Use the following information to answer the next three questions.

The energy from a car battery is generated as represented by the equation below.

\[ \text{Pb(s)} + \text{PbO}_2(s) + 4 \text{H}^+(aq) + 2 \text{SO}_4^{2-}(aq) \rightarrow 2 \text{PbSO}_4(s) + 2 \text{H}_2\text{O(l)} \]

\[ \Delta H = -315.9 \text{ kJ} \]

9. If 15.0 g of Pb(s) reacts in a car battery, the amount of energy released is

A. 4.74 MJ
B. 4.36 MJ
C. 22.9 kJ
D. 21.1 kJ

10. During the operation of a car battery, which of the following observations can be made?

A. The amount of Pb(s) increases as PbO$_2$(s) is reduced.
B. The amount of PbO$_2$(s) increases as Pb(s) is reduced.
C. The amount of PbO$_2$(s) decreases as Pb(s) is oxidized.
D. The amount of Pb(s) decreases as PbO$_2$(s) is oxidized.

Use the following information to answer the next two questions.

Commercial drain cleaners typically contain sodium hydroxide and aluminum. When the solid cleaner is poured down the drain and water is added, the reaction that occurs is represented by the equation

\[ 2\text{NaOH}(s) + 2\text{Al}(s) + 2\text{H}_2\text{O(l)} \rightarrow 2\text{NaAlO}_2(aq) + 3\text{H}_2(g) \]

\[ \Delta H = -850.0 \text{ kJ} \]

13. In this reaction, the oxidation number of aluminum changes from

A. 0 to +1
B. 0 to +3
C. +2 to +6
D. +3 to +6

Numerical Response

3. In the production of 4.00 mol of NaAlO$_2$(aq), the heat released is 1.70 MJ.

(Record your three-digit answer in the numerical-response section on the answer sheet.)
5. The heat released when 0.100 mol of oxidizing agent reacts is \(28.2\) kJ. (Record your answer to three digits.)

\[
\begin{align*}
\Delta H &= -463.9 \text{ kJ} \\
\Delta H_m &= -463.9 \text{ kJ} \\
\Delta H_{\text{m}} &= \frac{0.100 \text{ mol}}{2 \text{ mol}} \\
&= -23.2 \text{ kJ/mole}
\end{align*}
\]

2. When 0.235 mol of reducing agent reacts, the heat produced is \(85.7\) kJ. (Record your answer to three digits.)

\[
\begin{align*}
\Delta H &= -729.5 \text{ kJ} \\
\Delta H_m &= -729.5 \text{ kJ} \\
\Delta H_{\text{m}} &= \frac{0.235 \text{ mol}}{2 \text{ mol}} \\
&= -364.7 \text{ kJ/mole}
\end{align*}
\]

42. During the reaction \(C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)\), carbon changes in oxidation state from \(6\times (-2) = -12\) to \(6\times 0 = 0\). Oxygen changes from \(0\) to \(-2\).

A. from 0 to +4 and oxygen changes from 0 to -2
B. from +2 to +4 and oxygen changes from 0 to -2
C. from -1 to +4 and oxygen changes from -2 to 0
D. from 0 to +4 and oxygen changes from -2 to 0

43. Consider the equation \(3Hg_{(aq)} + 2AuCl_{3(aq)} \rightarrow 3Hg^{2+}_{(aq)} + 2Au_{(s)} + 8Cl^{-}_{(aq)}\). The CHANGE in the oxidation number of Au in this reaction is

A. 0
B. 1
C. 3
D. 6

12. The oxidation numbers of the carbon in \(C_6H_{12}O_6(aq)\), \(CO_2(g)\), and \(C_2H_5OH_{(aq)}\) are, respectively,

A. 0, +4, -2
B. 0, +4, +2
C. 0, -4, -2
D. +6, -4, +2
Nova Chemicals is a major producer of ethene in Alberta. Ethene is produced by thermally cracking ethane that has been separated from natural gas. The following equation represents the cracking process:

\[ \text{C}_2\text{H}_6(\text{g}) \rightarrow \text{C}_2\text{H}_4(\text{g}) + \text{H}_2(\text{g}) \]

24. In the cracking process, the oxidation number of

A. carbon changes from \(-2\) to \(-3\)
B. carbon changes from \(-3\) to \(-2\)
C. hydrogen changes from \(0\) to \(+1\)
D. hydrogen increases and decreases

13. In the balanced redox reaction equation:

\[ 3\text{Cu}(\text{s}) + 2\text{NO}_3^{-}(\text{aq}) + 8\text{H}^+(\text{aq}) \rightarrow 3\text{Cu}^{2+}(\text{aq}) + 2\text{NO} (\text{g}) + 4\text{H}_2\text{O}(\text{l}) \]

the oxidation number of nitrogen

A. decreases by \(3\)
B. increases by \(3\)
C. increases by \(2\)
D. decreases by \(6\)

Use the following information to answer question 44.

I. An oxidizing agent gains electrons
II. Conversion of bromine gas to bromide ions
III. Formation of gold ions from gold metal
IV. Change of an oxidation number from \(-2\) to \(-3\)

44. Which of the above are examples of reduction?

A. II, III, IV
B. I, III, IV
C. I, II, III
D. I, II, IV

Use the following unbalanced half-reaction to answer question 39.

\[ \text{ClO}_2^{-}(\text{aq}) + 8\text{H}^+(\text{aq}) + 7\text{e}^{-} \rightarrow \frac{1}{2}\text{Cl}_2(\text{g}) + 4\text{H}_2\text{O}(\text{l}) \]

39. The number of electrons needed to balance the half-reaction is

A. 1
B. 4
C. 7
D. 8
At the Wascana Gas Plant in Balzac, Alberta, environmental and economic concerns have resulted in the development of an efficient process for the removal of sulphur from sour gas, which is a mixture of hydrocarbons and \( \text{H}_2\text{S(g)} \). In the first step of the process, one-third of the \( \text{H}_2\text{S(g)} \) reacts with \( \text{O}_2(g) \) to produce \( \text{SO}_2(g) \). In the second step of the process, the \( \text{SO}_2(g) \) produced reacts with the remaining \( \text{H}_2\text{S(g)} \) to form elemental sulphur and water.

<table>
<thead>
<tr>
<th>Step I</th>
<th>( 2\text{H}_2\text{S(g)} + 3\text{O}_2(g) \rightleftharpoons 2\text{H}_2\text{O(g)} + 2\text{SO}_2(g) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step II</td>
<td>( 2\text{H}_2\text{S(g)} + \text{SO}_2(g) \rightleftharpoons 2\text{H}_2\text{O(g)} + 3\text{S(s)} )</td>
</tr>
<tr>
<td>Overall equation</td>
<td>( 2\text{H}_2\text{S(g)} + \text{O}_2(g) \rightleftharpoons 2\text{H}_2\text{O(g)} + 2\text{S(s)} )</td>
</tr>
</tbody>
</table>

To maximize the amount of sulphur removed from the sour gas, the gas plant engineers apply Le Chatelier's principle.

**11.** As \( \text{H}_2\text{S(g)} \) forms \( \text{S(s)} \), the oxidation number of sulphur

A. changes from 0 to -2 and sulphur is reduced
B. changes from -2 to 0 and sulphur is oxidized
C. decreases by 2 and hydrogen sulphide acts as the reducing agent
D. stays the same because the sulphur is neither oxidized nor reduced

Chlorine gas has an irritating odor and can cause lung damage. To prevent chlorine from escaping into the air, it can be bubbled through \( \text{Na}_2\text{S}_2\text{O}_3(aq) \). The reaction that occurs is

\[
4\text{Cl}_2(g) + \text{S}_2\text{O}_3^{2-}(aq) + 5\text{H}_2\text{O(l)} \rightarrow 2\text{SO}_4^{2-}(aq) + 10\text{H}^+(aq) + 8\text{Cl}^-(aq).
\]

The oxidizing agent in this reaction is

A. \( \text{Cl}_2(g) \)
B. \( \text{S}_2\text{O}_3^{2-}(aq) \)
C. \( \text{H}_2\text{O(l)} \)
D. \( \text{Cl}^-(aq) \)

**36.** The balanced reduction half-reaction for the reduction of \( \text{Nb}_2\text{O}_5(s) \) to \( \text{Nb}(s) \) in an acidic solution is

A. \( \text{Nb}_2\text{O}_5(s) + 10\text{H}^+(aq) + 10\text{e}^- \rightarrow 2\text{Nb}(s) + 5\text{H}_2\text{O(l)} \)
B. \( \text{Nb}_2\text{O}_5(s) + 5\text{H}^+(aq) + 5\text{e}^- \rightarrow \text{Nb}(s) + 5\text{H}_2\text{O(l)} \)
C. \( \text{Nb}_2\text{O}_5(s) + 2\text{H}^+(aq) + 2\text{e}^- \rightarrow \text{Nb}(s) + \text{H}_2\text{O(l)} \)
D. \( \text{Nb}_2\text{O}_5(s) + 5\text{e}^- \rightarrow 2\text{Nb}(s) + \frac{5}{2}\text{O}_2(g) \)
The beautiful patterns of butterfly wings, the stripes on zebra pelts, and the myriad of colours of tropical fish all result from oscillating chemical reactions. These chemical reactions can be studied in a much simpler form in the laboratory. In 1958, the Russian chemist B.P. Belousov discovered a complex reaction sequence in which the concentration of reactants and products oscillated over time.

Unbalanced Reaction Equations

I
\[ 2H^+_{(aq)} + \frac{1}{2}BrO_2^-_{(aq)} + \frac{1}{2}BrO_3^-_{(aq)} \rightleftharpoons 2BrO_2(aq) + \frac{1}{2}H_2O_{(l)} \]

II
\[ \text{--Ce}^{3+}_{(aq)} + \text{--BrO}_2_{(aq)} \rightleftharpoons \text{--Ce}^{4+}_{(aq)} + \text{--BrO}_2^-_{(aq)} \]

III
\[ \text{--BrO}_3^-_{(aq)} \rightleftharpoons \text{--BrO}_3^-_{(aq)} + \text{--BrO}^-_{(aq)} \]

Numerical Response

9. When reaction equation I is balanced with lowest whole number coefficients, the coefficient of

- \( H^+_{(aq)} \) is
- \( BrO_2^-_{(aq)} \) is
- \( BrO_3^-_{(aq)} \) is
- \( BrO_2(aq) \) is

(Record in the first column)

(Record in the second column)

(Record in the third column)

(Record in the fourth column)

(Record your answer in the numerical-response section on the answer sheet.)

19. In reaction III, the bromine in \( BrO_2^-_{(aq)} \)

A. undergoes oxidation only

B. undergoes reduction only

C. both loses and gains protons

D. both loses and gains electrons
43. As(s) reacts with acidified Cr$_2$O$_7^{2-}$(aq) to form As$_2$O$_3$(s) and Cr$^{3+}$(aq). The balanced redox equation for this reaction is

A. As(s) + Cr$_2$O$_7^{2-}$(aq) $\rightarrow$ As$_2$O$_3$(s) + Cr$^{3+}$(aq) + 4e$^-$
B. 2As(s) + 2HCr$_2$O$_7$(aq) $\rightarrow$ As$_2$O$_3$(s) + H$_2$O(l) + 5O$_2$(g) + 4Cr(s)
C. As(s) + Cr$_2$O$_7^{2-}$(aq) + H$^+$ (aq) $\rightarrow$ As$_2$O$_3$(s) + Cr$^{3+}$(aq) + H$_2$O(l)
D. 2As(s) + Cr$_2$O$_7^{2-}$(aq) + 8H$^+$ (aq) $\rightarrow$ As$_2$O$_3$(s) + 2Cr$^{3+}$(aq) + 4H$_2$O(l)

Balance other atoms.

Use the following information to answer the next question.

Ethanol reacts with acidified permanganate ion, as represented by the equation

5 C$_2$H$_5$OH(l) + 4 MnO$_4^{-}$(aq) + 12 H$^+$ (aq) $\rightarrow$ 5 CH$_3$COOH(aq) + 4 Mn$^{2+}$(aq) + 11 H$_2$O(l)

21. In this reaction, the oxidation-number for the oxidizing agent changes from

A. +7 to +2
B. +28 to +8
C. +2 to 0
D. +10 to 0

39. The chlorate ion (ClO$_3^{-}$) is reduced in an acidic solution to form the chloride ion (Cl$^{-}$). The balanced half-reaction is

A. ClO$_3^{-}$(aq) $\rightarrow$ Cl$^{-}$(aq) + $\frac{3}{2}$O$_2$(g)
B. ClO$_3^{-}$(aq) + 6H$^+$ (aq) $\rightarrow$ Cl$^{-}$(aq) + 3H$_2$O(l)
C. 6H$^+$ (aq) + ClO$_3^{-}$(aq) + 6e$^-$ $\rightarrow$ Cl$^{-}$(aq) + 3H$_2$O(l)
D. 3H$^+$ (aq) + ClO$_3^{-}$(aq) + 3e$^-$ $\rightarrow$ Cl$^{-}$(aq) + 3H$_2$O(l)