8. $2\ Ag^{+}_{(aq)} + X_{(s)} \rightarrow 2\ Ag_{(s)} + X^{2+}_{(aq)} \qquad \Delta E° = +1.08\ V$

$$
\begin{aligned}
\Delta E° &= E_r°_{(cathode)} - E_r°_{(anode)} \\
E_r°_{(anode)} &= E_r°_{(cathode)} - \Delta E° \\
&= +0.80\ V - (+1.08\ V) \\
E_r°_{(anode)} &= -0.28\ V
\end{aligned}
$$

The reduction potential for the $X^{2+}_{(aq)} \mid X_{(s)}$ half-cell is –0.28 V, which could represent $Co^{2+}_{(aq)} \mid Co_{(s)}$.

9.6 CORROSION

Try This Activity: Home Corrosion Experiment

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(a) According to the labels, 7-Up has more kinds of acids and electrolytes (carbonic acid, malic acid, and citric acid) than Coca-Cola (carbonic acid and phosphoric acid). This might suggest that the iron in the steel nail would corrode more in the 7-Up than in the Coca-Cola.

- After about 20 h, the nail in the 7-Up changed from the initial shiny, silvery-grey metal to a slightly darker grey appearance. The change was uniform and the nail was still smooth.
- After about 20 h, the nail in the Coca-Cola changed from the initial shiny, silvery-grey metal to a darker grey, speckled appearance throughout the whole nail. Some dark brown blotches were evident on the nail only where it was near the surface of the liquid.

(b) It appears that the nail in the Coca-Cola corroded more than the one in the 7-Up but a longer observation period would be necessary to confirm this. The concentrations of each of the acids are not given on the label. Qualitatively, it may be possible that phosphoric acid in Coca-Cola has a major effect. The initial prediction appears to be false but the reasons for this are not clear.

SECTION 9.6 QUESTIONS

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Understanding Concepts

1. For the corrosion of iron an oxidizing agent, most commonly oxygen and water, must be present and in contact with the iron.
2. The presence of acidic solutions, electrolytes, mechanical stresses, and contact with less active metals accelerate the corrosion of iron.
3.

$$
\begin{array}{llllllll}
O_{2(g)} & + & 2\ H_2O_{(l)} & + & 4\ e^- & \rightarrow & 4\ OH^-_{(aq)} & \\
 & & & & 2\ [Fe_{(s)} & \rightarrow & Fe^{2+}_{(aq)} & +\ 2\ e^-] \\
\hline
O_{2(g)} & + & 2\ H_2O_{(l)} & + & 2\ Fe_{(s)} & \rightarrow & 2\ Fe(OH)_{2(aq)} &
\end{array}
$$

4. (a)

$$
\begin{array}{llllllll}
O_{2(g)} & + & 2\ H_2O_{(l)} & + & 4\ e^- & \rightarrow & 4\ OH^-_{(aq)} & \\
 & & & & 2\ [Zn_{(s)} & \rightarrow & Zn^{2+}_{(aq)} & +\ 2\ e^-] \\
\hline
O_{2(g)} & + & 2\ H_2O_{(l)} & + & 2\ Zn_{(s)} & \rightarrow & 2\ Zn(OH)_{2(aq)} &
\end{array}
$$

(b)

$$
\begin{array}{lllllll}
2\ H^+_{(aq)} & + & 2\ e^- & \rightarrow & H_{2(g)} & & \\
 & & Pb_{(s)} & \rightarrow & Pb^{2+}_{(aq)} & + & 2\ e^- \\
\hline
2\ H^+_{(aq)} & + & Pb_{(s)} & \rightarrow & H_{2(g)} & + & Pb^{2+}_{(aq)}
\end{array}
$$

(c)

$$
\begin{array}{lllllll}
H_2S_{(g)} & + & 2\ e^- & \rightarrow & H_{2(g)} & + & S^{2-}_{(s)} \\
 & & 2\ [Ag_{(s)} & \rightarrow & Ag^+_{(s)} & + & e^-] \\
\hline
H_2S_{(g)} & + & 2\ Ag_{(s)} & \rightarrow & H_{2(g)} & + & Ag_2S_{(s)}
\end{array}
$$

5. (a) The painted surface is blistered, providing evidence for damage extending well beyond the break in the paint.
   (b) Moisture may be trapped between the steel and the paint, setting up an electrochemical cell. The iron below the paint is oxidized, releasing electrons that travel through the steel to the edge of the crack where both oxygen and water are present to pick up these electrons.
6. Since hydroxide ions (either alone or in combination with other ions) often act as reducing agents, a basic solution might prevent or slow down the corrosion of iron.
7. A zinc coating on iron is better than a tin coating because zinc is more easily oxidized than iron and the zinc will corrode first. Tin is less active than iron and will promote the oxidation of iron.
8. Impressed current and sacrificial anode are two methods of cathodic protection. They are similar in that both methods force the iron to become the cathode by supplying it with electrons.

Applying Inquiry Skills

9. (a) The independent variable is the oxidizing agent.
   The dependent variable is the extent of any corrosion.
   The controlled variables are temperature, concentration of oxidizing agent, and length of time exposed.
   (b) **Materials**

7 pieces of copper (same size and shape)	0.10 mol/L $HCl_{(aq)}$
7 large test tubes with stoppers	0.10 mol/L $HNO_{3(aq)}$
test-tube rack	0.10 mol/L $H_2SO_{4(aq)}$
source of oxygen gas	0.10 mol/L $H_3PO_{4(aq)}$
5 100-mL beakers	distilled water
steel wool	

   Procedure
   1. Wear safety glasses and rinse with cool water if any acid is spilled.
   2. Clean each piece of copper with steel wool, rinse with water, and dry thoroughly.
   3. Place each piece of copper in a different test tube, labelled 1 to 7.
   4. Seal test tube #1 with a stopper and note this is the control.
   5. Add oxygen gas to the bottom of test tube #2 for about 1 min and then seal test tube.
   6. Pour 50 mL of each of the following liquids into a different 100-mL beaker:
   distilled water, $HCl_{(aq)}$, $HNO_{3(aq)}$, $H_2SO_{4(aq)}$, $H_3PO_{4(aq)}$.
   7. Bubble oxygen gas through each solution for 1.0 min.
   8. Pour each oxygenated solution into a different test tube containing a copper strip, filling the test tube completely.
   9. Carefully observe the contents of each test tube after five minutes, thirty minutes, and one day. Note, in particular, any differences compared with the control.
   10. Dispose of all liquids into the sink while running water to rinse down the drain. Clean and recycle the pieces of copper.

Making Connections

10. (a) Zinc is being used as a sacrificial anode to protect the pipeline. Zinc is a more active metal than iron. A spontaneous electric cell is established with iron as the cathode and zinc as the anode.
    (b) Protective layers are always used and impressed currents may also be used.
    (c) The environmental and safety issues associated with not protecting pipelines come from the possibility of the pipe corroding so badly that it breaks, allowing gas and/or oil to escape into the environment. In addition to the risk of a catastrophic fire, oil and gas leaks can be very harmful to plants and animals. The environmental and safety issues associated with protecting pipelines are considerably less, although the oxidation of sacrificial anodes can release metal ions into ground water.
11. Some examples of metal corrosion are:
    - Corrosion of oil and/or gas pipelines and storage tanks (environmental, health, and safety issues)
    - Corrosion of steel bridges and towers (health and safety issues)
    - Corrosion of reinforcing steel in concrete structures (environmental, health, and safety issues)
    - Corrosion of the bodies of motor vehicles, boats, and airplanes (health and safety issues)

    Some examples of desirable metal corrosion are: self-protecting metals, e.g., aluminum and zinc; attractive patina forming on copper roofs and bronze statues; and corrosion of sacrificial anodes to protect buried pipes and tanks.
12. (Different results will be found with different search engines, with over 100 000 titles a typical result.)
    general site: http://www.cp.umist.ac.uk/ “Corrosion Infomation Server”
    Classes of iron corrosion: pitting corrosion, stress corrosion, corrosion in molten salts, corrosion in metal-cooled nuclear reactors, displacement, and hydrogen embrittlement.