1. How many electrons are needed to balance the half-reaction?

\[
\text{SO}_4^{2-} + 8 \text{H}^+ + \_\_\_\_\_\_\_\_\_\text{e}^- \rightarrow \text{S}_2^2- + 4 \text{H}_2\text{O}
\]

A) 0  B) 6  C) 8  D) 4  E) 10

2. In an electrolytic cell, the positive electrode is the

A) anode, where oxidation occurs
B) anode, where reduction occurs
C) cathode, where oxidation occurs
D) cathode, where reduction occurs

3. For which chemical reaction must an electrolytic cell be used?

A) \(\text{AgNO}_3 + \text{NaCl} \rightarrow \text{AgCl} + \text{NaNO}_3\)
B) \(\text{Cu} + \text{FeCl}_2 \rightarrow \text{CuCl}_2 + \text{Fe}\)
C) \(\text{Zn} + 2 \text{HCl} \rightarrow \text{ZnCl}_2 + \text{H}_2\)
D) \(2 \text{Al} + 3 \text{Ni(NO}_3)_2 \rightarrow 2 \text{Al(NO}_3)_3 + 3 \text{Ni}\)

4. Which occurs in an electrolytic cell containing \(\text{CuCl}_2\) (aq)?

A) \(\text{Cu}^{2+}\) ions migrate toward the positive electrode.
B) \(\text{Cl}^-\) ions migrate toward the negative electrode.
C) \(\text{Cu}^{2+}\) ions are reduced.
D) \(\text{Cl}^-\) ions are reduced.

5. Given the reaction:

\[
2 \text{H}_2\text{O} + \text{electricity} \rightarrow 2 \text{H}_2 + \text{O}_2
\]

In which type of cell would this reaction most likely occur?

A) a chemical cell, because it is exothermic
B) an electrolytic cell, because it is exothermic
C) a chemical cell, because it is endothermic
D) an electrolytic cell, because it is endothermic

6. Which half-reaction occurs at the negative electrode in an electrolytic cell in which an object is being plated with silver?

A) \(\text{Ag}^0 + 1\text{e}^- \rightarrow \text{Ag}^+\)
B) \(\text{Ag}^0 \rightarrow \text{Ag}^+ + 1\text{e}^-\)
C) \(\text{Ag}^+ + 1\text{e}^- \rightarrow \text{Ag}^0\)
D) \(\text{Ag}^+ \rightarrow \text{Ag}^0 + 1\text{e}^-\)

7. The diagram below represents an electrochemical cell.

What occurs when the switch is closed?

A) \(\text{Zn}\) is reduced.
B) \(\text{Cu}\) is oxidized.
C) Electrons flow from \(\text{Cu}\) to \(\text{Zn}\).
D) Electrons flow from \(\text{Zn}\) to \(\text{Cu}\).

8. Base your answer to the following question on the diagram below of an electrolytic cell in which the electrodes are tin and copper.

In this electrolytic cell, electrode \(A\) is designated as the

A) anode and is positive
B) anode and is negative
C) cathode and is positive
D) cathode and is negative
9. Which statement describes one characteristic of an operating electrolytic cell?

A) It produces electrical energy.
B) It requires an external energy source.
C) It uses radioactive nuclides.
D) It undergoes a spontaneous redox reaction.

10. Base your answer to the following question on the diagram below which represents the electroplating of a metal fork with Ag(s).

![Diagram of electroplating](image)

Which equation represents the half-reaction that takes place at the fork?

A) $\text{Ag}^+ + \text{NO}_3^- \rightarrow \text{AgNO}_3$
B) $\text{AgNO}_3 \rightarrow \text{Ag}^+ + \text{NO}_3^-$
C) $\text{Ag}^+ + e^- \rightarrow \text{Ag(s)}$
D) $\text{Ag(s)} \rightarrow \text{Ag}^+ + e^-$

11. Which energy change occurs in an operating voltaic cell?

A) chemical to electrical
B) electrical to chemical
C) chemical to nuclear
D) nuclear to chemical

12. Which half–cell reaction correctly represents reduction?

A) $\text{Sn}^{4+} \rightarrow \text{Sn}^{2+} + 2e^-$
B) $\text{Sn}^{2+} \rightarrow \text{Sn}^{4+} + 2e^-$
C) $\text{Sn}^{4+} + 2e^- \rightarrow \text{Sn}^{2+}$
D) $\text{Sn}^{2+} + 2e^- \rightarrow \text{Sn}^{4+}$
E) $\text{Sn}^{3+} + \text{Sn}^{2+} \rightarrow \text{Sn}^{6+} + 2e^-$

13. Which metal can be produced only by the electrolysis of its fused salt?

A) Ag  B) Zn  C) Pb  D) K

14. The diagram below shows a key being plated with copper in an electrolytic cell

![Diagram of electroplating with copper](image)

Given the reduction reaction for this cell:

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

This reduction occurs at

A) $A$, which is the anode
B) $A$, which is the cathode
C) $B$, which is the anode
D) $B$, which is the cathode

15. At the cathode during electrolysis, what is its charge and what type of reaction occurs.

A) $(-)$, oxidation
B) $(+)$, oxidation
C) $(-)$, reduction
D) $(+)$, reduction
E) no reaction occurs at the cathode

16. In an electrochemical cell, the electrons go from the

A) anode to the cathode through the wire
B) cathode to the anode through the wire
C) anode to the cathode through the salt bridge
D) cathode to the anode through the salt bridge
E) anode to the cathode through the wire and cathode to the anode through the salt bridge
17. The reaction \(2 \text{H}_2\text{O} \rightarrow 2 \text{H}_2(\text{g}) + \text{O}_2(\text{g})\) is forced to occur by use of an externally applied electric current. This procedure is called
A) neutralization  B) esterification  
C) electrolysis  D) hydrolysis

18. Electroplating always takes place
A) in the wire  B) at the anode  
C) at the cathode  D) at the salt bridge  
E) in solution

19. Which net reaction occurs by the process of electrolysis?
A) \(2 \text{H}_2\text{O}(\ell) \rightarrow 2 \text{H}_2(\text{g}) + \text{O}_2(\text{g})\)  
B) \(2 \text{HgO(s)} \rightarrow 2 \text{Hg(\ell)} + \text{O}_2(\text{g})\)  
C) \(2 \text{KClO}_3(\ell) \rightarrow 2 \text{KCl(s)} + 3 \text{O}_2(\text{g})\)  
D) \(\text{MgCO}_3(\text{s}) \rightarrow \text{MgO(s)} + \text{CO}_2(\text{s})\)

20. What are the anode and cathode half–reactions for the electrolysis of fused (melted) NaCl?
A) Anode: \(2 \text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^-\)  Cathode: \(2 \text{Na}^+ + 2\text{e}^- \rightarrow 2 \text{Na}\)  
B) Anode: \(2 \text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^-\)  Cathode: \(2 \text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2\text{OH}^-\)  
C) Anode: \(2 \text{H}_2\text{O} \rightarrow \text{O}_2 + 4 \text{H}^+ + 4\text{e}^-\)  Cathode: \(4 \text{Na}^+ + 4\text{e}^- \rightarrow 4 \text{Na}\)  
D) Anode: \(2 \text{H}_2\text{O} \rightarrow \text{O}_2 + 4 \text{H}^+ + 4\text{e}^-\)  Cathode: \(4 \text{H}_2\text{O} + 4\text{e}^- \rightarrow 2 \text{H}_2 + 4\text{OH}^-\)  
E) Anode: \(\text{Cl}_2 + 2\text{e}^- \rightarrow 2 \text{Cl}^-\)  Cathode: \(2 \text{Na} \rightarrow 2 \text{Na}^+ + 2\text{e}^-\)

21. Which statement is true about oxidation and reduction in an electrochemical cell?
A) Both occur at the anode.  
B) Both occur at the cathode.  
C) Oxidation occurs at the anode and reduction occurs at the cathode.  
D) Oxidation occurs at the cathode and reduction occurs at the anode.

22. A student wishes to set up an electrochemical cell. The following list of materials and equipment will be used:
- two 250-ml beakers
- wire
- one piece of Zn metal
- 125 ml of 0.10 M Zn(NO_3)_2
- voltmeter
- switch
- one piece of Pb metal
- 125 ml of 0.10 M Pb(NO_3)_2

For the cell to operate properly, the student will also need
A) an anode  
B) a cathode  
C) an external path for electrons  
D) a salt bridge

23. The net ionic reaction for an electrochemical cell is
\[2 \text{Cr(s)} + 3 \text{Cu}^{2+}(\text{aq}) \rightarrow 2 \text{Cr}^{3+}(\text{aq}) + 3 \text{Cu(s)}\]

What is the reaction occurring at the cathode?
A) \(2 \text{Cr(s)} \rightarrow 2 \text{Cr}^{3+}(\text{aq}) + 6\text{e}^-\)  
B) \(3 \text{Cu(s)} \rightarrow 3 \text{Cu}^{2+}(\text{aq}) + 6\text{e}^-\)  
C) \(2 \text{Cr}^{3+}(\text{aq}) + 6\text{e}^- \rightarrow 2 \text{Cr(s)}\)  
D) \(3 \text{Cu}^{2+}(\text{aq}) + 6\text{e}^- \rightarrow 3 \text{Cu(s)}\)  
E) It cannot be determined from the information given
24. What occurs during discharge in the lead-acid battery reaction below?

\[
Pb + PbO_2 + 2 H_2SO_4 \leftrightarrow 2 PbSO_4 + 2 H_2O
\]
A) Both Pb and Pb\(^{4+}\) undergo oxidation.
B) Both Pb and Pb\(^{4+}\) undergo reduction.
C) Pb is oxidized and Pb\(^{4+}\) is reduced.
D) Neither the Pb nor the Pb\(^{4+}\) is oxidized or reduced.

25. A diagram of a chemical cell and an equation are shown below.

\[
Pb(s) + Cu^{2+}(aq) \rightarrow Pb^{2+}(aq) + Cu(s)
\]
When the switch is closed, electrons will flow from
A) the Pb(s) to the Cu(s)
B) the Cu(s) to the Pb(s)
C) the Pb\(^{2+}\)(aq) to the Pb(s)
D) the Cu\(^{2+}\)(aq) to the Cu(s)

26. Given the balanced ionic equation representing the reaction in an operating voltaic cell:

\[
Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)
\]
The flow of electrons through the external circuit in this cell is from the
A) Cu anode to the Zn cathode
B) Cu cathode to the Zn anode
C) Zn anode to the Cu cathode
D) Zn cathode to the Cu anode

27. Base your answer to the following question on the diagram of the chemical cell at 298 K and on the equation below.

\[
Ni^0(s) + 2Ag^+(aq) \rightarrow Ni^{2+}(aq) + 2Ag^0(s)
\]
In the given reaction, the Ag\(^{+}\) ions
A) gain electrons
B) lose electrons
C) gain protons
D) lose protons

28. During the electrolysis of fused NaCl, which half-reaction occurs at the negative electrode?
A) Na\(^+\) + 1e\(^-\) → Na\(^0\)
B) Na\(^0\) → Na\(^+\) + 1e\(^-\)
C) 2 Cl\(^-\) → Cl\(^2_\) + 2e\(^-\)
D) Cl\(^2_\) + 2e\(^-\) → 2 Cl\(^-\)

29. To which electrode do the electrons move in the cell

\[
Zn/Zn^{2+}||Pb^{2+}/Pb
\]
A) Pb
B) Pb\(^{2+}\)
C) Zn
D) Zn\(^{2+}\)
E) It cannot be determined unless the potentials are known.
30. A student collects the materials and equipment below to construct a voltaic cell:

- two 250-mL beakers
- wire and a switch
- one strip of magnesium
- one strip of copper
- 125 mL of 0.20 M Mg(NO₃)₂(aq)
- 125 mL of 0.20 M Cu(NO₃)₂(aq)

Which additional item is required for the construction of the voltaic cell?

A) an anode  B) a battery  C) a cathode  D) a salt bridge

31. In the reaction

\[ \text{Sn}^{2+}(aq) + 2 \text{Ag}^+(aq) \rightarrow \text{Sn}^{4+}(aq) + 2 \text{Ag}(s) \]

What is the half–reaction equation for the oxidizing agent above?

A) \( \text{Sn}^{2+} \rightarrow \text{Sn}^{4+} + 2e^- \)  B) \( \text{Ag}^+ + e^- \rightarrow \text{Ag} \)
C) \( \text{Sn}^{2+} + 2e^- \rightarrow \text{Sn}^{4+} \)  D) \( \text{Ag}^+ \rightarrow \text{Ag} + e^- \)
E) \( \text{Sn}^{2+} + \text{Sn}^{4+} \rightarrow 2e^- \)

32. **STANDARD ELECTRODE POTENTIALS**

<table>
<thead>
<tr>
<th>Ion Concentrations 1.0 M H₂O at 298 K, 1 atm</th>
<th>Half–Reaction</th>
<th>( E^\circ ), volts</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 8 \text{H}^+ + \text{MnO}_4^- + 5e^- \rightarrow \text{Mn}^{2+} + 4 \text{H}_2\text{O} )</td>
<td>+1.51</td>
<td></td>
</tr>
<tr>
<td>( \text{Cu}^{2+} + 2e^- \rightarrow \text{Cu}(s) )</td>
<td>+0.34</td>
<td></td>
</tr>
</tbody>
</table>

What is the oxidation half–reaction for the reaction?

\( \text{Cu} + \text{MnO}_4^- + \text{H}^+ \rightarrow \text{Cu}^{2+} + \text{Mn}^{2+} + \text{H}_2\text{O} \)

A) \( \text{Cu}^{2+} + 2e^- \rightarrow \text{Cu}(s) \)
B) \( \text{Cu}(s) \rightarrow \text{Cu}^{2+} + 2e^- \)
C) \( 8 \text{H}^+ + \text{MnO}_4^- + 5e^- \rightarrow \text{Mn}^{2+} + 4 \text{H}_2\text{O} \)
D) \( \text{Mn}^{2+} + 4 \text{H}_2\text{O} \rightarrow 8 \text{H}^+ + \text{MnO}_4^- + 5e^- \)
E) \( \text{MnO}_4^- + 8 \text{H}^+ \rightarrow \text{Mn}^{2+} + 4 \text{H}_2\text{O} \)

33. The function of the salt bridge in an electrochemical cell is to:

A) increase the cell voltage  
B) maintain electrical neutrality  
C) increase the oxidation–reduction rate  
D) supply a travel pathway for electrons  
E) increase the rate of attainment of equilibrium

34. The diagram below shows the electrolysis of fused KCl.

![Diagram of electrolysis of fused KCl]

What occurs when the switch is closed?

A) Positive ions migrate toward the anode, where they lose electrons. 
B) Positive ions migrate toward the anode, where they gain electrons. 
C) Positive ions migrate toward the cathode, where they lose electrons. 
D) Positive ions migrate toward the cathode, where they gain electrons.

35. Which conversion of energy always occurs in a voltaic cell?

A) light energy to chemical energy  
B) electrical energy to chemical energy  
C) chemical energy to light energy  
D) chemical energy to electrical energy
36. The diagram below represents an operating electrochemical cell and the balanced ionic equation for the reaction occurring in the cell.

\[ \text{Zn(s)} + \text{Ni}^{2+}(aq) \rightarrow \text{Zn}^{2+}(aq) + \text{Ni(s)} \]

Which statement identifies the part of the cell that conducts electrons and describes the direction of electron flow as the cell operates?

A) Electrons flow through the salt bridge from the Ni(s) to the Zn(s).
B) Electrons flow through the salt bridge from the Zn(s) to the Ni(s).
C) Electrons flow through the wire from the Ni(s) to the Zn(s).
D) Electrons flow through the wire from the Zn(s) to the Ni(s).

37. When a voltaic cell operates, ions move through the

A) anode  B) cathode
C) salt bridge  D) external circuit

38. The negative ions go to which electrode in the voltaic cell

\[ \text{Mg/Mg}^{2+}||\text{Ag}^+/\text{Ag} \]

A) Ag  B) \text{Ag}^+
C) Mg  D) \text{Mg}^{2+}
E) both Ag and Mg

39. Given the redox reaction:

\[ 2 \text{NiOOH} + \text{Cd}^{[\text{charge}]} \rightarrow 2 \text{Ni(OH)}_2 + \text{Cd(OH)}_2 \]

Which species is oxidized during discharge?

A) Cd  B) \text{Cd}^{2+}
C) \text{Ni(OH)}_3  D) \text{Ni(OH)}_2

40. In the electrolysis of molten \text{CaCl}_2, the species oxidized is

A) Ca  B) \text{Ca}^{2+}
C) Cl\text{ }  D) \text{Cl}_2
E) Oxidation does not occur

41. Which statement best describes the key?

A) It acts as the cathode and is negative.
B) It acts as the cathode and is positive.
C) It acts as the anode and is negative.
D) It acts as the anode and is positive.
42. Consider the reaction,

\[ S^{6+} + ? \, e^- \rightarrow S^{2-} \]

How many electrons are needed to reduce \( S^{6+} \) to \( S^{2-} \)?
A) 6  B) 2  C) 8  D) 4  E) 10

43. The diagram below shows a spoon that will be electroplated with nickel metal.

What will occur when switch S is closed?
A) The spoon will lose mass, and the Ni(s) will be reduced.
B) The spoon will lose mass, and the Ni(s) will be oxidized.
C) The spoon will gain mass, and the Ni(s) will be reduced.
D) The spoon will gain mass, and the Ni(s) will be oxidized.

44. Which is the cathode of this electrochemical cell?

\[ Cr + Au^{3+} \rightarrow Cr^{3+} + Au \]

A) \( Cr \)  B) \( Au^{3+} \)  C) \( Cr^{3+} \)  D) \( Au \)  E) It cannot be determined unless the potentials are known

45. In an electrochemical cell, the positive ions go from the
A) anode to the cathode through the wire
B) cathode to the anode through the wire
C) anode to the cathode through the salt bridge
D) cathode to the anode through the salt bridge
E) cathode to the anode through the wire and anode to the cathode through the salt bridge

46. Which statement best describes the reaction represented by the equation below?

\[ 2 \text{NaCl} + 2 \text{H}_2\text{O} + \text{electricity} \rightarrow \text{Cl}_2 + \text{H}_2 + 2 \text{NaOH} \]

A) The reaction occurs in a chemical cell and releases energy.
B) The reaction occurs in a chemical cell and absorbs energy.
C) The reaction occurs in an electrolytic cell and releases energy.
D) The reaction occurs in an electrolytic cell and absorbs energy.
47. Base your answer to the following question on the diagram of the voltaic cell below.

Voltaic Cell

[Diagram of voltaic cell]

When the switch is closed, in which half-cell does oxidation occur?

48. Base your answer to the following question on the diagram and balanced equation below, which represent the electrolysis of molten NaCl.

[Diagram of electrolysis cell]

2NaCl \rightarrow \text{Cl}_2 + 2\text{Na}

Write the balanced half-reaction for the reduction that occurs in this electrolytic cell.
49. Base your answer to the following question on the information below.

A voltaic cell with magnesium and copper electrodes is shown in the diagram below. The copper electrode has a mass of 15.0 grams.

When the switch is closed, the reaction in the cell begins. The balanced ionic equation for the reaction in the cell is shown below the cell diagram. After several hours, the copper electrode is removed, rinsed with water, and dried. At this time, the mass of the copper electrode is greater than 15.0 grams.

Explain, in terms of copper ions and copper atoms, why the mass of the copper electrode increases as the cell operates. Your response must include information about both copper ions and copper atoms.
50. Base your answer to the following question on the information below.

The diagram below represents an operating electrolytic cell used to plate silver onto a nickel key. As the cell operates, oxidation occurs at the silver electrode and the mass of the silver electrode decreases.

Explain, in terms of Ag atoms and Ag\(^{+}\)(aq) ions, why the mass of the silver electrode decreases as the cell operates.
51. Base your answer to the following question on the information below.

A student places a 2.50-gram sample of magnesium metal in a bottle and fits the bottle with a 2-hole stopper as shown in the diagram. Hydrochloric acid is added to the bottle, causing a reaction. As the reaction proceeds, hydrogen gas travels through the tubing to an inverted bottle filled with water, displacing some of the water in the bottle.

Based on Reference Table J, explain why Ag(s) will not react with HCl (aq) to generate H₂(g).

52. Base your answer to the following question on the information below.

Electroplating is an electrolytic process used to coat metal objects with a more expensive and less reactive metal. The diagram below shows an electroplating cell that includes a battery connected to a silver bar and a metal spoon. The bar and spoon are submerged in AgNO₃(aq).

Explain the purpose of the battery in this cell.
53. Base your answer to the following question on the information below.

The diagram below represents an operating voltaic cell at 298 K and 1.0 atmosphere in a laboratory investigation. The reaction occurring in the cell is represented by the balanced ionic equation below.

\[ \text{\(2Ag^+(aq) + Ni(s) \rightarrow 2Ag(s) + Ni^{2+}(aq)\)} \]

Write a balanced half-reaction equation for the reduction that occurs in this cell.

54. Base your answer to the following question on the information below.

The diagram and balanced ionic equation below represent a voltaic cell with copper and silver electrodes and the reaction that occurs when the cell is operating.

\[ \text{\(Cu(s) + 2Ag^+(aq) \rightarrow Cu^{2+}(aq) + 2Ag(s)\)} \]

State the purpose of the salt bridge in this voltaic cell.
Underground iron pipes in contact with moist soil are likely to corrode. This corrosion can be prevented by applying the principles of electrochemistry. Connecting an iron pipe to a magnesium block with a wire creates an electrochemical cell. The magnesium block acts as the anode and the iron pipe acts as the cathode. A diagram of this system is shown below.

Explain, in terms of reactivity, why magnesium is preferred over zinc to protect underground iron pipes. Your response must include both magnesium and zinc.
1. How many electrons are needed to balance the half-reaction?

\[
\text{SO}_4^{2-} + 8 \text{H}^+ + \_\_ \text{e}^- \rightarrow \text{S}^{2-} + 4 \text{H}_2\text{O}
\]

A) 0  B) 6  C) 8  D) 4  E) 10

2. In an electrolytic cell, the positive electrode is the
A) anode, where oxidation occurs  
B) anode, where reduction occurs  
C) cathode, where oxidation occurs  
D) cathode, where reduction occurs

3. For which chemical reaction must an electrolytic cell be used?
A) \(\text{AgNO}_3 + \text{NaCl} \rightarrow \text{AgCl} + \text{NaNO}_3\)
B) \(\text{Cu} + \text{FeCl}_2 \rightarrow \text{CuCl}_2 + \text{Fe}\)
C) \(\text{Zn} + 2 \text{HCl} \rightarrow \text{ZnCl}_2 + \text{H}_2\)
D) \(2 \text{Al} + 3 \text{Ni(NO}_3)_2 \rightarrow 2 \text{Al(NO}_3)_3 + 3 \text{Ni}\)

4. Which occurs in an electrolytic cell containing \(\text{CuCl}_2\) (aq)?
A) \(\text{Cu}^{2+}\) ions migrate toward the positive electrode.  
B) \(\text{Cl}^-\) ions migrate toward the negative electrode.  
C) \(\text{Cu}^{2+}\) ions are reduced.  
D) \(\text{Cl}^-\) ions are reduced.

5. Given the reaction:

\[2 \text{H}_2\text{O} + \text{electricity} \rightarrow 2 \text{H}_2 + \text{O}_2\]

In which type of cell would this reaction most likely occur?
A) a chemical cell, because it is exothermic  
B) an electrolytic cell, because it is exothermic  
C) a chemical cell, because it is endothermic  
D) an electrolytic cell, because it is endothermic

6. Which half-reaction occurs at the negative electrode in an electrolytic cell in which an object is being plated with silver?
A) \(\text{Ag}^0 + 1\text{e}^- \rightarrow \text{Ag}^+\)  
B) \(\text{Ag}^0 \rightarrow \text{Ag}^+ + 1\text{e}^-\)  
C) \(\text{Ag}^+ + 1\text{e}^- \rightarrow \text{Ag}^0\)  
D) \(\text{Ag}^+ \rightarrow \text{Ag}^0 + 1\text{e}^-\)

7. The diagram below represents an electrochemical cell.

What occurs when the switch is closed?
A) \(\text{Zn}\) is reduced.  
B) \(\text{Cu}\) is oxidized.  
C) Electrons flow from \(\text{Cu}\) to \(\text{Zn}\).  
D) Electrons flow from \(\text{Zn}\) to \(\text{Cu}\).

8. Base your answer to the following question on the diagram below of an electrolytic cell in which the electrodes are tin and copper.

In this electrolytic cell, electrode \(A\) is designated as the
A) anode and is positive  
B) anode and is negative  
C) cathode and is positive  
D) cathode and is negative
9. Which statement describes one characteristic of an operating electrolytic cell?
   A) It produces electrical energy.
   B) It requires an external energy source.
   C) It uses radioactive nuclides.
   D) It undergoes a spontaneous redox reaction.

10. Base your answer to the following question on the diagram below which represents the electroplating of a metal fork with Ag(s).

![Diagram of electroplating]

Which equation represents the half-reaction that takes place at the fork?
   A) Ag⁺ + NO₃⁻ → AgNO₃
   B) AgNO₃ → Ag⁺ + NO₃⁻
   C) Ag⁺ + e⁻ → Ag(s)
   D) Ag(s) → Ag⁺ + e⁻

11. Which energy change occurs in an operating voltaic cell?
   A) chemical to electrical
   B) electrical to chemical
   C) chemical to nuclear
   D) nuclear to chemical

12. Which half-cell reaction correctly represents reduction?
   A) Sn⁴⁺ → Sn²⁺ + 2e⁻
   B) Sn²⁺ → Sn⁴⁺ + 2e⁻
   C) Sn⁴⁺ + 2e⁻ → Sn²⁺
   D) Sn²⁺ + 2e⁻ → Sn⁴⁺
   E) Sn⁺⁺ + Sn²⁺ → Sn⁶⁺ + 2e⁻

13. Which metal can be produced only by the electrolysis of its fused salt?
   A) Ag  B) Zn  C) Pb  D) K

14. The diagram below shows a key being plated with copper in an electrolytic cell.

![Diagram of electroplating]

Given the reduction reaction for this cell:
   \[ \text{Cu}^{2+}(aq) + 2e^- \rightarrow \text{Cu}(s) \]

This reduction occurs at
   A) A, which is the anode
   B) A, which is the cathode
   C) B, which is the anode
   D) B, which is the cathode

15. At the cathode during electrolysis, what is its charge and what type of reaction occurs.
   A) (−), oxidation
   B) (+), oxidation
   C) (−), reduction
   D) (+), reduction
   E) no reaction occurs at the cathode

16. In an electrochemical cell, the electrons go from the
   A) anode to the cathode through the wire
   B) cathode to the anode through the wire
   C) anode to the cathode through the salt bridge
   D) cathode to the anode through the salt bridge
   E) anode to the cathode through the wire and cathode to the anode through the salt bridge
17. The reaction \(2 \text{H}_2\text{O} (\ell) \rightarrow 2 \text{H}_2(\text{g}) + \text{O}_2(\text{g})\) is forced to occur by use of an externally applied electric current. This procedure is called
A) neutralization       B) esterification
C) electrolysis        D) hydrolysis

18. Electroplating always takes place
A) in the wire       B) at the anode
C) at the cathode    D) at the salt bridge
E) in solution

19. Which net reaction occurs by the process of electrolysis?
A) \(2 \text{H}_2\text{O} (\ell) \rightarrow 2 \text{H}_2(\text{g}) + \text{O}_2(\text{g})\)
B) \(2 \text{HgO}(\text{s}) \rightarrow 2 \text{Hg}(\ell) + \text{O}_2(\text{g})\)
C) \(2 \text{KClO}_3(\ell) \rightarrow 2 \text{KCl}(\text{s}) + 3 \text{O}_2(\text{g})\)
D) \(\text{MgCO}_3(\text{s}) \rightarrow \text{MgO}(\text{s}) + \text{CO}_2(\text{s})\)

20. What are the anode and cathode half–reactions for the electrolysis of fused (melted) \(\text{NaCl}\)?
A) **Anode:** \(2 \text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^-\)  **Cathode:** \(2 \text{Na}^+ + 2\text{e}^- \rightarrow 2 \text{Na}\)
B) **Anode:** \(2 \text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^-\)  **Cathode:** \(2 \text{H}_2\text{O} + 2\text{e}^- \rightarrow \text{H}_2 + 2 \text{OH}^-\)
C) **Anode:** \(2 \text{H}_2\text{O} \rightarrow \text{O}_2 + 4 \text{H}^+ + 4\text{e}^-\)  **Cathode:** \(4 \text{Na}^+ + 4\text{e}^- \rightarrow 4 \text{Na}\)
D) **Anode:** \(2 \text{H}_2\text{O} \rightarrow \text{O}_2 + 4 \text{H}^+ + 4\text{e}^-\)  **Cathode:** \(4 \text{H}_2\text{O} + 4\text{e}^- \rightarrow 2 \text{H}_2 + 4 \text{OH}^-\)
E) **Anode:** \(\text{Cl}_2 + 2\text{e}^- \rightarrow 2 \text{Cl}^-\)  **Cathode:** \(2 \text{Na} \rightarrow 2 \text{Na}^+ + 2\text{e}^-\)

21. Which statement is true about oxidation and reduction in an electrochemical cell?
A) Both occur at the anode.
B) Both occur at the cathode.
C) Oxidation occurs at the anode and reduction occurs at the cathode.
D) Oxidation occurs at the cathode and reduction occurs at the anode.

22. A student wishes to set up an electrochemical cell. The following list of materials and equipment will be used:
- two 250-ml beakers
- wire
- one piece of \(\text{Zn}\) metal
- 125 ml of 0.10 M \(\text{Zn(NO}_3)_2\)
- voltmeter
- switch
- one piece of \(\text{Pb}\) metal
- 125 ml of 0.10 M \(\text{Pb(NO}_3)_2\)

For the cell to operate properly, the student will also need
A) an anode
B) a cathode
C) an external path for electrons
D) a salt bridge

23. The net ionic reaction for an electrochemical cell is
\(2 \text{Cr}(\text{s}) + 3 \text{Cu}^{2+}(\text{aq}) \rightarrow 2 \text{Cr}^{3+}(\text{aq}) + 3 \text{Cu}(\text{s})\)

What is the reaction occurring at the *cathode*?
A) \(2 \text{Cr}(\text{s}) \rightarrow 2 \text{Cr}^{3+}(\text{aq}) + 6\text{e}^-\)
B) \(3 \text{Cu}(\text{s}) \rightarrow 3 \text{Cu}^{2+}(\text{aq}) + 6\text{e}^-\)
C) \(2 \text{Cr}^{3+}(\text{aq}) + 6\text{e}^- \rightarrow 2 \text{Cr}(\text{s})\)
D) \(3 \text{Cu}^{2+}(\text{aq}) + 6\text{e}^- \rightarrow 3 \text{Cu}(\text{s})\)
E) It cannot be determined from the information given
### 24. What occurs during discharge in the lead-acid battery reaction below?

\[
Pb + PbO_2 + 2 H_2SO_4 \leftrightarrow 2 PbSO_4 + 2 H_2O
\]

A) Both Pb and Pb\(^{4+}\) undergo oxidation.
B) Both Pb and Pb\(^{4+}\) undergo reduction.
C) **Pb is oxidized and Pb\(^{4+}\) is reduced.**
D) Neither the Pb nor the Pb\(^{4+}\) is oxidized or reduced.

### 25. A diagram of a chemical cell and an equation are shown below.

When the switch is closed, electrons will flow from

A) **the Pb(s) to the Cu(s)**
B) the Cu(s) to the Pb(s)
C) the Pb\(^{2+}\)(aq) to the Pb(s)
D) the Cu\(^{2+}\)(aq) to the Cu(s)

### 26. Given the balanced ionic equation representing the reaction in an operating voltaic cell:

\[
Zn(s) + Cu^{2+}(aq) \rightarrow Zn^{2+}(aq) + Cu(s)
\]

The flow of electrons through the external circuit in this cell is from the

A) Cu anode to the Zn cathode
B) Cu cathode to the Zn anode
C) **Zn anode to the Cu cathode**
D) Zn cathode to the Cu anode

### 27. Base your answer to the following question on the diagram of the chemical cell at 298 K and on the equation below.

\[
Ni^0(s) + 2Ag^+(aq) \rightarrow Ni^{2+}(aq) + 2Ag^0(s)
\]

In the given reaction, the Ag\(^{+}\) ions

A) **gain electrons**
B) lose electrons
C) gain protons
D) lose protons

### 28. During the electrolysis of fused NaCl, which half-reaction occurs at the negative electrode?

A) Na\(^+\) + 1e\(^-\) → Na\(^0\)
B) Na\(^0\) → Na\(^+\) + 1e\(^-\)
C) 2 Cl\(^-\) → Cl\(^2\)(aq) + 2e\(^-\)
D) Cl\(^2\)(aq) + 2e\(^-\) → 2 Cl\(^-\)

### 29. To which electrode do the electrons move in the cell

\[
Zn/Zn^{2+}||Pb^{2+}/Pb
\]

A) **Pb**
B) Pb\(^{2+}\)
C) Zn
D) Zn\(^{2+}\)
E) It cannot be determined unless the potentials are known.
30. A student collects the materials and equipment below to construct a voltaic cell:

- two 250-mL beakers
- wire and a switch
- one strip of magnesium
- one strip of copper
- 125 mL of 0.20 M Mg(NO\textsubscript{3})\textsubscript{2}(aq)
- 125 mL of 0.20 M Cu(NO\textsubscript{3})\textsubscript{2}(aq)

Which additional item is required for the construction of the voltaic cell?
A) an anode  B) a battery  C) a cathode  D) a salt bridge

31. In the reaction

\[ \text{Sn}^{2+}(aq) + 2 \text{Ag}^+(aq) \rightarrow \text{Sn}^{4+}(aq) + 2 \text{Ag(s)} \]

What is the half–reaction equation for the oxidizing agent above?
A) \( \text{Sn}^{2+} \rightarrow \text{Sn}^{4+} + 2e^- \)  B) \( \text{Ag}^+ + e^- \rightarrow \text{Ag} \)
C) \( \text{Sn}^{2+} + 2e^- \rightarrow \text{Sn}^{4+} \)  D) \( \text{Ag}^+ \rightarrow \text{Ag} + e^- \)

32. **STANDARD ELECTRODE POTENTIALS**

<table>
<thead>
<tr>
<th>Half–Reaction</th>
<th>( E^\circ, \text{volts} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 8 \text{H}^+ + \text{MnO}_4^- + 5e^- \rightarrow \text{Mn}^{2+} + 4 \text{H}_2\text{O} )</td>
<td>+1.51</td>
</tr>
<tr>
<td>( \text{Cu}^{2+} + 2e^- \rightarrow \text{Cu(s)} )</td>
<td>+0.34</td>
</tr>
</tbody>
</table>

What is the oxidation half–reaction for the reaction?
\[ \text{Cu} + \text{MnO}_4^- + \text{H}^+ \rightarrow \text{Cu}^{2+} + \text{Mn}^{2+} + \text{H}_2\text{O} \]
A) \( \text{Cu}^{2+} + 2e^- \rightarrow \text{Cu(s)} \)
B) \( \text{Cu(s)} \rightarrow \text{Cu}^{2+} + 2e^- \)
C) \( 8 \text{H}^+ + \text{MnO}_4^- + 5e^- \rightarrow \text{Mn}^{2+} + 4 \text{H}_2\text{O} \)
D) \( \text{Mn}^{2+} + 4 \text{H}_2\text{O} \rightarrow 8 \text{H}^+ + \text{MnO}_4^- + 5e^- \)
E) \( \text{MnO}_4^- + 8 \text{H}^+ \rightarrow \text{Mn}^{2+} + 4 \text{H}_2\text{O} \)

33. The function of the salt bridge in an electrochemical cell is to
A) increase the cell voltage
B) **maintain electrical neutrality**
C) increase the oxidation–reduction rate
D) supply a travel pathway for electrons
E) increase the rate of attainment of equilibrium

34. The diagram below shows the electrolysis of fused KCl.

What occurs when the switch is closed?
A) Positive ions migrate toward the anode, where they lose electrons.
B) Positive ions migrate toward the anode, where they gain electrons.
C) Positive ions migrate toward the cathode, where they lose electrons.
D) **Positive ions migrate toward the cathode, where they gain electrons.**

35. Which conversion of energy always occurs in a voltaic cell?
A) light energy to chemical energy
B) electrical energy to chemical energy
C) chemical energy to light energy
D) **chemical energy to electrical energy**
36. The diagram below represents an operating electrochemical cell and the balanced ionic equation for the reaction occurring in the cell.

\[
\text{Zn(s) + Ni}^{2+}(aq) \rightarrow \text{Zn}^{2+}(aq) + \text{Ni(s)}
\]

Which statement identifies the part of the cell that conducts electrons and describes the direction of electron flow as the cell operates?

A) Electrons flow through the salt bridge from the Ni(s) to the Zn(s).
B) Electrons flow through the salt bridge from the Zn(s) to the Ni(s).
C) Electrons flow through the wire from the Ni(s) to the Zn(s).
D) Electrons flow through the wire from the Zn(s) to the Ni(s).

37. When a voltaic cell operates, ions move through the

A) anode  
B) cathode  
C) salt bridge  
D) external circuit

38. The negative ions go to which electrode in the voltaic cell

\[
\text{Mg/Mg}^{2+}||\text{Ag}^+/\text{Ag}
\]

A) Ag  
B) Ag$^+$  
C) Mg  
D) Mg$^{2+}$  
E) both Ag and Mg

39. Given the redox reaction:

\[
2 \text{NiOOH} + \text{Cd} \rightarrow \text{2Ni(OH)}_2 + \text{Cd(OH)}_2
\]

Which species is oxidized during discharge?

A) Cd  
B) Cd$^{2+}$  
C) Ni(OH)$_3$  
D) Ni(OH)$_2$

40. In the electrolysis of molten CaCl$_2$, the species oxidized is

A) Ca  
B) Ca$^{2+}$  
C) Cl$^-$  
D) Cl$_2$  
E) Oxidation does not occur

41. Which statement best describes the key?

A) It acts as the cathode and is negative.  
B) It acts as the cathode and is positive.  
C) It acts as the anode and is negative.  
D) It acts as the anode and is positive.
42. Consider the reaction,

\[ \text{S}^{6+} + ? \, \text{e}^{-} \rightarrow \text{S}^{2-} \]

How many electrons are needed to reduce S\(^{6+}\) to S\(^{2-}\)?
A) 6  B) 2  C) 8  D) 4  E) 10

43. The diagram below shows a spoon that will be electroplated with nickel metal.

What will occur when switch S is closed?
A) The spoon will lose mass, and the Ni(s) will be reduced.
B) The spoon will lose mass, and the Ni(s) will be oxidized.
C) The spoon will gain mass, and the Ni(s) will be reduced.
D) The spoon will gain mass, and the Ni(s) will be oxidized.

44. Which is the cathode of this electrochemical cell?

\[ \text{Cr} + \text{Au}^{3+} \rightarrow \text{Cr}^{3+} + \text{Au} \]

A) Cr  B) Au\(^{3+}\)  C) Cr\(^{3+}\)  D) Au  E) It cannot be determined unless the potentials are known

45. In an electrochemical cell, the positive ions go from the
A) anode to the cathode through the wire
B) cathode to the anode through the wire
C) anode to the cathode through the salt bridge
D) cathode to the anode through the salt bridge
E) cathode to the anode through the wire and anode to the cathode through the salt bridge

46. Which statement best describes the reaction represented by the equation below?

\[ 2 \text{NaCl} + 2 \text{H}_2\text{O} + \text{electricity} \rightarrow \text{Cl}_2 + \text{H}_2 + 2 \text{NaOH} \]

A) The reaction occurs in a chemical cell and releases energy.
B) The reaction occurs in a chemical cell and absorbs energy.
C) The reaction occurs in an electrolytic cell and releases energy.
D) The reaction occurs in an electrolytic cell and absorbs energy.
47. Base your answer to the following question on the diagram of the voltaic cell below.

![Voltaic Cell Diagram]

When the switch is closed, in which half-cell does oxidation occur?

48. Base your answer to the following question on the diagram and balanced equation below, which represent the electrolysis of molten NaCl.

![Electrolysis Diagram]

2NaCl → Cl₂ + 2Na

Write the balanced half-reaction for the reduction that occurs in this electrolytic cell.
When the switch is closed, the reaction in the cell begins. The balanced ionic equation for the reaction in the cell is shown below the cell diagram. After several hours, the copper electrode is removed, rinsed with water, and dried. At this time, the mass of the copper electrode is greater than 15.0 grams.

Explain, in terms of copper ions and copper atoms, why the mass of the copper electrode increases as the cell operates. Your response must include information about both copper ions and copper atoms.
50. Base your answer to the following question on the information below.

The diagram below represents an operating electrolytic cell used to plate silver onto a nickel key. As the cell operates, oxidation occurs at the silver electrode and the mass of the silver electrode decreases.

Explain, in terms of Ag atoms and Ag⁺(aq) ions, why the mass of the silver electrode decreases as the cell operates.
51. Base your answer to the following question on the information below.

A student places a 2.50-gram sample of magnesium metal in a bottle and fits the bottle with a 2-hole stopper as shown in the diagram. Hydrochloric acid is added to the bottle, causing a reaction. As the reaction proceeds, hydrogen gas travels through the tubing to an inverted bottle filled with water, displacing some of the water in the bottle.

Based on Reference Table J, explain why Ag(s) will not react with HCl (aq) to generate H₂(g).

52. Base your answer to the following question on the information below.

Electroplating is an electrolytic process used to coat metal objects with a more expensive and less reactive metal. The diagram below shows an electroplating cell that includes a battery connected to a silver bar and a metal spoon. The bar and spoon are submerged in AgNO₃(aq).

Explain the purpose of the battery in this cell.
53. Base your answer to the following question on the information below.

The diagram below represents an operating voltaic cell at 298 K and 1.0 atmosphere in a laboratory investigation. The reaction occurring in the cell is represented by the balanced ionic equation below.

\[2\text{Ag}^+(aq) + \text{Ni}(s) \rightarrow 2\text{Ag}(s) + \text{Ni}^{2+}(aq)\]

Write a balanced half-reaction equation for the reduction that occurs in this cell.

54. Base your answer to the following question on the information below.

The diagram and balanced ionic equation below represent a voltaic cell with copper and silver electrodes and the reaction that occurs when the cell is operating.

\[\text{Cu}(s) + 2\text{Ag}^+(aq) \rightarrow \text{Cu}^{2+}(aq) + 2\text{Ag}(s)\]

State the purpose of the salt bridge in this voltaic cell.
Underground iron pipes in contact with moist soil are likely to corrode. This corrosion can be prevented by applying the principles of electrochemistry. Connecting an iron pipe to a magnesium block with a wire creates an electrochemical cell. The magnesium block acts as the anode and the iron pipe acts as the cathode. A diagram of this system is shown below.

Cross-Sectional View of Underground Pipe Protection System

Explain, in terms of reactivity, why magnesium is preferred over zinc to protect underground iron pipes. Your response must include both magnesium and zinc.
Answer Key

electrochemistry

1. C  
2. A  
3. B  
4. C  
5. D  
6. C  
7. D  
8. A  
9. B  
10. C  
11. A  
12. C  
13. D  
14. B  
15. C  
16. A  
17. C  
18. C  
19. A  
20. A  
21. C  
22. D  
23. D  
24. C  
25. A  
26. C  
27. A  
28. A  
29. A  
30. D  
31. B  
32. B  
33. B  
34. D  
35. D  
36. D  
37. C  
38. C  
39. A  
40. C  
41. A  
42. C  
43. D  
44. D  
45. C  
46. D  
47. Acceptable responses: half-cell 1, Pb, left, lead. 
48. Na⁺ + e⁻ → Na or 2Na⁺ + 2e⁻ → 2Na
49. copper ions from the solution are reduced to copper atoms at the electrode, increasing the mass of the electrode; Copper ions become copper atoms; The number of copper ions decreases, and the number of copper atoms increases. 
50. —Silver atoms lose electrons and become silver ions in the solution. —Some of the Ag atoms become Ag⁺ ions. —Silver atoms are oxidized to silver ions. 
51. Examples: —Ag is below H₂ in the activity series. —Ag is more difficult to oxidize.
52. Examples: —The battery provides the electrical energy necessary for the reaction to occur. 
53. Ag⁺ + e⁻ → Ag or 2Ag⁺ + 2e⁻ → 2Ag
54. Acceptable responses include, but are not limited to: • The salt bridge allows for the migration of ions between the half-cells. • The salt bridge prevents polarization of the half-cells maintains electrical neutrality 
55. Examples: —Magnesium atoms lose electrons more easily than zinc atoms. —Mg oxidizes more readily than Zn. —Mg is more active than Zn.