \qquad E_r^\circ = -0.76\text{ V}$$
$$\text{(anode)}\quad 2\,I^-_{(aq)} \rightarrow I_{2(s)} + 2\,e^- \qquad E_r^\circ = +0.54\text{ V}$$
$$\text{(net)}\quad Zn^{2+}_{(aq)} + 2\,I^-_{(aq)} \rightarrow Zn_{(s)} + I_{2(s)}$$
$$\Delta E^\circ = E_r^\circ{}_{\text{(cathode)}} - E_r^\circ{}_{\text{(anode)}}$$
$$= -0.76\text{ V} - (+0.54\text{ V})$$
$$\Delta E^\circ = -1.30\text{ V}$$

The cell potential is – 1.30 V.

8. (a) As the applied voltage is slowly increased, half-reactions occur at the anode in the following order:
   1. $Zn_{(s)} \rightarrow Zn^{2+}_{(aq)} + 2\,e^-$
   2. $Ni_{(s)} \rightarrow Ni^{2+}_{(aq)} + 2\,e^-$
   3. $Cu_{(s)} \rightarrow Cu^{2+}_{(aq)} + 2\,e^-$

   (Whether copper oxidizes to copper(I) ion or to copper(II) ion can be controlled by the potential applied.)

   (b) At the platinum cathode, the following half-reaction occurs: $2\,H_2O_{(l)} + 2\,e^- \rightarrow H_{2(g)} + 2\,OH^-_{(aq)}$.
9. No spontaneous reaction should occur in the cell, because theoretically, the E_r° values at both electrodes are the same, giving a cell potential of zero. Thus, a potential difference *greater* than zero must be applied to cause any reaction.

10.2 SCIENCE AND TECHNOLOGY OF ELECTROLYSIS

PRACTICE

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Understanding Concepts

1. (a) Producing active metals by electrolysis of their aqueous compounds is a problem because water will react at the cathode before the metal ions will. As well, many ionic compounds of these metals have low solubility.

   (b) These problems can be overcome by performing the electrolysis in the absence of water (e.g., using molten ionic compounds) or sometimes by using high potential to "overpower" the slower reaction of water.
2. The ions present in the electrolysis cell are $Sc^{3+}_{(l)}$ and $Cl^-_{(l)}$.

$$\text{(cathode)}\quad 2\,[Sc^{3+}_{(l)} + 3\,e^- \rightarrow Sc_{(s)}\,]$$
$$\text{(anode)}\quad 3\,[2\,Cl^-_{(l)} \rightarrow Cl_{2(g)} + 2\,e^-\,]$$
$$\text{(net)}\quad 2\,Sc^{3+}_{(l)} + 6\,Cl^-_{(l)} \rightarrow 2\,Sc_{(s)} + 3\,Cl_{2(g)}$$

3. (a) $Ca(OH)_{2(s)} + MgCl_{2(aq)} \rightarrow Mg(OH)_{2(s)} + CaCl_{2(aq)}$

   (b) $Mg(OH)_{2(s)} + 2\,HCl_{(aq)} \rightarrow MgCl_{2(aq)} + 2\,H_2O_{(l)}$

   (c) The ions present in the electrolysis cell are $Mg^{2+}_{(l)}$ and $Cl^-_{(l)}$.

$$\text{(cathode)}\quad Mg^{2+}_{(l)} + 2\,e^- \rightarrow Mg_{(s)}$$
$$\text{(anode)}\quad 2\,Cl^-_{(l)} \rightarrow Cl_{2(g)} + 2\,e^-$$
$$\text{(net)}\quad Mg^{2+}_{(l)} + 2\,Cl^-_{(l)} \rightarrow Mg_{(s)} + Cl_{2(g)}$$

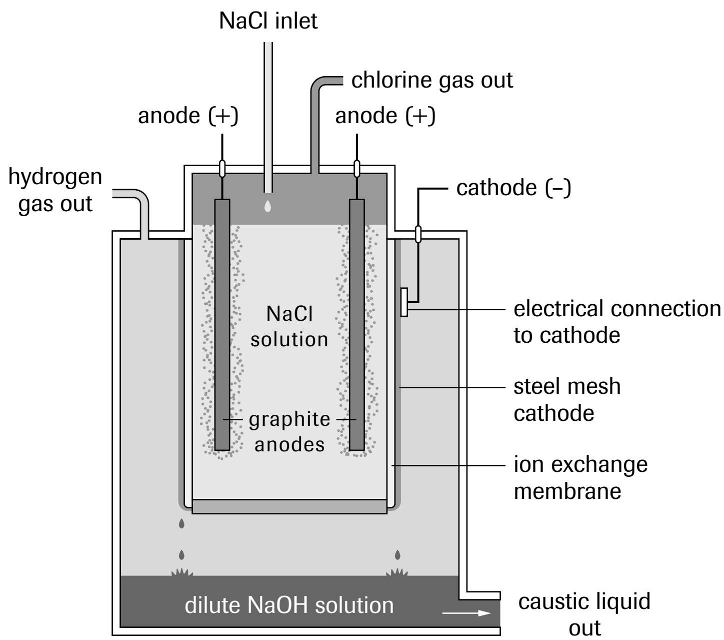
   (d) Dolomite has the advantage of being a more concentrated source of magnesium than seawater and may require fewer initial reactions before the electrolysis. A possible disadvantage is that it is more difficult and requires more energy to mine the solid than to pump the seawater. Another disadvantage is that the seas contain an almost limitless supply of magnesium salts, whereas dolomite is likely present in more limited and localized quantities.

Making Connections

4. Caustic drain cleaners and chlorine bleaches may come from a chlor-alkali process.
5. Recycling metals such as aluminum lessens the need for mining, and thus benefits the environment. It helps to reduce the cost of the metal and thus benefits the consumer. It also encourages the process of recycling and waste management, helping to foster the idea of sustainable lifestyles.
6. Uses for aluminum listed on this site include jewellery, sculpture, furniture, fabrics (fashionable or protective), cars, trains, aircraft, containers (cans), cookware, and stereo components. All make use of aluminum's light weight, high strength, and corrosion resistance.

Extension

7. The new chlor-alkali cell design eliminates the use of mercury as a cathode, or of diaphragm designs that incorporate asbestos. Both of the older designs use toxic/dangerous materials. The membrane design requires the aqueous sodium ions to pass through a fluoropolymer membrane before reacting at the steel-mesh cathode. The hydrogen gas formed by the cathode half-reaction is thus separated from the chlorine that is formed at the anodes inside the cell—a critical point, as these gases are explosively reactive when mixed! The membrane design is really an example of molecular design—it is structured at a molecular level to allow sodium ions and water molecules through only when attracted by a negative charge on the other side.



Explore an Issue: Take a Stand: The Case For and Against Chlorine
(Page 742)

(a) (A typical student report will contain information such as some of the following.)
Production of chlorine is primarily by chlor-alkali electrolysis of brine solutions. Chlorine is made in huge quantities: in 1985 it was ninth in the list of chemicals produced (in volume) in North America. The chemical is normally stored as a liquid under pressure (about 8 atm). Chlorine is transported by ship in sealed tanks; and overland in railway tank cars, in tanker trucks, and by pipeline. Chlorine has a huge variety of uses. It is used in bleaching of paper products and in laundering fabrics; in making pharmaceuticals; for air-conditioning and refrigerating fluids; in manufacturing vinyl plastics; and in water purification and disinfecting. Chlorine is very corrosive, and a very strong oxidizing agent. The chemical is harmful to humans by skin contact and especially harmful by breathing the vapour. Edema of the lungs and chronic bronchitis may result from exposure by inhalation. Many groups concerned with chlorine's potential for harm to the environment and to human health are actively campaigning to have its use in water treatment and the pulp industry replaced by other chemicals. Some chlorine compounds are now banned. While these compounds initially seemed chemically inert, it has been discovered that they accelerate the breakdown of ozone in the stratosphere — "thinning" the ozone layer that absorbs some of our sun's harmful UV radiation.

(b) (Answers will vary, depending on the issue assessed, but should include a presentation of findings, and a strongly reasoned argument for the chosen position.)

PRACTICE
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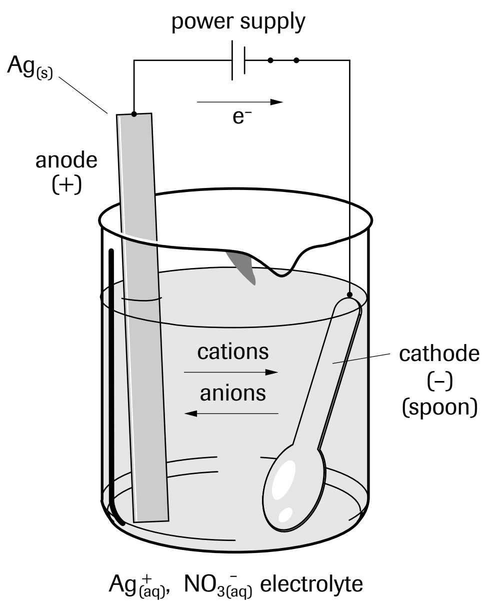
Understanding Concepts

8. A metal product must form at the cathode during electrolysis because metal ions are positively charged, and must gain electrons (be reduced) to become atoms of metal.
9. (a) Impure copper is placed at the anode to oxidize copper atoms to copper ions, which dissolve in solution.
   (b) The minimum electric potential difference required for this cell is theoretically zero.
   (c) The minimum potential difference is a theoretical minimum and would mean a very long reaction time. A higher voltage is used to get the reaction to occur rapidly. (Note that the choice of voltage is also influenced by the cost of electricity.)
10. A reduction potentials table may be used to predict which metals might be refined from an aqueous solution. Metal ions that are weaker oxidizing agents (lower) than water cannot be easily refined from solution.
11. Electroplating is done usually to coat a strong base metal with a surface that is more attractive, or corrosion resistant, or both. Other metals are commonly plated with silver and gold for appearance, nickel for corrosion resistance, and chromium for both appearance and corrosion resistance.

Applying Inquiry Skills

12. (a)



   (b) Some variables that need to be considered when planning the electrolysis include the selection, solubility, and concentration of the electrolyte, the potential difference that will be applied and the current to be used, the time the cell will operate, and the mass of silver. (Some of these variables are related to each other.)

Making Connections

13. (a) A copper wire is attached to a shoe or other nonconducting object. A conductive lacquer paint, containing copper, is then sprayed onto the object which becomes the cathode of the electrolytic cell.
   (b) The object is first washed and dried, and then sprayed with a lacquer, shellac, or varnish. A copper wire is attached and the object is sprayed with two coats of a conductive lacquer. The object is plated at 1 V for about 30 min and then at 1.5 to 2 V for additional time required to produce a coating of the desired thickness (0.025 mm of copper per hour). One particular kit with all equipment and supplies costs $460.

14.

Type of waste	Potential hazard
heavy metal waste (Cd, Cr, Pb, Hg)	toxic
alkaline and acidic solutions	environmental damage
solvents	carcinogen, greenhouse gas destroys ozone layer
cyanide waste	toxic

Companies reduce electroplating wastes by getting the most life out of their plating baths, recycling solutions, minimizing rinse water, and letting objects drain completely. Electroplating wastes can be recovered using special processes to extract metals such as copper from a solution, using solvent extraction. Treatment of wastes can use various processes such as precipitation and reverse osmosis.

15. To make an aluminum can, aluminum ingots are rolled into sheets of metal. Shallow cups are punched out and then ironed out to the full can size of the desired thickness. The end is trimmed and the open can is cleaned, coated, and labelled. The top of the can is punched out of a sheet of aluminum and then seated and sealed on the open end of the can.

    Aluminum cans were first used in 1965 and the main change in the can is the thickness of the aluminum. Improved technology means that the number of cans per kilogram of aluminum has increased from 48 in 1972 to 70 in 1998. Using recycled aluminum is much better than using new aluminum because of the savings in energy and natural resources and the reduction of waste.

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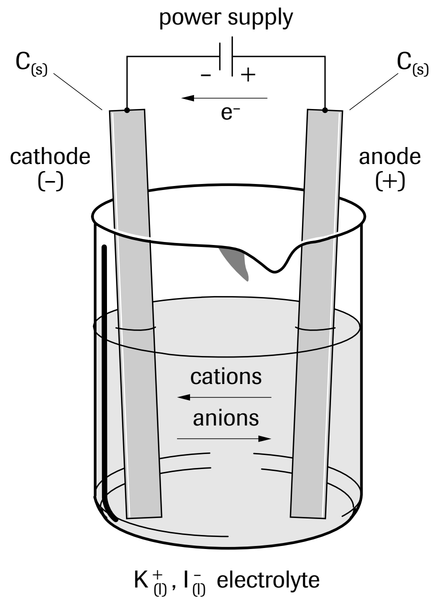
Making Connections
16. (Answers will vary depending on the career chosen, but should include a general description of the job, the necessary education, and current opportunities and salaries.)

SECTION 10.2 QUESTIONS
(Page 746)

Understanding Concepts
1. Electrolytic cells in industry are used to produce chemicals, to refine metals, and for electroplating.
2. Many metals were discovered only after the invention of the electric cell because they are too reactive to exist naturally and their compounds were too stable to be decomposed by heat.
3. The only metals that occur naturally are those that are very weak reducing agents, appearing near the top right of the redox table.
4. A compound with a very high melting point can be mixed with an inert substance to produce a mixture with a lower melting point. Sodium chloride mixed with calcium chloride and aluminum oxide mixed with cryolite are two examples.
5. In the solid state, the ions in ionic compounds cannot move to transfer electric charge in a cell.

6.



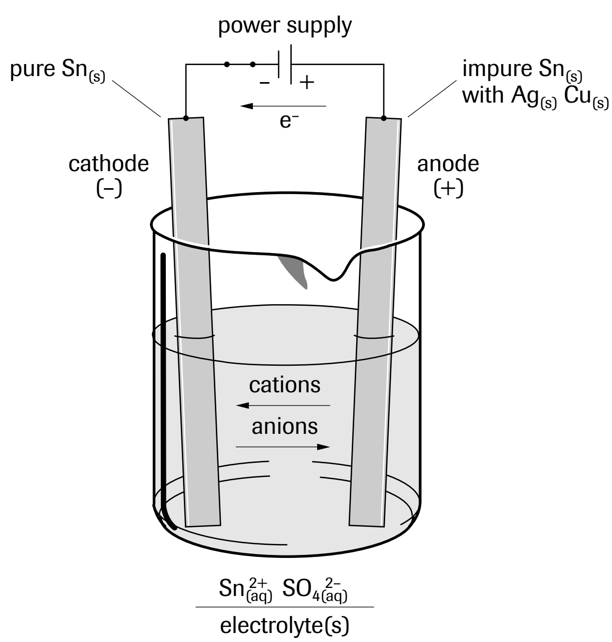
(cathode) $2\ [K^+_{(l)} + e^- \rightarrow K_{(l)}]$

(anode) $2\ I^-_{(l)} \rightarrow I_{2(g)} + 2\ e^-$

(net) $2\ K^+_{(l)} + 2\ I^-_{(l)} \rightarrow 2\ K_{(l)} + I_{2(g)}$

7. (a) The pure metal piece should be the cathode and the impure metal piece should be the anode. According to redox theory, the anode metals will lose electrons and dissolve into solution as ions, while the potential difference applied will be controlled so that only tin(II) ions will gain electrons and plate onto the cathode.

(b)



(c) The substance reduced at the cathode will be tin(II) ions.
$Sn^{2+}_{(aq)} + 2\ e^- \rightarrow Sn_{(s)}$

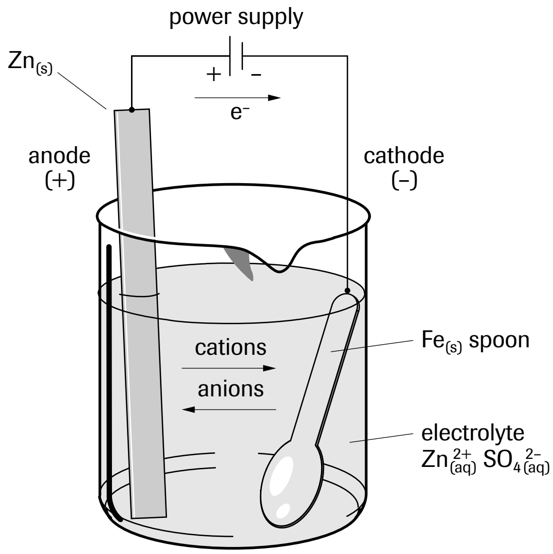
(d) The only substance oxidized will be tin, at the anode.
$Sn_{(s)} \rightarrow Sn^{2+}_{(aq)} + 2\ e^-$

(e) The applied potential difference can be between 0 V and 0.48 V. At or above 0.48 V, the copper atoms in the impure tin anode will oxidize [+0.34 V – (–0.14 V)], and some of the resulting copper(II) ions in solution will then react at the cathode, making the tin deposit impure. At even higher voltages (0.94 V), silver will behave similarly.

(f) The silver and copper metals will fall to the bottom of the cell as the tin in the anode oxidizes.

Applying Inquiry Skills

8.



9. (a) The nickel(II) ion solution is the electrolyte in an electrolytic cell with inert (e.g., platinum) electrodes. The ions plate out as solid pure nickel metal on the inert cathode.
   (b) Typical questions might include: What effect will other ions in the solution have? How expensive are inert electrodes? How long will the process take? What is the toxicity of nickel(II) ions? What chemical disposal regulations apply? Is there a faster, cheaper, non-electrolysis recovery method available?

Making Connections

10. The production of zinc metal involves electrolysis of an acidic aqueous solution of zinc ions.
    The production of galvanized (zinc-plated) objects is often accomplished by electroplating the zinc onto a metal object that is the cathode of an electrolytic cell.
11. (a) A pure nickel core (called a blank) is electroplated with a copper–tin bronze alloy, $Cu_{88}Sn_{12}$.
    (b) The golden aureate finish is created by a diffusion heat treatment of the plated bronze alloy. The bronze plating is about 20-25 μm thick on the face and 40-70 μm thick on the edges.
    (c) The master dies for the original design were lost by a courier delivering these to Winnipeg. Therefore, a new design featuring the loon was created as a replacement.