CHAPTER 9 SELF-QUIZ

(Page 725)

1. True
2. False: ~~Reduction~~ *Oxidation* is a process in which electrons are lost or donated by an atom or ion in a redox reaction.
3. True
4. False: The strongest oxidizing agent in a galvanic cell is above the strongest reducing agent in the redox table producing a cell potential that is ~~negative~~ *positive*.
5. False: The ~~cathode~~ *anode* of a cell is the electrode where electrons are lost or given up by the reducing agent.
6. True
7. False: The cell potential of a standard lead–nickel cell is ~~–0.39~~ *+0.13* V.
8. True
9. True
10. (a)
11. (d)
12. (c)
13. (a)
14. (b)
15. (d)
16. (c)
17. (c)
18. (b)

CHAPTER 9 REVIEW

(Page 726)

Understanding Concepts

1. (a) Oxidation is a chemical process involving a loss of electrons and an increase in oxidation number.
   (b) Reduction is a chemical process involving a gain of electrons and a decrease in oxidation number.
   (c) A redox reaction is the transfer of electrons from a reducing agent to an oxidizing agent.
2. (a) $Fe^{3+}_{(aq)} + e^- \rightarrow Fe^{2+}_{(aq)}$ (reduction)

   $Ni_{(s)} \rightarrow Ni^{2+}_{(aq)} + 2\ e^-$ (oxidation)

   (b) $Br_{2(aq)} + 2\ e^- \rightarrow 2\ Br^-_{(aq)}$ (reduction)

   $2\ I^-_{(aq)} \rightarrow I_{2(s)} + 2\ e^-$ (oxidation)

   (c) $Pd^{2+}_{(aq)} + 2\ e^- \rightarrow Pd_{(s)}$ (reduction)

   $Sn^{2+}_{(aq)} \rightarrow Sn^{4+}_{(aq)} + 2\ e^-$ (oxidation)
3. (a) 0
   (b) –1
   (c) +1
   (d) +1
   (e) –1
4. (a)
   $$\overset{0}{2\ Al_{(s)}} + \overset{+3\ -2}{Fe_2O_{3(s)}} \rightarrow \overset{0}{2\ Fe_{(s)}} + \overset{+3\ -2}{Al_2O_{3(s)}}$$
   $Al_{(s)}$ is oxidized, $Fe^{3+}_{(s)}$ is reduced

   (b)
   $$\overset{0}{In_{(s)}} + \overset{+1}{3\ Tl^+_{(aq)}} \rightarrow \overset{+3}{In^{3+}_{(aq)}} + \overset{0}{3\ Tl_{(s)}}$$
   $In_{(s)}$ is oxidized, $Tl^+_{(aq)}$ is reduced

(c) +3 +2 +2 +4

$$2\,Cr^{3+}_{(aq)} + Sn^{2+}_{(aq)} \rightarrow 2\,Cr^{2+}_{(aq)} + Sn^{4+}_{(aq)}$$

$Cr^{3+}_{(aq)}$ is reduced, $Sn^{2+}_{(aq)}$ is oxidized

(d) 0 –1 –1 0

$$Cl_{2(aq)} + 2\,I^-_{(aq)} \rightarrow 2\,Cl^-_{(aq)} + I_{2(aq)}$$

$Cl_{2(aq)}$ is reduced, $I^-_{(aq)}$ is oxidized

(e) +4 –1 0 +2 –1 0

$$UCl_{4(s)} + 2\,Ca_{(s)} \rightarrow 2\,CaCl_{2(s)} + U_{(s)}$$

$U^{4+}_{(s)}$ is reduced, $Ca_{(s)}$ is oxidized

5. A net ionic equation is balanced in terms of the numbers of different kinds of atoms or ions and the total electric charge on each side of the equation.

6. (a) +2 +1 –2 +1 0

$$Ag^{2+}_{(aq)} + H_2O_{(l)} \rightarrow Ag^+_{(aq)} + O_{2(g)}$$

(b) $4\,Ag^{2+}_{(aq)} + 2\,H_2O_{(l)} \rightarrow 4\,Ag^+_{(aq)} + O_{2(g)} + 4\,H^+_{(aq)}$

7. (a) 0 +5 +2 +2

$$3\,Cu_{(s)} + 2\,NO^-_{3(aq)} + 8\,H^+_{(aq)} \rightarrow 3\,Cu^{2+}_{(aq)} + 2\,NO_{(g)} + 4\,H_2O_{(l)}$$

$2\,e^-/Cu$ $3\,e^-/NO_3^-$

$$3\,Cu_{(s)} + 8\,HNO_{3(aq)} \rightarrow 3\,Cu(NO_3)_{2(aq)} + 2\,NO_{(g)} + 4\,H_2O_{(l)}$$

(b) +7 +3 +2 +4

$$MnO^-_{4(aq)} + H_2C_2O_{4(aq)} \rightarrow Mn^{2+}_{(aq)} + CO_{2(g)} + H_2O_{(l)}$$

$5\,e^-/MnO_4^-$ $2\,e^-/H_2C_2O_4$

$$2\,MnO^-_{4(aq)} + 5\,H_2C_2O_{4(aq)} + 6\,H^+_{(aq)} \rightarrow 2\,Mn^{2+}_{(aq)} + 10\,CO_{2(g)} + 8\,H_2O_{(l)}$$

(c) +5 –1 0

$$KIO_{3(aq)} + KI_{(aq)} + HCl_{(aq)} \rightarrow KCl_{(aq)} + I_{2(s)} + H_2O_{(l)}$$

$5\,e^-/KIO_3$ $1\,e^-/\,KI$

$$KIO_{3(aq)} + 5\,KI_{(aq)} + 6\,HCl_{(aq)} \rightarrow 6\,KCl_{(aq)} + 3\,I_{2(s)} + 3\,H_2O_{(l)}$$

8. (a)

$$3\,[O_{3(g)} + 2\,H^+_{(aq)} + 2\,e^- \rightarrow O_{2(g)} + H_2O_{(l)}]$$
$$I^-_{(aq)} + 3\,H_2O_{(l)} \rightarrow IO^-_{3(aq)} + 6\,H^+_{(aq)} + 6\,e^-$$
$$\overline{3\,O_{3(g)} + I^-_{(aq)} \rightarrow IO^-_{3(aq)} + 3\,O_{2(g)}}$$

(b)

$$Pt_{(s)} + 6\,Cl^-_{(aq)} \rightarrow PtCl^{2-}_{6(aq)} + 4\,e^-$$
$$4\,[NO^-_{3(aq)} + 2\,H^+_{(aq)} + e^- \rightarrow NO_{2(g)} + H_2O_{(l)}]$$
$$\overline{Pt_{(s)} + 6\,Cl^-_{(aq)} + 4\,NO^-_{3(aq)} + 8\,H^+_{(aq)} \rightarrow PtCl^{2-}_{6(aq)} + 4\,NO_{2(g)} + 4\,H_2O_{(l)}}$$

(c)

$$2\,[CN^-_{(aq)} + 2\,OH^-_{(aq)} \rightarrow CNO^-_{(aq)} + H_2O_{(l)} + 2\,e^-]$$
$$ClO^-_{2(aq)} + 2\,H_2O_{(l)} + 4\,e^- \rightarrow Cl^-_{(aq)} + 4\,OH^-_{(aq)}$$
$$\overline{2\,CN^-_{(aq)} + ClO^-_{2(aq)} \rightarrow 2\,CNO^-_{(aq)} + Cl^-_{(aq)}}$$

(d)

$$4\,PH_{3(g)} + 12\,OH^-_{(aq)} \rightarrow P_{4(s)} + 12\,H_2O_{(l)} + 12\,e^-$$
$$4\,[CrO^{2-}_{4(aq)} + 4\,H_2O_{(l)} + 3\,e^- \rightarrow Cr(OH)^-_{4(aq)} + 4\,OH^-_{(aq)}]$$
$$\overline{4\,PH_{3(g)} + 4\,CrO^{2-}_{4(aq)} + 4\,H_2O_{(l)} \rightarrow P_{4(s)} + 4\,Cr(OH)^-_{4(aq)} + 4\,OH^-_{(aq)}}$$

(e) $MnO_{4(aq)}^{2-} + 8\ H^+_{(aq)} + 4\ e^- \rightarrow Mn^{2+}_{(aq)} + 4\ H_2O_{(l)}$

$4\ [MnO_{4(aq)}^{2-} \rightarrow MnO^-_{4(aq)} + e^-]$

$$5\ MnO_{4(aq)}^{2-} + 8\ H^+_{(aq)} \rightarrow Mn^{2+}_{(aq)} + 4\ MnO^-_{4(aq)} + 4\ H_2O_{(l)}$$

9. (a) $Co^{2+}_{(aq)} + 2\ e^- \rightleftharpoons Co_{(s)}$

$Mn^{2+}_{(aq)} + 2\ e^- \rightleftharpoons Mn_{(s)}$

$V^{2+}_{(aq)} + 2\ e^- \rightleftharpoons V_{(s)}$

$Ti^{2+}_{(aq)} + 2\ e^- \rightleftharpoons Ti_{(s)}$

(b) In this table the strongest oxidizing agent is $Co^{2+}_{(aq)}$ and the strongest reducing agent is $Ti_{(s)}$.

10. (a)

OA	–SOA–	OA		OA
$H^+_{(aq)}$	$NO^-_{3(aq)}$	$K^+_{(aq)}$	$Br^-_{(aq)}$	$H_2O_{(l)}$
			SRA	RA

$2\ [NO^-_{3(aq)} + 2\ H^+_{(aq)} + e^- \rightarrow NO_{2(g)} + H_2O_{(l)}]$

$2\ Br^-_{(aq)} \rightarrow Br_{2(l)} + 2e^-$

$2\ NO_{3(aq)} + 4\ H^+_{(aq)} + 2\ Br^-_{(aq)} \rightarrow 2\ NO_{2(g)} + 2\ H_2O_{(l)} + Br_{2(l)}$ (nonspontaneous)

(b)

OA	–SOA–	OA	OA	–OA–	OA	
$K^+_{(aq)}$	$MnO^-_{4(aq)}$	$H^+_{(aq)}$	$Fe^{2+}_{(aq)}$	$SO_{4(aq)}^{2-}$	$H^+_{(aq)}$,	$H_2O_{(l)}$
			SRA		RA	

$MnO^-_{4(aq)} + 8\ H^+_{(aq)} + 5\ e^- \rightarrow Mn^{2+}_{(aq)} + 4\ H_2O_{(l)}$

$5\ [Fe^{2+}_{(aq)} \rightarrow Fe^{3+}_{(aq)} + e^-]$

$MnO^-_{4(aq)} + 8\ H^+_{(aq)} + 5\ Fe^{2+}_{(aq)} \rightarrow Mn^{2+}_{(aq)} + 5\ Fe^{3+}_{(aq)} + 4\ H_2O_{(l)}$ (spontaneous)

(c)

	SOA		OA
$Cu_{(s)}$	$H^+_{(aq)}$	$Cl^-_{(aq)}$	$H_2O_{(l)}$
SRA		RA	RA

$2\ H^+_{(aq)} + 2\ e^- \rightarrow H_{2(g)}$

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

$2\ H^+_{(aq)} + Cu_{(s)} \rightarrow H_{2(g)} + Cu^{2+}_{(aq)}$ (nonspontaneous)

(d)

	–SOA–	OA
$Fe_{(s)}$	$O_{2(g)}$	$H_2O_{(l)}$
SRA		RA

$O_{2(g)} + 2\ H_2O_{(l)} + 4\ e^- \rightarrow 4\ OH^-_{(aq)}$

$2\ [Fe_{(s)} \rightarrow Fe^{2+}_{(aq)} + 2\ e^-]$

$O_{2(g)} + 2\ H_2O_{(l)} + 2\ Fe_{(s)} \rightarrow 2\ Fe(OH)_{2(s)}$ (spontaneous)

(e)

SOA	–OA–	OA	OA		
$Co^{2+}_{(aq)}$	$SO_{4(aq)}^{2-}$	$H_2O_{(l)}$	$Na^+_{(aq)}$	$SO_{3(aq)}^{2-}$	$OH^-_{(aq)}$
		RA		–SRA–	RA

$Co^{2+}_{(aq)} + 2\ e^- \rightarrow Co_{(s)}$

$SO_{3(aq)}^{2-} + 2\ OH^-_{(aq)} \rightarrow SO_{4(aq)}^{2-} + H_2O_{(l)} + 2\ e^-$

$Co^{2+}_{(aq)} + SO_{3(aq)}^{2-} + 2\ OH^-_{(aq)} \rightarrow Co_{(s)} + SO_{4(aq)}^{2-} + H_2O_{(l)}$ (spontaneous)

(f) OA $Cr^{2+}_{(aq)}$ SRA $\quad$ $NO^-_{3(aq)}$ $\quad$ SOA $Sn^{2+}_{(aq)}$ RA $\quad$ OA $H_2O_{(l)}$ RA

$$
\begin{array}{l}
Sn^{2+}_{(aq)} + 2\ e^- \rightarrow Sn_{(s)} \\
2\ [Cr^{2+}_{(aq)} \rightarrow Cr^{3+}_{(aq)} + e^-] \\
\hline
Sn^{2+}_{(aq)} + 2\ Cr^{2+}_{(aq)} \rightarrow Sn_{(s)} + 2\ Cr^{3+}_{(aq)}
\end{array}
\qquad \text{(spontaneous)}
$$

11. (a)

$$
\begin{array}{l}
2\ H_2O_{(l)} + 2\ e^- \rightarrow H_{2(g)} + 2\ OH^-_{(aq)} \\
Ca_{(s)} \rightarrow Ca^{2+}_{(aq)} + 2\ e^- \\
\hline
Ca_{(s)} + 2\ H_2O_{(l)} \rightarrow Ca(OH)_{2(s)} + H_{2(g)}
\end{array}
$$

(b) If a gas is collected and exposed to a flame, and a "pop" sound is heard, then hydrogen gas was likely produced. If a piece of red litmus paper is placed into the reaction mixture and the litmus turns blue, then hydroxide ions were likely produced (slight dissociation of calcium hydroxide precipitate). If a sample of the final solution is placed into a burner flame and a yellow-red colour is produced, then calcium ions were likely produced.

12. The three essential components of an electric cell are two electrodes (solid conductors) and an electrolyte (aqueous conductor).

13. (a)

$$
\begin{array}{ll}
\text{cathode:} & HgO_{(s)} + H_2O_{(l)} + 2\ e^- \rightarrow Hg_{(l)} + 2\ OH^-_{(aq)} \\
\text{anode:} & Zn_{(s)} + 2\ OH^-_{(aq)} \rightarrow ZnO_{(s)} + H_2O_{(l)} + 2\ e^- \\
\hline
\text{net:} & HgO_{(s)} + Zn_{(s)} \rightarrow Hg_{(l)} + ZnO_{(s)}
\end{array}
$$

(b) The electrons flow from zinc to mercury, because they are released by the zinc and gained by the mercury(II) oxide.

(c) Mercury oxide (in a conducting paste) is likely the cathode and zinc metal the anode.

14. (a)

$$
\begin{array}{lll}
\text{cathode:} & MnO^-_{4(aq)} + 8\ H^+_{(aq)} + 5\ e^- \rightarrow Mn^{2+}_{(aq)} + 4\ H_2O_{(l)} & E_r° = +1.51\ V \\
\text{anode:} & Ag_{(s)} \rightarrow Ag^+_{(aq)} + e^- & E_r° = +0.80\ V
\end{array}
$$

$$
\begin{aligned}
\Delta E° &= E_r°_{\text{(cathode)}} - E_r°_{\text{(anode)}} \\
&= 1.51\ V - (+0.80\ V) \\
\Delta E° &= +0.71\ V
\end{aligned}
$$

The predicted cell potential is +0.71 V.

(b)

$$
\begin{array}{lll}
\text{cathode:} & Sn^{2+}_{(aq)} + 2\ e^- \rightarrow Sn_{(s)} & E_r° = -0.14\ V \\
\text{anode:} & Zn_{(s)} \rightarrow Zn^{2+}_{(aq)} + 2\ e^- & E_r° = -0.76\ V
\end{array}
$$

$$
\begin{aligned}
\Delta E° &= E_r°_{\text{(cathode)}} - E_r°_{\text{(anode)}} \\
&= -0.14\ V - (-0.76\ V) \\
\Delta E° &= +0.62\ V
\end{aligned}
$$

The predicted cell potential is +0.62 V.

15. (a)

$$
\begin{aligned}
\Delta E° &= E_r°_{\text{(cathode)}} - E_r°_{\text{(anode)}} \\
&= -0.28\ V - (-0.76\ V) \\
\Delta E° &= +0.48\ V
\end{aligned}
$$

The predicted standard cell potential is +0.48 V.

(b) $\Delta E° = E_r°_{(cathode)} - E_r°_{(anode)}$

$= +0.34 \text{ V} - (–0.14 \text{ V})$

$\Delta E° = +0.48 \text{ V}$

The predicted standard cell potential is +0.48 V.

(c) $\Delta E° = E_r°_{(cathode)} - E_r°_{(anode)}$

$= +1.51 \text{ V} - (–0.26 \text{ V})$

$\Delta E° = +1.77 \text{ V}$

The predicted standard cell potential is +1.77 V.

16. (a) Nickel will be the cathode because it is immersed in the strongest oxidizing agent, $Ni^{2+}_{(aq)}$. Cadmium will be the anode because $Cd_{(s)}$ is the strongest reducing agent.

(b)

	SOA		OA	OA
$Ni_{(s)}$	$Ni^{2+}_{(aq)}$	$Cd_{(s)}$	$Cd^{2+}_{(aq)}$	$H_2O_{(l)}$
RA		SRA		RA

cathode: $Ni^{2+}_{(aq)} + 2\,e^- \rightarrow Ni_{(s)}$ $\quad E_r° = –0.26 \text{ V}$

anode: $Cd_{(s)} \rightarrow Cd^{2+}_{(aq)} + 2\,e^-$ $\quad E_r° = –0.40 \text{ V}$

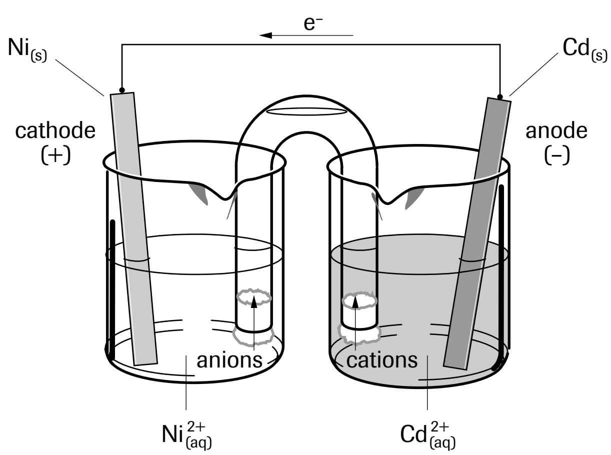
$\Delta E° = E_r°_{(cathode)} - E_r°_{(anode)}$

$= –0.26 \text{ V} - (–0.40 \text{ V})$

$\Delta E° = +0.14 \text{ V}$

The predicted standard cell potential is +0.14 V.

(c)



17. Standard reduction potentials for all other half-cells are measured relative to that of the standard hydrogen half-cell, defined as zero volts. The standard hydrogen half-cell consists of an inert platinum electrode immersed in a 1.00 mol/L solution of hydrogen ions, with hydrogen gas at 1.00 kPa bubbling over the electrode, and at 25ºC.

18. $\Delta E° = E_r°_{(cathode)} - E_r°_{(anode)}$

$E_r°_{(cathode)} = \Delta E° + E_r°_{(anode)}$

$= +1.94 \text{ V} + (–0.40 \text{ V})$

$E_r°_{(cathode)} = +1.54 \text{ V}$

The standard reduction potential for the $Ce^{3+}_{(aq)}$ | $Ce_{(s)}$ half-cell is +1.54 V.

19. A "dead" galvanic cell has a voltage of zero and has reached an equilibrium state.

20. (a) Tin coatings adhere well to iron and provide a strong shiny coating. As long as the tin coating remains intact, the iron underneath is protected; but if the surface coating breaks, the iron beneath corrodes quickly because iron is a stronger reducing agent than tin.

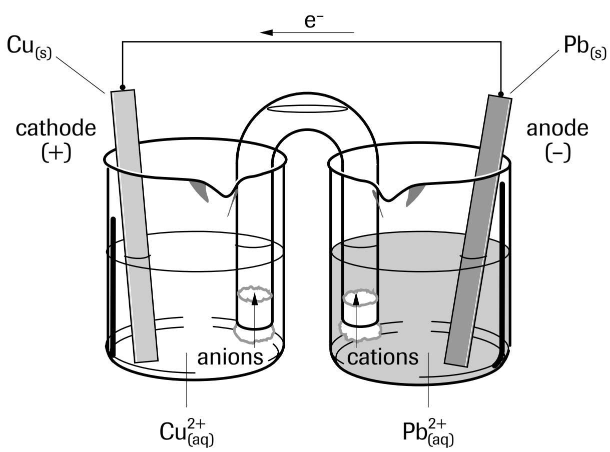
(b) Zinc coatings adhere well to iron and provide a strong coating that oxidizes to a silver-grey colour. The zinc reaction coating is basic zinc carbonate, which protects zinc and the iron underneath. If the zinc coating is broken, the zinc is preferentially oxidized compared to iron, resealing the opening and preventing the corrosion of the iron.

21. (a) The impressed current method of cathodic protection uses a battery or DC generator to supply electrons to the iron object being protected. The negative terminal of the power supply is connected to the iron object and the positive terminal is connected to an inert carbon electrode. The iron is forced to become the cathode and is protected from corroding.

(b) The sacrificial anode method of cathodic protection uses a metal that is more easily oxidized than iron, such as zinc or magnesium. The sacrificial anode is connected to the iron object being protected, forming a galvanic cell with iron as the cathode.

Applying Inquiry Skills

22. (a)



(b) cathode: $Cu^{2+}_{(aq)} + 2\ e^- \rightarrow Cu_{(s)}$ $E_r° = +0.34\ V$

anode: $Pb_{(s)} \rightarrow Pb^{2+}_{(aq)} + 2\ e^-$ $E_r° = -0.13\ V$

net: $Cu^{2+}_{(aq)} + Pb_{(s)} \rightarrow Cu_{(s)} + Pb^{2+}_{(aq)}$

(c)
$$\Delta E° = E_r°_{(cathode)} - E_r°_{(anode)}$$
$$= +0.34\ V - (-0.13\ V)$$
$$\Delta E° = +0.47\ V$$

The predicted cell potential is +0.47 V.

23. (a) **Procedure**

1. Clean three small strips of zinc with steel wool.
2. Add a few millilitres of each unknown solution into separate, clean test tubes.
3. Place a strip of zinc metal into each solution and record evidence of reaction.
4. For each solution that was unreactive with zinc, add a few millilitres of each solution to separate test tubes.
5. To each of these test tubes, add a few drops of sodium carbonate solution and record evidence of reaction.
6. Dispose of all solutions in the waste beaker.

(b) **Evidence/Analysis**

- For step 3, two solutions showed no change with zinc. A dark precipitate formed on the metal in the third solution, which must therefore be the lead(II) nitrate solution, because lead(II) ions react spontaneously with zinc.
- For step 5, one solution showed no change when sodium carbonate was added. One solution produced a white precipitate, so that solution must be calcium nitrate (because calcium carbonate is a low-solubility compound). (Several other procedures are also possible.)

Making Connections

24. (a) The Ballard fuel cell consists of an anode and a cathode separated by a polymer membrane electrolyte. Hydrogen fuel admitted through a porous anode is then converted into hydrogen ions (protons) and free electrons in the presence of a catalyst at the anode. An external circuit conducts the free electrons and produces the desired electric current. Water and heat are produced when the protons, after migrating through the polymer membrane to the cathode, react both with oxygen molecules from the air and with the free electrons from the external circuit.

(b) The widespread use of electric cars could significantly reduce air pollution from internal-combustion engines, thereby reducing both photochemical smog and acid rain. The main social impact of the widespread use of electric cars is likely in employment opportunities as transportation technology shifts from a gasoline base to a hydrogen base.

25. (a) cathode: $2\,[O_{2(g)} + 2\,H_2O_{(g)} + 4\,e^- \rightarrow 4\,OH^-_{(aq)}]$ $\quad E_r^\circ = +0.40\text{ V}$

anode: $CH_{4(g)} + 10\,OH^-_{(l)} \rightarrow CO^{2-}_{3(l)} + 7\,H_2O_{(g)} + 8\,e^-$ $\quad E_r^\circ = +0.17\text{ V}$

net: $CH_{4(g)} + 2\,OH^-_{(l)} + 2\,O_{2(g)} \rightarrow CO^{2-}_{3(l)} + 3\,H_2O_{(g)}$

$$\Delta E^\circ = E_r^\circ{}_{(\text{cathode})} - E_r^\circ{}_{(\text{anode})}$$
$$= +0.40\text{ V} - (+0.17\text{ V})$$
$$\Delta E^\circ = +0.23\text{ V}$$

The approximate cell potential is +0.23 V.

(b) Advantages: fuel cell using readily available natural gas; high efficiency; does not produce greenhouse gas
Disadvantages: likely relatively expensive; storage and distribution of the gas may be a problem