Assessment Exemplars

Chemistry 30

Alberta Provincial Diploma Examinations 2020–2021
For further information, contact Brenda Elder at Brenda.Elder@gov.ab.ca or Deanna Shostak at Deanna.Shostak@gov.ab.ca at the Provincial Assessment Sector at (780) 427-0010. To call toll-free from outside Edmonton, dial 310-0000.

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Chemistry 30 Assessment Exemplars

These Chemistry 30 assessment exemplars were developed by the Provincial Assessment Sector in cooperation with the Curriculum Branch of Alberta Education and Alberta Chemistry teachers to assist teachers with the interpretation of curricular outcomes in the program of studies (implemented in September 2007). The assessment exemplars, which include multiple-choice and numerical-response questions, illustrate how a particular concept can be assessed in a machine-scored format. Teachers are encouraged to use other assessment tools as well as machine-scored questions to assess the learning of their students.

This exemplar document parallels the Chemistry 30 Program of Studies. Each outcome is identified by a letter that indicates the unit of study (A, B, C, or D); by a number that indicates the general learner outcome within the unit; and by a number that indicates the specific outcome. Each specific outcome is further classified as knowledge (k); science, technology, and society (STS); or skills (s). For example, A2.1k indicates that the concept is from Unit A, general outcome 2, specific outcome 1, and that the outcome is knowledge-based.

This exemplars document is neither exhaustive nor prescriptive. Its purpose is simply to provide a variety of useful examples of how specific outcomes in the Chemistry 30 Program of Studies can be assessed.
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Unit A—Thermochemical Changes

Use the following information to answer questions 1 and 2.

A student used an aluminium calorimeter as part of the apparatus below to determine the molar enthalpy of combustion for pentane, C₅H₁₂(l).

The following data were recorded when a sample of pentane was burned.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of calorimeter</td>
<td>58.5 g</td>
</tr>
<tr>
<td>Mass of calorimeter and water</td>
<td>558.5 g</td>
</tr>
<tr>
<td>Initial temperature of water</td>
<td>21.2 °C</td>
</tr>
<tr>
<td>Final temperature of water</td>
<td>40.0 °C</td>
</tr>
</tbody>
</table>

1. The energy absorbed by the water in the calorimeter is

A. 39.4 kJ  
B. 44.0 kJ  
C. 83.8 kJ  
D. 93.6 kJ

Answer: A
Outcome: A1.1k, A1.4s
Use the following additional information to answer question 2.

\[
\text{C}_5\text{H}_{12}(l) + 8 \text{O}_2(g) \rightarrow 5 \text{CO}_2(g) + 6 \text{H}_2\text{O}(g) \quad \Delta H = -3244.8 \text{ kJ}
\]

2. If 1.07 g of pentane burns, the energy released is

A. 45.0 kJ  
B. 48.1 kJ  
C. \(3.03 \times 10^3\) kJ  
D. \(3.47 \times 10^3\) kJ

Answer: B  
Outcome: A1.5k

Use the following information to answer numerical-response question 1.

Hydrogen gas can be produced by the reaction of methane and water vapour in the presence of a nickel catalyst, as represented by the following equation.

\[
\text{CH}_4(g) + \text{H}_2\text{O}(g) + 205.9 \text{ kJ} \xrightarrow{\text{Ni catalyst}} \text{CO}(g) + 3 \text{H}_2(g)
\]

**Numerical Response**

1. The molar enthalpy of reaction for hydrogen gas in the reaction above is +/-________kJ/mol.

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

   Answer: 68.6  
   Outcome: A1.3k
3. Which of the following equations represents the balanced chemical equation for the decomposition of water into its elements and the energy transfer during the reaction?

A. \( \text{H}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g}) \rightarrow \text{H}_2\text{O}(\text{l}) + 285.8 \text{ kJ} \)

B. \( \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g}) + 285.8 \text{ kJ} \)

C. \( 2 \text{H}_2\text{O}(\text{l}) + 285.8 \text{ kJ} \rightarrow 2 \text{H}_2(\text{g}) + \text{O}_2(\text{g}) \)

D. \( \text{H}_2\text{O}(\text{l}) + 285.8 \text{ kJ} \rightarrow \text{H}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g}) \)

Answer: D
Outcome: A1.4k

Use the following information to answer question 4.

When used as a fuel in automobiles, ethanol burns more efficiently than fossil fuels.

4. The balanced equation, including the appropriate enthalpy change for the complete combustion of ethanol, is

A. \( \text{C}_2\text{H}_5\text{OH}(\text{l}) + 3 \text{O}_2(\text{g}) \rightarrow 2 \text{CO}_2(\text{g}) + 3 \text{H}_2\text{O}(\text{g}) \) \( \Delta H^o = +1234.8 \text{ kJ} \)

B. \( \text{C}_2\text{H}_5\text{OH}(\text{l}) + 3 \text{O}_2(\text{g}) \rightarrow 2 \text{CO}_2(\text{g}) + 3 \text{H}_2\text{O}(\text{g}) \) \( \Delta H^o = -1234.8 \text{ kJ} \)

C. \( \text{C}_2\text{H}_5\text{OH}(\text{l}) \rightarrow 2 \text{C}(\text{s}) + 3 \text{H}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g}) \) \( \Delta H^o = +277.6 \text{ kJ} \)

D. \( \text{C}_2\text{H}_5\text{OH}(\text{l}) \rightarrow 2 \text{C}(\text{s}) + 3 \text{H}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g}) \) \( \Delta H^o = -277.6 \text{ kJ} \)

Answer: B
Outcome: A1.4k, A1.6k, C2.2k, C2.4k, A1.1sts
**Numerical Response**

2. The energy released when 0.500 mol of AgI(s) is formed from its elements is _________ kJ.

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

Answer: 30.9
Outcome: A1.5k

---

**Use the following information to answer question 5.**

Disposable lighters contain butane gas, C₄H₁₀(g), which undergoes combustion, as represented by the following equation.

\[2 \text{C}_4\text{H}_{10}(g) + 13 \text{O}_2(g) \rightarrow 8 \text{CO}_2(g) + 10 \text{H}_2\text{O}(g)\]

5. The molar enthalpy of combustion of butane is

A. $-2657.3 \text{ kJ/mol}$
B. $-2877.3 \text{ kJ/mol}$
C. $-5314.6 \text{ kJ/mol}$
D. $-5754.6 \text{ kJ/mol}$

Answer: A
Outcome: A1.3k, A1.6k, C2.4k, A1.1sts
Ammonium dichromate, (NH₄)₂Cr₂O₇(s), is known as “Vesuvian Fire” because of its use in pyrotechnic displays. Its decomposition can be represented by the following equation.

$$(\text{NH}_4)_2\text{Cr}_2\text{O}_7(s) \rightarrow \text{N}_2(g) + 4\text{H}_2\text{O}(g) + \text{Cr}_2\text{O}_3(s) \quad \Delta H = -300.9 \text{ kJ}$$

6. The molar enthalpy of formation for (NH₄)₂Cr₂O₇(s) is

A. $−1682.4 \text{ kJ/mol}$
B. $−1806.0 \text{ kJ/mol}$
C. $−1982.0 \text{ kJ/mol}$
D. $−2106.9 \text{ kJ/mol}$

Answer: B
Outcome: A1.6k, A1.1sts

---

7. The enthalpy of the reaction represented by the equation $2\text{NO}_2(g) + \frac{1}{2}\text{O}_2(g) \rightarrow \text{N}_2\text{O}_5(g)$ is

A. $−167.6 \text{ kJ}$
B. $−109.5 \text{ kJ}$
C. $+109.5 \text{ kJ}$
D. $+167.6 \text{ kJ}$

Answer: B
Outcome: A1.7k
Use the following information to answer numerical-response question 3.

The complete combustion of cyclopropane, C₃H₆(g), is represented below.

\[
C₃H₆(g) + \frac{9}{2}O₂(g) \rightarrow 3 CO₂(g) + 3 H₂O(g) \quad \Delta H^° = -1 959.2 \text{ kJ}
\]

**Numerical Response**

3. The molar enthalpy of formation of cyclopropane is +/-__________ kJ/mol.

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

Answer: 53.3
Outcome: A1.6k

Use the following information to answer question 8.

The complete combustion of methanol, CH₃OH(l), is represented below.

\[
2 \text{CH}_3\text{OH}(l) + 3 \text{O}_2(g) \rightarrow 2 \text{CO}_2(g) + 4 \text{H}_2\text{O}(g) \quad \Delta H^° = -1 275.8 \text{ kJ}
\]

8. The amount of methanol that must be burned to raise the temperature of 250.0 g of water from 20.0 °C to 35.0 °C is

A. \(6.16 \times 10^{-3}\) mol
B. \(1.23 \times 10^{-2}\) mol
C. \(2.46 \times 10^{-2}\) mol
D. \(2.46 \times 10^1\) mol

Answer: C
Outcome: A1.8k, A1.4s
9. The products of photosynthesis are \( i \), and the products of hydrocarbon combustion in an open system are \( ii \).

The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>( i )</th>
<th>( ii )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>( \text{CO}_2(\text{g}) ) and ( \text{H}_2\text{O(\text{l})} )</td>
<td>( \text{CO}_2(\text{g}) ) and ( \text{H}_2\text{O(\text{g})} )</td>
</tr>
<tr>
<td>B.</td>
<td>( \text{CO}_2(\text{g}) ) and ( \text{H}_2\text{O(\text{l})} )</td>
<td>( \text{CO}_2(\text{g}) ) and ( \text{H}_2\text{O(\text{l})} )</td>
</tr>
<tr>
<td>C.</td>
<td>( \text{C}<em>6\text{H}</em>{12}\text{O}_6(\text{s}) ) and ( \text{O}_2(\text{g}) )</td>
<td>( \text{CO}_2(\text{g}) ) and ( \text{H}_2\text{O(\text{g})} )</td>
</tr>
<tr>
<td>D.</td>
<td>( \text{C}<em>6\text{H}</em>{12}\text{O}_6(\text{s}) ) and ( \text{O}_2(\text{g}) )</td>
<td>( \text{CO}_2(\text{g}) ) and ( \text{H}_2\text{O(\text{l})} )</td>
</tr>
</tbody>
</table>

Answer: C
Outcome: A1.9k

Use the following information to answer question 10.

In order to pollinate its flowers, the corpse plant generates heat to diffuse a chemical that attracts flies. The energy generated by the plant comes from the metabolism of fats, which can be represented by the following simplified equation.

\[
\text{C}_5\text{H}_{11}\text{COOH(\text{l})} + 8 \text{O}_2(\text{g}) \rightarrow 6 \text{CO}_2(\text{g}) + 6 \text{H}_2\text{O(\text{l})} + 3 494.3 \text{ kJ}
\]

10. The products of fat metabolism are the same as those of \( i \). In the photosynthesis reaction that also occurs in the plant, carbon dioxide, \( \text{CO}_2(\text{g}) \), and water, \( \text{H}_2\text{O(\text{l})} \), are the \( ii \).

The statements above are completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>( i )</th>
<th>( ii )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>cellular respiration</td>
<td>products</td>
</tr>
<tr>
<td>B.</td>
<td>cellular respiration</td>
<td>reactants</td>
</tr>
<tr>
<td>C.</td>
<td>hydrocarbon combustion in an open system</td>
<td>products</td>
</tr>
<tr>
<td>D.</td>
<td>hydrocarbon combustion in an open system</td>
<td>reactants</td>
</tr>
</tbody>
</table>

Answer: B
Outcome: A1.9k
Use the following information to answer numerical-response question 4.

**Nine Thermochemical Processes**

1. The reaction that represents the $\Delta_f H^\circ$ for $C_2H_4(g)$
2. The reaction that represents the $\Delta_f H^\circ$ for $C_6H_{12}O_6(s)$
3. Photosynthesis
4. Cellular respiration
5. Hydrocarbon combustion
6. $\text{PCl}_5(s) + \text{energy} \rightarrow \text{PCl}_3(l) + \text{Cl}_2(g)$
7. $C_2H_4(g) + H_2(g) \rightarrow C_2H_6(g) + \text{energy}$
8. $\text{CH}_4(g) + \text{H}_2\text{O}(g) \rightarrow \text{CO}(g) + 3 \text{H}_2(g)$ \hspace{1cm} $\Delta H = +205.9 \text{ kJ}$
9. $\text{CH}_4(g) + \text{Cl}_2(g) \rightarrow \text{CH}_3\text{Cl}(g) + \text{HCl}(g)$ \hspace{1cm} $\Delta H = -101.4 \text{ kJ}$

**Numerical Response**

4. The thermochemical processes above that would be classified as endothermic are numbered _____, _____, _____, and _____.

(Record all four digits of your answer in any order in the numerical-response section on the answer sheet.)

Answer: 1368, any order
Outcome: A1.10k

11. One reason that could explain why dynamite releases a large quantity of energy when it explodes is that the reaction is

A. endothermic, and the products have more potential energy than the reactants
B. endothermic, and the reactants have more potential energy than the products
C. exothermic, and the products have more potential energy than the reactants
D. exothermic, and the reactants have more potential energy than the products

Answer: D
Outcome: A1.10k, A2.2k, A1.1sts
12. The energy barrier that must be overcome for the forward catalyzed reaction to occur is called the \( i \), and in the diagram above it is the difference between \( ii \).

The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>( i )</th>
<th>( ii )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>enthalpy change</td>
<td>I and II</td>
</tr>
<tr>
<td>B.</td>
<td>enthalpy change</td>
<td>I and III</td>
</tr>
<tr>
<td>C.</td>
<td>activation energy</td>
<td>I and II</td>
</tr>
<tr>
<td>D.</td>
<td>activation energy</td>
<td>I and III</td>
</tr>
</tbody>
</table>

Answer: C
Outcome: A2.1k, A2.3k, A2.3s
Use the following information to answer question 13 and numerical-response question 5.

Naphthalene, C\(_{10}\)H\(_8\)(s), is commonly found in coal tar but has also been isolated from meteorites. Its combustion can be represented by the following equation.

\[
C_{10}H_8(s) + 12 O_2(g) \rightarrow 10 CO_2(g) + 4 H_2O(g)
\]

When a 0.820 g sample of naphthalene was burned in a calorimeter containing 250 mL of water, a temperature change of 12.5 °C was observed.

13. *The chemical energy stored in naphthalene originally came from \(i\), and during the combustion of naphthalene the chemical potential energy will \(ii\).*

The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>(i)</th>
<th>(ii)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>the Sun</td>
<td>decrease</td>
</tr>
<tr>
<td>B.</td>
<td>the Sun</td>
<td>increase</td>
</tr>
<tr>
<td>C.</td>
<td>a hydrocarbon</td>
<td>decrease</td>
</tr>
<tr>
<td>D.</td>
<td>a hydrocarbon</td>
<td>increase</td>
</tr>
</tbody>
</table>

Answer: A
Outcome: A1.2k, A2.2k, A1.1sts

**Numerical Response**

5. The experimental value for the molar enthalpy of combustion of naphthalene, C\(_{10}\)H\(_8\)(s), expressed in scientific notation, is +/-\(a.bc\) × 10\(^d\) kJ/mol. The values of \(a\), \(b\), \(c\), and \(d\) are \(a\), \(b\), \(c\), and \(d\).

(Record all four digits of your answer in the numerical-response section on the answer sheet.)

Answer: 2053
Outcome: A1.8k, A1.2s, A1.4s, A1.1sts
Use the following information to answer question 14.

14. In the reaction represented by the enthalpy diagram above, the products are produced from the reactants as the result of chemical bonds ____i____, and compared to the reactants, the potential energy of the products is ____ii____.

The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>i</th>
<th>ii</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>breaking and forming</td>
<td>less</td>
</tr>
<tr>
<td>B.</td>
<td>breaking and forming</td>
<td>greater</td>
</tr>
<tr>
<td>C.</td>
<td>breaking</td>
<td>less</td>
</tr>
<tr>
<td>D.</td>
<td>breaking</td>
<td>greater</td>
</tr>
</tbody>
</table>

Answer: B
Outcome: A2.2k, A2.3k, A2.3s
Use the following information to answer question 15.

\[
\text{MgO}(s) + \text{CO}_2(g) \rightarrow \text{MgCO}_3(s)
\]

15. When a catalyst is added to the reaction above, the

A. enthalpy change for the reaction increases
B. enthalpy change for the reaction decreases
C. catalyst provides an alternative pathway at a higher energy
D. catalyst provides an alternative pathway at a lower energy

Answer: D
Outcome: A2.4k
**Unit B—Electrochemical Changes**

*Use the following information to answer question 1.*

<table>
<thead>
<tr>
<th>Four Statements</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
</tr>
<tr>
<td>II</td>
</tr>
<tr>
<td>III</td>
</tr>
<tr>
<td>IV</td>
</tr>
</tbody>
</table>

1. The statements numbered above that refer to oxidation are

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

   Answer: D
   Outcome: B1.1k, B1.2k
Leaching technology is used in the mining and refining of copper ore. In the first step of the leaching process, concentrated aqueous sulfuric acid, H_2SO_4(aq), flows through a copper ore deposit. Solid copper(II) oxide, CuO(s), reacts with sulfuric acid as represented by the following net ionic equation.

\[
\text{CuO(s)} + 2 \text{H}^+(aq) \rightarrow \text{Cu}^{2+}(aq) + \text{H}_2\text{O}(l)
\]

The resulting solution that contains copper(II) ions is transferred to an electrolytic cell where pure copper is produced.

2. In the reaction represented by the equation above, copper undergoes

A. reduction only
B. oxidation only
C. both oxidation and reduction
D. neither oxidation nor reduction

Answer: D
Outcome: B1.1k, B1.1sts

3. Which of the following rows identifies the process O_2(g) undergoes and describes the change in oxidation number for sulfur?

<table>
<thead>
<tr>
<th>Row</th>
<th>Process O_2(g) Undergoes</th>
<th>Change in Oxidation Number for Sulfur</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>Oxidation</td>
<td>Increases by two</td>
</tr>
<tr>
<td>B.</td>
<td>Oxidation</td>
<td>Increases by six</td>
</tr>
<tr>
<td>C.</td>
<td>Reduction</td>
<td>Increases by two</td>
</tr>
<tr>
<td>D.</td>
<td>Reduction</td>
<td>Increases by six</td>
</tr>
</tbody>
</table>

Answer: D
Outcome: B1.1k, B1.2k
4. Which of the following equations represents a disproportionation reaction?

A. \(2 \text{Na}(s) + \text{I}_2(s) \rightarrow 2 \text{NaI}(s)\)
B. \(2 \text{F}_2(g) + \text{O}_2(g) \rightarrow 2 \text{OF}_2(g)\)
C. \(\text{Cl}_2(\text{aq}) + \text{H}_2\text{O}(l) \rightarrow \text{HOCl}(\text{aq}) + \text{H}^+(\text{aq}) + \text{Cl}^-(\text{aq})\)
D. \(2 \text{NH}_3(\text{aq}) + \text{NaOCl}(\text{aq}) \rightarrow \text{N}_2\text{H}_4(\text{aq}) + \text{NaCl}(\text{aq}) + \text{H}_2\text{O}(l)\)

Answer: C
Outcome: B1.2k

Use the following information to answer question 5.

<table>
<thead>
<tr>
<th>Three Equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (\text{NaCl}(\text{aq}) + 3 \text{H}_2\text{O}(l) \rightarrow \text{NaClO}_3(\text{aq}) + 3 \text{H}_2(\text{g}))</td>
</tr>
<tr>
<td>II (3 \text{NaOCl}(\text{aq}) \rightarrow \text{NaClO}_3(\text{aq}) + 2 \text{NaCl}(\text{aq}))</td>
</tr>
<tr>
<td>III (\text{NaClO}_3(\text{aq}) + \text{KCl}(\text{aq}) \rightarrow \text{KClO}_3(\text{aq}) + \text{NaCl}(\text{aq}))</td>
</tr>
</tbody>
</table>

5. The equations above that represent a redox reaction are equations \(i\), and the equation that represents a disproportionation reaction is Equation \(ii\).

The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>(i)</th>
<th>(ii)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>I and II</td>
<td>II</td>
</tr>
<tr>
<td>B.</td>
<td>I and II</td>
<td>III</td>
</tr>
<tr>
<td>C.</td>
<td>II and III</td>
<td>II</td>
</tr>
<tr>
<td>D.</td>
<td>II and III</td>
<td>III</td>
</tr>
</tbody>
</table>

Answer: A
Outcome: B1.2k, B1.3k
Use the following information to answer questions 6 and 7.

Methanol gas, \( \text{CH}_3\text{OH}(g) \), can be manufactured industrially by the catalytic hydrogenation of carbon monoxide, \( \text{CO}(g) \), as represented by the following equation.

\[
\text{CO}(g) + 2 \text{H}_2(g) \rightarrow \text{CH}_3\text{OH}(g)
\]

6. Which of the following rows identifies the process carbon undergoes and the type of agent \( \text{H}_2(g) \) is acting as?

<table>
<thead>
<tr>
<th>Row</th>
<th>Process Carbon Undergoes</th>
<th>Type of Agent ( \text{H}_2(g) ) is Acting As</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>Oxidation</td>
<td>Reducing agent</td>
</tr>
<tr>
<td>B.</td>
<td>Oxidation</td>
<td>Oxidizing agent</td>
</tr>
<tr>
<td>C.</td>
<td>Reduction</td>
<td>Reducing agent</td>
</tr>
<tr>
<td>D.</td>
<td>Reduction</td>
<td>Oxidizing agent</td>
</tr>
</tbody>
</table>

Answer: C
Outcome: B1.2k, B1.1sts

7. During the catalytic hydrogenation of carbon monoxide, the total number of electrons transferred is

A. 2 
B. 4 
C. 6 
D. 8 

Answer: B
Outcome: B1.4k, B1.7k, B1.1sts
Use the following information to answer question 8.

**Cellular Respiration**

\[
\text{C}_6\text{H}_{12}\text{O}_6(\text{s}) + 6 \text{O}_2(\text{g}) \rightarrow 6 \text{CO}_2(\text{g}) + 6 \text{H}_2\text{O}(\text{l})
\]

8. During cellular respiration, the oxidizing agent is

A. \(\text{O}_2(\text{g})\)
B. \(\text{CO}_2(\text{g})\)
C. \(\text{H}_2\text{O}(\text{l})\)
D. \(\text{C}_6\text{H}_{12}\text{O}_6(\text{s})\)

Answer: A
Outcome: B1.2k, B1.4k

Use the following information to answer question 9.

**Metallurgical Processes**

I \[2 \text{Al}_2\text{O}_3(\text{s}) \rightarrow 4 \text{Al}(\text{s}) + 3 \text{O}_2(\text{g})\]
II \[2 \text{PbO}(\text{s}) + \text{C}(\text{s}) \rightarrow 2 \text{Pb}(\text{s}) + \text{CO}_2(\text{g})\]
III \[\text{Zn}(\text{s}) + 2 \text{HCl}(\text{aq}) \rightarrow \text{ZnCl}_2(\text{aq}) + \text{H}_2(\text{g})\]
IV \[\text{Cu}(\text{s}) + 4 \text{HNO}_3(\text{aq}) \rightarrow \text{Cu(NO}_3)_2(\text{aq}) + 2 \text{NO}_2(\text{g}) + 2 \text{H}_2\text{O}(\text{l})\]

9. The metallurgical processes in which the metal loses electrons are

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

Answer: D
Outcome: B1.2k, B1.4k
Use the following information to answer question 10.

### Spontaneity of Reactions for Various Chemical Species

<table>
<thead>
<tr>
<th></th>
<th>Be(^{2+})(aq)</th>
<th>Cd(^{2+})(aq)</th>
<th>Ra(^{2+})(aq)</th>
<th>V(^{2+})(aq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Be(s)</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>Cd(s)</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>Ra(s)</td>
<td>✓</td>
<td>✓</td>
<td>×</td>
<td>✓</td>
</tr>
<tr>
<td>V(s)</td>
<td>×</td>
<td>✓</td>
<td>×</td>
<td>×</td>
</tr>
</tbody>
</table>

✓ evidence of a spontaneous reaction
× no evidence of reaction

10. When listed in order from strongest to weakest, the oxidizing agents are

A. Ra(s), Be(s), V(s), Cd(s)
B. Cd(s), V(s), Be(s), Ra(s)
C. Ra\(^{2+}\)(aq), Be\(^{2+}\)(aq), V\(^{2+}\)(aq), Cd\(^{2+}\)(aq)
D. Cd\(^{2+}\)(aq), V\(^{2+}\)(aq), Be\(^{2+}\)(aq), Ra\(^{2+}\)(aq)

Answer: D
Outcome: B1.5k, B1.3s
During an investigation, a student mixed various chemicals and observed all evidence of reaction. The observations can be represented by the following equations.

\[ M^{2+}(aq) + 2\, Q(s) \rightarrow M(s) + 2\, Q^+(aq) \]
\[ 2\, Q(s) + X^+(aq) \rightarrow \text{no reaction} \]
\[ 2\, Z^{3+}(aq) + 3\, M(s) \rightarrow 2\, Z(s) + 3\, M^{2+}(aq) \]

**Reaction Types**

1. Spontaneous
2. Nonspontaneous

**Numerical Response**

1. For each of the following, match the number describing the reaction type to the set of reactants.

   - \( Z(s) + Q^+(aq) \) (Record in the first column)
   - \( M(s) + X(s) \) (Record in the second column)
   - \( Z^{3+}(aq) + X(s) \) (Record in the third column)
   - \( M(s) + X^+(aq) \) (Record in the fourth column)

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

Answer: 2212
Outcome: B1.5k, B1.6k, B1.3s
Use the following information to answer question 11.

A student collected the data below.

\[
\begin{align*}
\text{Ir}^{3+}(aq) + 3 \text{ e}^- & \rightarrow \text{Ir(s)} \quad E^0 = +1.16 \text{ V} \\
\text{AuCl}_4^-(aq) + 3 \text{ e}^- & \rightarrow \text{Au(s)} + \text{Cl}^-(aq) \quad E^0 = +1.00 \text{ V} \\
\text{Yb}^{3+}(aq) + \text{ e}^- & \rightarrow \text{Yb}^{2+}(aq) \quad E^0 = -1.05 \text{ V} \\
\text{Te(s)} + 2 \text{ e}^- & \rightarrow \text{Te}^{2-}(aq) \quad E^0 = -1.23 \text{ V}
\end{align*}
\]

11. From the student’s data, the strongest reducing agent is

A. \( \text{Ir}^{3+}(aq) \)
B. \( \text{Te}^{2-}(aq) \)
C. \( \text{Te(aq)} \)
D. \( \text{Ir(s)} \)

Answer: B
Outcome: B1.6k

12. Which of the following equations represents a spontaneous redox reaction?

A. \( \text{Zn}^{2+}(aq) + \text{Pb(s)} \rightarrow \text{Zn(s)} + \text{Pb}^{2+}(aq) \)
B. \( \text{Sn}^{4+}(aq) + \text{Fe(s)} \rightarrow \text{Sn}^{2+}(aq) + \text{Fe}^{2+}(aq) \)
C. \( \text{Zn}^{2+}(aq) + \text{Co(s)} \rightarrow \text{Zn(s)} + \text{Co}^{2+}(aq) \)
D. \( \text{O}_2(g) + 2 \text{H}_2\text{O}(l) + 4 \text{Br}^-(aq) \rightarrow 2 \text{Br}_2(l) + 4 \text{OH}^-(aq) \)

Answer: B
Outcome: B1.6k, B1.2s

13. The reducing agent that can convert 1.0 mol/L \( \text{Sn}^{4+}(aq) \) ions to \( \text{Sn}^{2+}(aq) \) but not 1.0 mol/L \( \text{Sn}^{2+}(aq) \) to \( \text{Sn(s)} \) is

A. \( \text{Cu(s)} \)
B. \( \text{Pb(s)} \)
C. \( \text{Ni(s)} \)
D. \( \text{Cr(s)} \)

Answer: B
Outcome: B1.6k, B1.2s
Use the following information to answer question 14.

The anammox process, carried out by certain bacteria, converts nitrite, NO$_2^-$ (aq), and ammonium ions, NH$_4^+$ (aq), directly to nitrogen, N$_2$ (g). The relevant half-reaction equations and reduction potentials are given below.

\[
2 \text{NH}_4^+ (aq) \rightarrow \text{N}_2 (g) + 8 \text{H}^+ (aq) + 6 \text{e}^- \quad E^\circ = +0.28 \text{ V}
\]

\[
2 \text{NO}_2^- (aq) + 8 \text{H}^+ (aq) + 6 \text{e}^- \rightarrow \text{N}_2 (g) + 4 \text{H}_2\text{O} (l) \quad E^\circ = +1.52 \text{ V}
\]

This process is used to treat municipal wastewater to remove nitrogenous waste.

14. An ion capable of reacting spontaneously with acidified NO$_2^-$ (aq) is

A. Zn$^{2+}$ (aq)
B. Pb$^{2+}$ (aq)
C. Ni$^{2+}$ (aq)
D. Cr$^{2+}$ (aq)

Answer: D
Outcome: B1.6k, B1.2s
Use the following information to answer question 15.

\[
\begin{array}{c}
\text{OCI}^- (aq) + \text{I}^- (aq) + \text{H}^+ (aq) \rightarrow \text{I}_2 (aq) + \text{Cl}^- (aq) + \text{H}_2 \text{O} (l)
\end{array}
\]

15. When the equation above is balanced under acidic conditions, the lowest whole number coefficient for \( \text{H}^+ (aq) \) is \( i \) and the amount of electrons transferred is \( ii \).

The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>( i )</th>
<th>( ii )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>1</td>
<td>1 mol</td>
</tr>
<tr>
<td>B.</td>
<td>1</td>
<td>2 mol</td>
</tr>
<tr>
<td>C.</td>
<td>2</td>
<td>1 mol</td>
</tr>
<tr>
<td>D.</td>
<td>2</td>
<td>2 mol</td>
</tr>
</tbody>
</table>

Answer: D
Outcome: B1.7k
Use the following information to answer numerical-response question 2 and question 16.

Two species that are important to biological cells are NAD\(^+\)(aq), a biological oxidizing agent, and NADH(aq), a biological reducing agent. Two half-reactions that occur are represented by the equations below.

**Equation I** \[ \text{O}_2(aq) + 4 \text{H}^+(aq) + 4 \text{e}^- \rightarrow 2 \text{H}_2\text{O}(l) \]

**Equation II** \[ \text{NADH}(aq) \rightarrow \text{NAD}^+(aq) + \text{H}^+(aq) + 2 \text{e}^- \]

### Numerical Response

2. When the net ionic equation is balanced with the lowest possible whole numbers, the coefficient for

- \( \text{O}_2(aq) \) is \[ \underline{\text{________}} \] (Record in the **first** column)
- \( \text{H}^+(aq) \) is \[ \underline{\text{________}} \] (Record in the **second** column)
- \( \text{NADH}(aq) \) is \[ \underline{\text{________}} \] (Record in the **third** column)
- \( \text{H}_2\text{O}(l) \) is \[ \underline{\text{________}} \] (Record in the **fourth** column)

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

Answer: 1222

Outcome: B1.7k, B1.3s
Other important chemical species are also found in biological cells. A student collected the following data when studying the reactions of several of these species.

$$
\begin{array}{|c|c|c|c|}
\hline
 & Cu^{2+} \text{cytochrome} & Fe^{3+} \text{ferredoxin} & NAD^+(aq) + H^+(aq) & O_2(g) + H^+(aq) \\
\hline
Cu^{+} \text{cytochrome} & \text{—} & \checkmark & \times & \checkmark \\
Fe^{2+} \text{ferredoxin} & \times & \text{—} & \times & \checkmark \\
NADH(aq) & \checkmark & \checkmark & \text{—} & \checkmark \\
H_2O(l) & \times & \times & \times & \text{—} \\
\hline
\end{array}
$$

\(\checkmark\) = evidence of a spontaneous reaction  
\(\times\) = no evidence of a reaction  
\(\text{—}\) = no experiment performed

16. When the reducing agents are listed from strongest to weakest, the order is

A. \(NAD^+(aq) + H^+(aq), \ Cu^{2+} \text{cytochrome}, \ Fe^{3+} \text{ferredoxin}, \ O_2(g) + H^+(aq)\)

B. \(O_2(g) + H^+(aq), \ Fe^{3+} \text{ferredoxin}, \ Cu^{2+} \text{cytochrome}, \ NAD^+(aq) + H^+(aq)\)

C. \(H_2O(l), \ Fe^{2+} \text{ferredoxin}, \ Cu^{+} \text{cytochrome}, \ NADH(aq)\)

D. \(NADH(aq), \ Cu^{+} \text{cytochrome}, \ Fe^{2+} \text{ferredoxin}, \ H_2O(l)\)

Answer: D  
Outcome: B1.5k, B1.3s
Use the following information to answer questions 17 and 18.

High levels of nitrite ions, \( \text{NO}_2^- \) (aq), in drinking water are a health concern. The concentration of nitrite ions can be determined by titrating acidified samples of drinking water with potassium permanganate, as represented by the following equation.

\[
2 \text{MnO}_4^- (aq) + 5 \text{NO}_2^- (aq) + 6 \text{H}^+ (aq) \rightarrow 2 \text{Mn}^{2+} (aq) + 5 \text{NO}_3^- (aq) + 3 \text{H}_2\text{O}(l)
\]

An average of 21.6 mL of 0.0300 mol/L KMnO\(_4\) (aq) was required to react completely with the \( \text{NO}_2^- \) (aq) in 25.0 mL samples of drinking water.

17. When the incomplete half-reaction \( \text{NO}_2^- (aq) \rightarrow \text{NO}_3^- (aq) \) is balanced in acidic conditions, \( \text{H}_2\text{O}(l) \) will appear in the equation as a \( i \), and the equation will represent \( ii \) half-reaction.

The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>( i )</th>
<th>( ii )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>product</td>
<td>a reduction</td>
</tr>
<tr>
<td>B.</td>
<td>product</td>
<td>an oxidation</td>
</tr>
<tr>
<td>C.</td>
<td>reactant</td>
<td>a reduction</td>
</tr>
<tr>
<td>D.</td>
<td>reactant</td>
<td>an oxidation</td>
</tr>
</tbody>
</table>

Answer: D
Outcome: B1.1k, B1.7k, B1.1sts

18. The experimental concentration of \( \text{NO}_2^- \) (aq) in the drinking water was

- A. \( 1.04 \times 10^{-2} \) mol/L
- B. \( 2.59 \times 10^{-2} \) mol/L
- C. \( 3.47 \times 10^{-2} \) mol/L
- D. \( 6.48 \times 10^{-2} \) mol/L

Answer: D
Outcome: B1.8k, B1.4s, B1.1sts
Use the following information to answer question 19.

A standardized 0.125 mol/L potassium dichromate solution, $K_2Cr_2O_7$ (aq), was used to titrate 20.0 mL samples of acidified $Sn^{2+}$ (aq). The data is represented in the following table.

<table>
<thead>
<tr>
<th>Trial</th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Final burette volume (mL)</td>
<td>15.35</td>
<td>27.65</td>
<td>39.85</td>
</tr>
<tr>
<td>Initial burette volume (mL)</td>
<td>3.25</td>
<td>15.35</td>
<td>27.65</td>
</tr>
</tbody>
</table>

19. The concentration of $Sn^{2+}$ (aq) in the sample is

A. 0.0254 mol/L
B. 0.0763 mol/L
C. 0.229 mol/L
D. 0.615 mol/L

Answer: C
Outcome: B1.8k, B1.4s
Use the following information to answer question 20.

The Statue of Liberty is located on an island in New York Harbour which is surrounded by the Atlantic Ocean. The statue, which has a skin made of copper that is supported by iron ribs, has undergone many attempts to repair the damage caused by the corrosion of the iron ribs. Recently, the iron ribs have been replaced with stainless steel alloys, which resist corrosion.

20. The corrosion of the Statue of Liberty occurred because the metal that was most readily oxidized was ______, and the oxidation process caused this metal to act as ______.

The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>i</th>
<th>ii</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>iron</td>
<td>an anode</td>
</tr>
<tr>
<td>B.</td>
<td>iron</td>
<td>a cathode</td>
</tr>
<tr>
<td>C.</td>
<td>copper</td>
<td>an anode</td>
</tr>
<tr>
<td>D.</td>
<td>copper</td>
<td>a cathode</td>
</tr>
</tbody>
</table>

Answer: A
Outcome: B1.6k, B1.1sts
21. Which of the following rows identifies the direction the electrons would flow and the direction the anions would flow?

<table>
<thead>
<tr>
<th>Row</th>
<th>Direction Electrons Would Flow</th>
<th>Direction Anions Would Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>From the C(s) electrode to the Cu(s) electrode</td>
<td>Toward the Cu(s) electrode</td>
</tr>
<tr>
<td>B.</td>
<td>From the C(s) electrode to the Cu(s) electrode</td>
<td>Away from the Cu(s) electrode</td>
</tr>
<tr>
<td>C.</td>
<td>From the Cu(s) electrode to the C(s) electrode</td>
<td>Toward the Cu(s) electrode</td>
</tr>
<tr>
<td>D.</td>
<td>From the Cu(s) electrode to the C(s) electrode</td>
<td>Away from the Cu(s) electrode</td>
</tr>
</tbody>
</table>

Answer: C
Outcome: B2.1k, B2.2s
Use the following information to answer question 22 and numerical-response question 3.

Pure aluminium metal can be extracted from aluminium oxide, $\text{Al}_2\text{O}_3(\text{l})$, through the process of electrolysis. A technician sets up an electrochemical cell to produce aluminium, $\text{Al}(\text{s})$. Two rods made of graphite, $\text{C}(\text{s})$, are used for the electrodes, and a current is applied to the cell. The reaction that occurs in the cell is represented by the equation below.

$$3\text{C}(\text{s}) + 2\text{Al}_2\text{O}_3(\text{l}) \rightarrow 4\text{Al}(\text{s}) + 3\text{CO}_2(\text{g})$$

22. Which of the following rows identifies the type of reaction that occurs in the cell and the sign of the cell potential of the cell constructed by the technician?

<table>
<thead>
<tr>
<th>Row</th>
<th>Type of Reaction</th>
<th>Sign of the Cell Potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>Spontaneous</td>
<td>Positive</td>
</tr>
<tr>
<td>B.</td>
<td>Spontaneous</td>
<td>Negative</td>
</tr>
<tr>
<td>C.</td>
<td>Nonspontaneous</td>
<td>Positive</td>
</tr>
<tr>
<td>D.</td>
<td>Nonspontaneous</td>
<td>Negative</td>
</tr>
</tbody>
</table>

Answer: D
Outcome: B2.2k, B2.6k, B2.2sts
Use the following additional information to answer numerical-response question 3.

Eight Statements Regarding the Anode

1. It is a graphite rod.
2. It is a strip of aluminium.
3. Electrons move toward it.
4. Electrons move away from it.
5. Anions migrate toward it.
6. Cations migrate toward it.
7. It is the site where Al(s) is produced.
8. It is the site where CO$_2$(g) is produced.

Numerical Response

3. The statements above that describe the anode in the cell constructed by the technician are numbered _____, _____, _____, and _____.

(Record all four digits of your answer in any order in the numerical-response section on the answer sheet.)

Answer: 1458, any order
Outcome: B2.1k, B2.3k, B2.3s, B2.2sts
Use the following information to answer numerical-response question 4.

<table>
<thead>
<tr>
<th>Seven Statements About Electrochemical Cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Oxidation occurs at the anode.</td>
</tr>
<tr>
<td>2 The oxidizing agent reacts at the cathode.</td>
</tr>
<tr>
<td>3 Cations move through the wire to the cathode.</td>
</tr>
<tr>
<td>4 Cations move through the electrolyte to the cathode.</td>
</tr>
<tr>
<td>5 Electrons move through the wire to the cathode.</td>
</tr>
<tr>
<td>6 Electrical energy is converted to chemical energy.</td>
</tr>
<tr>
<td>7 Chemical energy is converted to electrical energy.</td>
</tr>
</tbody>
</table>

**Numerical Response**

4. The statements numbered above that apply to both electrolytic cells and voltaic cells are _____, _____, _____, and _____.

(Record all four digits of your answer in any order in the numerical-response section on the answer sheet.)

Answer: 1245, any order
Outcome: B2.2k
Use the following information to answer question 23.

23. The net ionic equation for the reaction that occurs in the electrochemical cell shown in the diagram above is

A. \( \text{Sn}(s) + 2 \text{Pb}^{2+}(aq) \rightarrow \text{Sn}^{4+}(aq) + 2 \text{Pb}(s) \)
B. \( \text{Sn}(s) + \text{Pb}^{2+}(aq) \rightarrow \text{Sn}^{2+}(aq) + \text{Pb}(s) \)
C. \( \text{Sn}^{4+}(aq) + 2 \text{Pb}(s) \rightarrow \text{Sn}(s) + 2 \text{Pb}^{2+}(aq) \)
D. \( \text{Sn}^{2+}(aq) + \text{Pb}(s) \rightarrow \text{Sn}(s) + \text{Pb}^{2+}(aq) \)

Answer: B
Outcome: B2.3k, B2.3s
Use the following information to answer question 24.

<table>
<thead>
<tr>
<th>Electrochemical Cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>C(s)</td>
</tr>
</tbody>
</table>

24. If the standard lead half-cell had been chosen as the reference half-cell instead of the standard hydrogen half-cell, then the cell potential for the electrochemical cell above would be

A. +0.15 V  
B. +0.28 V  
C. +0.65 V  
D. +0.78 V  

Answer: A  
Outcome: B2.5k, B2.6k
Use the following information to answer numerical-response question 5.

The cell potential for the electrochemical cell in the diagram above is +/– _________ V.

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

Answer: 1.33
Outcome: B2.6k
Use the following information to answer numerical-response question 8.

A student designs an experiment that requires an electrochemical cell that uses a silver electrode and that produces an electrical potential of at least 1.20 V. The direction of electron flow is from metal electrode A to metal electrode B. The design is shown in the diagram below.

**Available Materials**

1. Silver metal, Ag(s)  
2. Nickel metal, Ni(s)  
3. Zinc metal, Zn(s)  
4. Iron metal, Fe(s)  
5. Nickel(II) nitrate solution, Ni(NO₃)₂(aq)  
6. Silver nitrate solution, AgNO₃(aq)  
7. Zinc nitrate solution, Zn(NO₃)₂(aq)  
8. Iron(II) nitrate solution, Fe(NO₃)₂(aq)  
9. Sodium nitrate solution, NaNO₃(aq)
Use the following information to answer question 25.

The reduction half-reaction for a Hall–Héroult electrolytic cell is represented by the following equation.

\[ \text{Al}^{3+}(l) + 3 \text{e}^- \rightarrow \text{Al}(l) \]

25. If a current of 10.0 A is applied for 5.00 h to the Hall–Héroult electrolytic cell, then the amount of electrons transferred is

A. 5.60 mol  
B. 1.87 mol  
C. $6.22 \times 10^{-1}$ mol  
D. $5.18 \times 10^{-4}$ mol

Answer: B  
Outcome: B2.8k, B2.4s
An electrolytic cell is used to produce molten aluminium from molten aluminium oxide, as represented by the simplified equation below.

\[ 2 \text{Al}_2\text{O}_3(\text{l}) \rightarrow 4 \text{Al(1)} + 3 \text{O}_2(\text{g}) \]

26. If a current of $5.00 \times 10^4$ A were applied to the electrolytic cell for 5.00 h, then the predicted mass of aluminium produced would be

A. $9.33 \times 10^3$ g
B. $8.39 \times 10^4$ g
C. $2.52 \times 10^5$ g
D. $7.55 \times 10^5$ g

Answer: B
Outcome: B2.8k, B2.4s, B2.1sts
Use the following information to answer numerical-response question 1.

Eight Chemical Compounds

1. CO₂(g)  
2. CH₃OH(l)  
3. H₂CO₃(aq)  
4. ClCH₃(l)  
5. Co(OH)₂(s)  
6. NaCN(s)  
7. CH₃COOCH₃(aq)  
8. HCOOH(l)

Numerical Response

1. The chemical compounds numbered above that represent organic compounds are _____, _____, _____, and _____.

   (Record all four digits of your answer in any order in the numerical-response section on the answer sheet.)

   Answer: 2478, any order
   Outcome: C1.1k
Many gaseous compounds have been classified as air pollutants.

**Eight Air Pollutants**

1. ICN(g)
2. CO(g)
3. CH₄(g)
4. CCl₂F₂(g)
5. NH₃(g)
6. CH₂O(g)
7. CO₂(g)
8. C₈H₁₀(g)

**Numerical Response**

2. The air pollutants above that would be classified as organic compounds are numbered _____, _____, _____, and _____.

(Record all **four digits** of your answer in any order in the numerical-response section on the answer sheet.)

Answer: 3468, any order
Outcome: C1.1k
1. Which of the following rows identifies the structural diagram and the corresponding IUPAC name of the compound with the chemical formula \( \text{C}_8\text{H}_{16}(\ell) \)?

<table>
<thead>
<tr>
<th>Row</th>
<th>Structural Diagram</th>
<th>IUPAC Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td><img src="image.png" alt="Structural Diagram A" /></td>
<td>ethylbenzene</td>
</tr>
<tr>
<td>B.</td>
<td><img src="image.png" alt="Structural Diagram B" /></td>
<td>ethylcyclohexane</td>
</tr>
<tr>
<td>C.</td>
<td><img src="image.png" alt="Structural Diagram C" /></td>
<td>cyclopentylpropane</td>
</tr>
<tr>
<td>D.</td>
<td><img src="image.png" alt="Structural Diagram D" /></td>
<td>propylcyclopentene</td>
</tr>
</tbody>
</table>

Answer: B
Outcome: C1.3k, C1.3s

Use the following information to answer question 2.

**Condensed Structural Diagram**

```
CH₃
CH – CH₂ – CH – CH – CH₃
\text{CH₃} \quad \text{OH} \quad \text{OH}
```

2. The IUPAC name for the organic molecule represented by the diagram above is

A. 2-methylhexane-4,5-diol
B. 5-methylhexane-2,3-diol
C. 1,1-dimethylpentane-3,4-diol
D. 5,5-dimethylpentane-2,3-diol

Answer: B
Outcome: C1.3k, C1.3s
Use the following information to answer numerical-response question 3.

**Six Models of Organic Molecules**

1.  
2.  
3.  
4.  
5.  
6.  

<table>
<thead>
<tr>
<th>Legend</th>
<th></th>
</tr>
</thead>
</table>
|        | num
| Hydrogen |  |
| Carbon  |  |
| Oxygen  |  |
| Halogen |  |

**Numerical Response**

3. Match the molecular models numbered above with the descriptions below.

- Unbranched alkane
- Cyclic alkane
- Halogenated hydrocarbon
- Alcohol

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

Answer: 2135  
Outcome: C1.3k, C1.4k, C1.2s
Use the following information to answer question 3.

A student added a bromine solution, Br₂(aq), to a hydrocarbon sample that contains an isomer of C₆H₁₂(l). After shaking the sample, the student observed that the colour of the bromine solution changed from orange-brown to colourless.

3. An interpretation that could be made from the student’s observation is that the hydrocarbon sample is _____i_____ and the IUPAC name of the sample could be _____ii_____.

The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>i</th>
<th>ii</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>saturated</td>
<td>hex-2-ene</td>
</tr>
<tr>
<td>B.</td>
<td>saturated</td>
<td>cyclohexane</td>
</tr>
<tr>
<td>C.</td>
<td>unsaturated</td>
<td>hex-2-ene</td>
</tr>
<tr>
<td>D.</td>
<td>unsaturated</td>
<td>cyclohexane</td>
</tr>
</tbody>
</table>

Answer: C
Outcome: C1.3k, C1.5k, C1.3s
Use the following information to answer question 4.

Sodium fluoroethanoate, NaCH$_2$FCOO(aq), is a potent metabolic poison that can be used to kill rodents. The conjugate acid of the fluoroethanoate ion is fluoroethanoic acid, CH$_2$FCOOH(aq).

**Fluoroethanoic Acid**

\[
\begin{align*}
\text{H} & \\
\text{H - C - C} & \text{\(^\circ\) O} \\
\text{F} & \text{O - H}
\end{align*}
\]

**Structure**

- **I** Methyl
- **II** Carboxyl
- **III** Ester linkage
- **IV** Halogen

4. The structure(s) numbered above found in fluoroethanoic acid is/are

- **A.** I and II
- **B.** II only
- **C.** II and IV
- **D.** III and IV

Answer: C
Outcome: C1.4k, C1.1sts
5. Which of the following rows identifies three classifications of the organic compound represented above?

<table>
<thead>
<tr>
<th>Row</th>
<th>Classification One</th>
<th>Classification Two</th>
<th>Classification Three</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>Aromatic</td>
<td>Carboxyl</td>
<td>Alkene</td>
</tr>
<tr>
<td>B.</td>
<td>Aromatic</td>
<td>Hydroxyl</td>
<td>Ester</td>
</tr>
<tr>
<td>C.</td>
<td>Aliphatic</td>
<td>Carboxyl</td>
<td>Alkene</td>
</tr>
<tr>
<td>D.</td>
<td>Aliphatic</td>
<td>Hydroxyl</td>
<td>Ester</td>
</tr>
</tbody>
</table>

Answer: B
Outcome: C1.3k, C1.4k, C1.1sts
6. Which of the following rows identifies a structural diagram and the IUPAC name of an isomer of C₆H₁₂?

<table>
<thead>
<tr>
<th>Row</th>
<th>Condensed Structural Diagram or Line Diagram</th>
<th>IUPAC Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>![Methylcyclopentane Diagram]</td>
<td>Methylcyclopentane</td>
</tr>
<tr>
<td>B.</td>
<td>![Cyclohexene Diagram]</td>
<td>Cyclohexene</td>
</tr>
<tr>
<td>C.</td>
<td>![3-methylpent-3-ene Diagram]</td>
<td>3-methylpent-3-ene</td>
</tr>
<tr>
<td>D.</td>
<td>![Hex-3-yne Diagram]</td>
<td>Hex-3-yne</td>
</tr>
</tbody>
</table>

Answer: A
Outcome: C1.3k, C1.5k, C1.3s
7. When a mixture of dodecane, $C_{12}H_{26}(l)$, and hexadecane, $C_{16}H_{34}(l)$, is heated in the tower, the hydrocarbon that will condense at a lower collection point in the tower is __i__ because its boiling point is __ii__.

The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>i</th>
<th>ii</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>hexadecane</td>
<td>lower</td>
</tr>
<tr>
<td>B.</td>
<td>hexadecane</td>
<td>higher</td>
</tr>
<tr>
<td>C.</td>
<td>dodecane</td>
<td>lower</td>
</tr>
<tr>
<td>D.</td>
<td>dodecane</td>
<td>higher</td>
</tr>
</tbody>
</table>

Answer: B
Outcome: C1.7k
Use the following information to answer question 8.

o–Xylene can be used industrially to remove paraffin wax from pipes. The line diagram for o–xylene is given below.

8. o–Xylene is classified as an _____ i _____ compound, and its solubility in water is expected to be _____ ii _____.

The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>i</th>
<th>ii</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>aliphatic</td>
<td>high</td>
</tr>
<tr>
<td>B.</td>
<td>aliphatic</td>
<td>low</td>
</tr>
<tr>
<td>C.</td>
<td>aromatic</td>
<td>high</td>
</tr>
<tr>
<td>D.</td>
<td>aromatic</td>
<td>low</td>
</tr>
</tbody>
</table>

Answer: D
Outcome: C1.3k, C1.6k, C1.2sts
Use the following information to answer numerical-response question 4.

<table>
<thead>
<tr>
<th>Four Common Organic Equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  $\text{C}_2\text{H}_4(\text{g}) + \text{H}_2(\text{g}) \rightarrow \text{C}_2\text{H}_6(\text{g})$</td>
</tr>
<tr>
<td>2  $\text{C}_2\text{H}_5\text{OH}(\text{l}) \rightarrow \text{C}_2\text{H}_4(\text{g}) + \text{H}_2\text{O}(\text{l})$</td>
</tr>
<tr>
<td>3  $\text{C}_6\text{H}_6(\text{l}) + \text{Br}_2(\text{l}) \rightarrow \text{C}_6\text{H}_5\text{Br}(\text{l}) + \text{HBr}(\text{g})$</td>
</tr>
<tr>
<td>4  $\text{CH}_3\text{COOH}(\text{l}) + \text{CH}_3\text{OH}(\text{l}) \rightarrow \text{CH}_3\text{COOCH}_3(\text{l}) + \text{H}_2\text{O}(\text{l})$</td>
</tr>
</tbody>
</table>

**Numerical Response**

4. Match each equation numbered above with the corresponding reaction type below. (Use each number only once.)

Addition  __________ (Record in the **first** column)
Substitution __________ (Record in the **second** column)
Elimination __________ (Record in the **third** column)
Esterification __________ (Record in the **fourth** column)

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

Answer: 1324
Outcome: C2.1k
Use the following information to answer questions 9 and 10.

**Four Equations**

<table>
<thead>
<tr>
<th>Row</th>
<th>Reactant with Lowest Boiling Point</th>
<th>Product with Highest Boiling Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>$\text{C}_2\text{H}_6(g)$</td>
<td>$\text{C}_2\text{H}_4(g) + \text{H}_2(g)$</td>
</tr>
<tr>
<td>II</td>
<td>$\text{C}_2\text{H}_5\text{OH}(l)$</td>
<td>$\text{C}_2\text{H}_4(g) + \text{H}_2\text{O}(l)$</td>
</tr>
<tr>
<td>III</td>
<td>$\text{C}_2\text{H}_6(g) + \text{Cl}_2(g)$</td>
<td>$\text{C}_2\text{H}_5\text{Cl}(g) + \text{HCl}(g)$</td>
</tr>
<tr>
<td>IV</td>
<td>$\text{CH}_3\text{COOH}(l) + \text{C}_2\text{H}_5\text{OH}(l)$</td>
<td>$\text{CH}_3\text{COOC}_2\text{H}_5(l) + \text{H}_2\text{O}(l)$</td>
</tr>
</tbody>
</table>

9. Which of the following rows identifies the equations that contain the organic reactant with the lowest boiling point and the organic product with the highest boiling point?

<table>
<thead>
<tr>
<th>Row</th>
<th>Reactant with Lowest Boiling Point</th>
<th>Product with Highest Boiling Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>I</td>
<td>II</td>
</tr>
<tr>
<td>B.</td>
<td>IV</td>
<td>III</td>
</tr>
<tr>
<td>C.</td>
<td>IV</td>
<td>I</td>
</tr>
<tr>
<td>D.</td>
<td>III</td>
<td>IV</td>
</tr>
</tbody>
</table>

Answer: D
Outcome: C1.6k

10. An elimination reaction is represented by Equation

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

Answer: A
Outcome: C2.1k
Use the following information to answer numerical-response question 5.

Below are two methods for chemically producing ethanol.

**Method I**

\[
\text{Possible reactant} + \text{NaOH(aq)} \rightarrow H-\overset{\text{C}}{\text{C}}-\overset{\text{O}}{\text{C}}-H + \text{NaI(aq)}
\]

**Method II**

\[
\text{Possible reactant} + \text{HOH(l)} \rightarrow H-\overset{\text{C}}{\text{C}}-\overset{\text{O}}{\text{C}}-H
\]

<table>
<thead>
<tr>
<th>Possible Reactants</th>
<th>Possible Reaction Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (\overset{\text{H}}{\text{H}}) (\overset{\text{H}}{\text{H}}) (\overset{\text{H}}{\text{H}}) (\overset{\text{H}}{\text{H}}) (\overset{\text{H}}{\text{H}}) (\overset{\text{H}}{\text{H}})</td>
<td>5 Addition</td>
</tr>
<tr>
<td>2 (\overset{\text{H}}{\text{H}}) (\overset{\text{H}}{\text{H}}) (\overset{\text{H}}{\text{H}}) (\overset{\text{H}}{\text{H}})</td>
<td>6 Substitution</td>
</tr>
<tr>
<td>3 (\overset{\text{H}}{\text{H}}) (\overset{\text{H}}{\text{H}}) (\overset{\text{H}}{\text{H}}) (\overset{\text{H}}{\text{H}})</td>
<td>7 Elimination</td>
</tr>
<tr>
<td>4 (\overset{\text{H}}{\text{H}}) (\overset{\text{H}}{\text{H}}) (\overset{\text{H}}{\text{H}}) (\overset{\text{H}}{\text{H}}) (\overset{\text{H}}{\text{H}})</td>
<td>8 Condensation</td>
</tr>
</tbody>
</table>
**Numerical Response**

5. Match the numbers above with the descriptions below to identify the possible reactants and reaction types for Method I and Method II.

The reactant in Method I is numbered __________ (Record in the first column)

The reaction type of Method I is numbered __________ (Record in the second column)

The reactant in Method II is numbered __________ (Record in the third column)

The reaction type of Method II is numbered __________ (Record in the fourth column)

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

Answer: 4625
Outcome: C2.1k, C2.2k

11. When methanol and ethanoic acid react, the product(s) is/are

A. ethyl methanoate only
B. methyl ethanoate only
C. ethyl methanoate and water
D. methyl ethanoate and water

Answer: D
Outcome: C2.2k, C2.1s

12. The type of reaction that occurs when ethene gas and chlorine gas react is _____i____, and the name of the organic compound produced is _____ii____.

The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>i</th>
<th>ii</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>addition</td>
<td>1,2-dichloroethane</td>
</tr>
<tr>
<td>B.</td>
<td>addition</td>
<td>1-chloroethene</td>
</tr>
<tr>
<td>C.</td>
<td>substitution</td>
<td>1,2-dichloroethane</td>
</tr>
<tr>
<td>D.</td>
<td>substitution</td>
<td>1-chloroethene</td>
</tr>
</tbody>
</table>

Answer: A
Outcome: C2.1k, C2.2k
Use the following information to answer questions 13 and 14.

Many esters are responsible for the odour and taste of fruits such as apricots, pears, and pineapples. The line diagram for one of these molecules is shown below.

13. A structural isomer of the ester represented above is
   A. ethyl octanoate
   B. methyl heptanoate
   C. 2-methyloctanoic acid
   D. 3-propylheptanoic acid

Answer: C
Outcome: C1.3k, C1.5k, C1.3s

14. Which of the following rows contains the structural diagrams of the reactants necessary to produce the ester represented above?

<table>
<thead>
<tr>
<th>Row</th>
<th>Structural Diagrams</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td><img src="image" alt="Diagram A" /></td>
</tr>
<tr>
<td>B.</td>
<td><img src="image" alt="Diagram C" /></td>
</tr>
<tr>
<td>C.</td>
<td><img src="image" alt="Diagram E" /></td>
</tr>
<tr>
<td>D.</td>
<td><img src="image" alt="Diagram G" /></td>
</tr>
</tbody>
</table>

Answer: A
Outcome: C2.2k, C2.3s
Use the following information to answer question 15.

Certain bacteria manufacture an organic polymer to store energy. The structural diagram that represents a segment of this polymer is given below.

\[
\begin{array}{c}
\text{O} \\
\text{C} \\
\text{O} \\
\end{array}
\]

15. *The monomer that makes up this polymer contains a ___i____, and the structure of this polymer closely resembles the structure of the polymer found in ___ii____.*

The statement above is completed by the information in row ___i___.

<table>
<thead>
<tr>
<th>Row</th>
<th>i</th>
<th>ii</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>carbon–carbon double bond</td>
<td>polyester</td>
</tr>
<tr>
<td>B.</td>
<td>carbon–carbon double bond</td>
<td>polypropene</td>
</tr>
<tr>
<td>C.</td>
<td>carboxyl and a hydroxyl functional group</td>
<td>polyester</td>
</tr>
<tr>
<td>D.</td>
<td>carboxyl and a hydroxyl functional group</td>
<td>polypropene</td>
</tr>
</tbody>
</table>

Answer: C  
Outcome: C2.3k, C2.3s

Use the following information to answer question 16.

\[
\begin{array}{c}
\text{CH}_2\text{–CH} \\
\text{Cl} \\
\end{array}
\]

16. Which of the following monomers is required to produce the polymer in the structural diagram above?

A.  \(\text{CH}_2\text{–Cl–CH}_2\text{–Cl}\)  
B.  \(\text{CH}_3\text{–CH}_2\text{–Cl}\)  
C.  \(\text{CH}_2\text{=CHCl}\)  
D.  \(\text{CH≡CCl}\)

Answer: C  
Outcome: C2.3k, C2.3s
Use the following information to answer question 1.

\[
\text{N}_2\text{O}_4(\text{g}) + \text{heat} \rightleftharpoons 2 \text{NO}_2(\text{g})
\]

| colourless   | brown           |

1. Which of the following properties would not be used to determine if the equilibrium system represented by the equation above is at equilibrium?

A. Temperature  
B. Pressure  
C. Colour  
D. Mass

Answer: D  
Outcome: D1.1k

2. When applied to an equilibrium system, which of the following stresses would cause a change in the \( K_c \) value after the equilibrium has been re-established?

A. Addition of a catalyst  
B. Decrease in temperature by cooling the system  
C. Addition of an inert gas to increase the pressure  
D. Decrease in concentration by removing a product

Answer: B  
Outcome: D1.3k
Use the following information to answer numerical-response question 1.

\[ 2 \text{NO}_2(g) \rightleftharpoons \text{N}_2\text{O}_4(g) + \text{heat} \]

\text{brown} \quad \text{colourless}

**Stresses Applied to an Equilibrium System**

1. Increase volume
2. Decrease volume
3. Increase temperature
4. Decrease temperature
5. Increase \text{NO}_2(g)\text{ concentration}
6. Decrease \text{NO}_2(g)\text{ concentration}
7. Increase \text{N}_2\text{O}_4(g)\text{ concentration}
8. Decrease \text{N}_2\text{O}_4(g)\text{ concentration}

**Numerical Response**

1. The stresses numbered above that will cause the equilibrium system to shift toward the reactants are \(\), \(\), \(\), and \(\).

(Record all **four digits** of your answer **in any order** in the numerical-response section on the answer sheet.)

Answer: 1367, any order
Outcome: D1.3k, D1.3s
Use the following information to answer question 3.

\[ \text{HNO}_2(\text{aq}) + \text{H}_2\text{O}(\ell) \rightleftharpoons \text{H}_3\text{O}^+(\text{aq}) + \text{NO}_2^-\text{(aq)} \quad K_a = 5.6 \times 10^{-4} \]

3. Which of the following rows identifies the equilibrium-law expression and compares the amount of products and reactants present at equilibrium?

<table>
<thead>
<tr>
<th>Row</th>
<th>Equilibrium-law Expression</th>
<th>Equilibrium Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>[ K_a = \frac{[\text{H}_3\text{O}^+(\text{aq})][\text{NO}_2^-\text{(aq)}]}{[\text{HNO}_2\text{(aq)}]} ]</td>
<td>Amount of products is less than the amount of reactants</td>
</tr>
<tr>
<td>B.</td>
<td>[ K_a = \frac{[\text{H}_3\text{O}^+(\text{aq})][\text{NO}_2^-\text{(aq)}]}{[\text{HNO}_2\text{(aq)}]} ]</td>
<td>Amount of products is greater than the amount of reactants</td>
</tr>
<tr>
<td>C.</td>
<td>[ K_a = \frac{[\text{H}_3\text{O}^+(\text{aq})][\text{NO}_2^-\text{(aq)}]}{[\text{HNO}_2\text{(aq)}][\text{H}_2\text{O}(\ell)]} ]</td>
<td>Amount of products is less than the amount of reactants</td>
</tr>
<tr>
<td>D.</td>
<td>[ K_a = \frac{[\text{H}_3\text{O}^+(\text{aq})][\text{NO}_2^-\text{(aq)}]}{[\text{HNO}_2\text{(aq)}][\text{H}_2\text{O}(\ell)]} ]</td>
<td>Amount of products is greater than the amount of reactants</td>
</tr>
</tbody>
</table>

Answer: A
Outcome: D1.4k, D1.3s
Use the following information to answer numerical-response question 2 and question 4.

When samples of CO(g) and H₂O(g) are added to an empty reaction container, the system at equilibrium is represented by the following equilibrium equation.

\[
\text{CO(g)} + \text{H}_2\text{O(g)} \rightleftharpoons \text{CO}_2(g) + \text{H}_2(g) \quad K_c = 4.2
\]

**Statements About Equilibrium Systems**

1. There are more moles of products present than moles of reactants.
2. There are more moles of reactants present than moles of products.
3. Less than 50% of the reactants will be converted to products.
4. More than 50% of the reactants will be converted to products.
5. The system could be represented by the following diagram.

6. The system could be represented by the following diagram.

---

**Numerical Response**

2. The statements that apply to the equilibrium system above are numbered _____, _____, and _____.

(Record all three digits of your answer in any order in the numerical-response section on the answer sheet.)

Answer: 145, any order
Outcome: D1.1k, D1.4k, D1.3s
4. With the addition of a catalyst to the equilibrium system on the previous page, the amount of products present would _____i____. Another stress that would cause the same effect on the amount of products is an _____ii____.

The statements above are completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>i</th>
<th>ii</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>increase</td>
<td>increase in the volume</td>
</tr>
<tr>
<td>B.</td>
<td>increase</td>
<td>addition of CO(g)</td>
</tr>
<tr>
<td>C.</td>
<td>not change</td>
<td>increase in the volume</td>
</tr>
<tr>
<td>D.</td>
<td>not change</td>
<td>addition of CO(g)</td>
</tr>
</tbody>
</table>

Answer: C
Outcome: D1.3k, D1.3s

Use the following information to answer question 5.

\[ K_a = \frac{[\text{NO}_2(g)]^2}{[\text{NO}(g)]^2 [\text{O}_2(g)]} \]

5. The equation that is represented by the equilibrium-law expression above is

A. \( 2 \text{NO}_2(g) \rightleftharpoons 2 \text{NO}(g) + \text{O}_2(g) \)
B. \( 2 \text{NO}(g) + \text{O}_2(g) \rightleftharpoons 2 \text{NO}_2(g) \)
C. \( \text{NO}_2(g) \rightleftharpoons \text{NO}(g) + \text{O}_2(g) \)
D. \( \text{NO}(g) + \text{O}_2(g) \rightleftharpoons \text{NO}_2(g) \)

Answer: B
Outcome: D1.4k, D1.3s

Unit D
Chemical Equilibrium
Focusing on Acid–Base Systems
Use the following information to answer numerical-response question 3.

Some oil fractions are treated with hydrogen to remove impurities such as sulfur and nitrogen. The hydrogen needed for this treatment can be produced by the steam-reforming process, represented by the following unbalanced equilibrium equation.

\[ \text{CH}_4(g) + \text{H}_2\text{O}(g) \rightleftharpoons \text{H}_2(g) + \text{CO}_2(g) \]

Equilibrium-law Expression

\[ K_c = \frac{[W]^w[X]^x}{[Y]^y[Z]^z} \]

**Numerical Response**

3. When the reactants and products are entered into the equilibrium-law expression above, the values of the exponents \( w, x, y, \) and \( z \) are ___ , ___ , ___ , and ___ .

(Record all four digits of your answer in the numerical-response section on the answer sheet.)

Answer: 4112, 4121, 1412, 1421
Outcome: D1.4k, D1.3s

6. Which of the following substances can act as a Brønsted–Lowry base?

A. NaCl(aq)
B. CH₃OH(aq)
C. HCOOH(aq)
D. NaHCO₃(aq)

Answer: D
Outcome: D1.5k
Use the following information to answer numerical-response question 4.

A Venn diagram is used to identify the similarities and differences between acids and bases.

Characteristics and Examples of Acids and Bases

1. Water
2. Carbonic acid
3. Sodium carbonate
4. Sodium hydrogen carbonate
5. Can be diprotic
6. Can be monoprotic
7. Accepts protons
8. Donates protons

Numerical Response

4. The characteristics and examples that belong in Section II of the Venn diagram are numbered _____, _____, _____, and _____.

(Record all four digits of your answer in any order in the numerical-response section on the answer sheet.)

Answer: 1456, any order
Outcome: D1.5k, D1.6k, D1.3s
Use the following information to answer question 7.

\[
\text{HCO}_3^-(aq) + \text{HSO}_3^-(aq) \rightleftharpoons \text{H}_2\text{CO}_3(aq) + \text{SO}_3^{2-}(aq)
\]

7. The Brønsted–Lowry acids in the reaction equation above are

A. \(\text{HCO}_3^-(aq)\) and \(\text{HSO}_3^-(aq)\)
B. \(\text{HCO}_3^-(aq)\) and \(\text{H}_2\text{CO}_3(aq)\)
C. \(\text{HSO}_3^-(aq)\) and \(\text{H}_2\text{CO}_3(aq)\)
D. \(\text{HSO}_3^-(aq)\) and \(\text{SO}_3^{2-}(aq)\)

Answer: C
Outcome: D1.5k

8. Which of the following equations represents an equilibrium system that favours the products?

A. \(\text{HOCl}(aq) + \text{HCO}_3^-(aq) \rightleftharpoons \text{OCl}^-(aq) + \text{H}_2\text{CO}_3(aq)\)
B. \(\text{H}_2\text{SO}_3(aq) + \text{Cl}^-(aq) \rightleftharpoons \text{HSO}_3^-(aq) + \text{HCl}(aq)\)
C. \(\text{HF}(aq) + \text{NO}_2^-(aq) \rightleftharpoons \text{F}^-(aq) + \text{HNO}_2(aq)\)
D. \(\text{H}_2\text{S}(aq) + \text{F}^-(aq) \rightleftharpoons \text{HS}^-(aq) + \text{HF}(aq)\)

Answer: C
Outcome: D1.6k

9. Which of the following rows identifies the equilibrium equation and solution colour that would occur when a few drops of phenol red indicator, \(\text{HPr}(aq)/\text{Pr}^-(aq)\), are added to a 100.00 mL sample of 0.50 mol/L nitrous acid?

<table>
<thead>
<tr>
<th>Row</th>
<th>Equilibrium Equation</th>
<th>Solution Colour</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>(\text{HNO}_2(aq) + \text{Pr}^-(aq) \rightleftharpoons \text{NO}_2^-(aq) + \text{HPr}(aq))</td>
<td>Yellow</td>
</tr>
<tr>
<td>B.</td>
<td>(\text{HNO}_2(aq) + \text{Pr}^-(aq) \rightleftharpoons \text{NO}_2^-(aq) + \text{HPr}(aq))</td>
<td>Red</td>
</tr>
<tr>
<td>C.</td>
<td>(\text{HNO}_2(aq) + \text{HPr}(aq) \rightleftharpoons \text{NO}_2^-(aq) + \text{H}_2\text{Pr}^+(aq))</td>
<td>Yellow</td>
</tr>
<tr>
<td>D.</td>
<td>(\text{HNO}_2(aq) + \text{HPr}(aq) \rightleftharpoons \text{NO}_2^-(aq) + \text{H}_2\text{Pr}^+(aq))</td>
<td>Red</td>
</tr>
</tbody>
</table>

Answer: A
Outcome: D1.6
Use the following information to answer question 10.

The following equilibrium system describes a buffer that maintains a constant pH in the intracellular fluid in the body.

\[
\text{H}_2\text{PO}_4^- (aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{HPO}_4^{2-} (aq) + \text{H}_3\text{O}^+ (aq)
\]

10. Which of the following ions would react with this buffer in a reaction that would favour the products?

A. Carbonate ion, \(\text{CO}_3^{2-}(aq)\)
B. Acetate ion, \(\text{CH}_3\text{COO}^- (aq)\)
C. Oxalate ion, \(\text{OOCCOO}^2-(aq)\)
D. Benzoate ion, \(\text{C}_6\text{H}_5\text{COO}^- (aq)\)

Answer: A
Outcome: D1.6k, D1.8k

11. Which of the following substances is an amphiprotic species?

A. \(\text{CH}_4(\text{g})\)
B. \(\text{CH}_3\text{OH}(\text{aq})\)
C. \(\text{CH}_3\text{COO}^- (aq)\)
D. \(\text{HOOC\text{COO}}^- (aq)\)

Answer: D
Outcome: D1.7k
Use the following information to answer question 12.

\[
\text{HNO}_2(\text{aq}) + \text{H}_2\text{BO}_3^- (\text{aq}) \rightleftharpoons \text{NO}_2^- (\text{aq}) + \text{H}_3\text{BO}_3(\text{aq})
\]

12. In the reaction represented by the equation above, an amphiprotic species is \(i\), and a conjugate acid–base pair is \(ii\).

The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>(i)</th>
<th>(ii)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>HNO₂(aq)</td>
<td>HNO₂(aq) and NO₂⁻(aq)</td>
</tr>
<tr>
<td>B</td>
<td>HNO₂(aq)</td>
<td>H₂BO₃⁻(aq) and NO₂⁻(aq)</td>
</tr>
<tr>
<td>C</td>
<td>H₂BO₃⁻(aq)</td>
<td>HNO₂(aq) and NO₂⁻(aq)</td>
</tr>
<tr>
<td>D</td>
<td>H₂BO₃⁻(aq)</td>
<td>H₂BO₃⁻(aq) and NO₂⁻(aq)</td>
</tr>
</tbody>
</table>

Answer: C
Outcome: D1.7k
Isocitric acid, $\text{C}_3\text{H}_5\text{O(COOH)}_3(\text{aq})$, is found in low concentrations in citrus fruits. The equilibrium formed by isocitric acid in solution can be represented by the following equation.

$$\text{C}_3\text{H}_5\text{O(COOH)}_3(\text{aq}) + \text{H}_2\text{O}(l) \rightleftharpoons \text{C}_3\text{H}_5\text{O(COOH)}_2\text{COO}^- (\text{aq}) + \text{H}_3\text{O}^+(\text{aq}) \quad K_a = 5.1 \times 10^{-4}$$

13. Which of the following rows identifies the number of conjugate acid–base pairs and the number of amphiprotic species in the equation above?

<table>
<thead>
<tr>
<th>Row</th>
<th>Number of Conjugate Acid–Base Pairs</th>
<th>Number of Amphiprotic Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>B.</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>C.</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>D.</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Answer: C
Outcome: D1.7k

14. In order to prepare a suitable buffer with a solution of isocitric acid, a student could add ___i___ until the ___ii___.

The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>i</th>
<th>ii</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>$\text{NaC}_3\text{H}_5\text{O(COOH)}_2\text{COO}(aq)$</td>
<td>pH is equal to 7</td>
</tr>
<tr>
<td>B.</td>
<td>$\text{NaC}_3\text{H}_5\text{O(COOH)}_2\text{COO}(aq)$</td>
<td>amount of each component is equal</td>
</tr>
<tr>
<td>C.</td>
<td>$\text{Na}_2\text{C}_3\text{H}_5\text{OCOOH(COO)}_2(aq)$</td>
<td>pH is equal to 7</td>
</tr>
<tr>
<td>D.</td>
<td>$\text{Na}_2\text{C}_3\text{H}_5\text{OCOOH(COO)}_2(aq)$</td>
<td>amount of each component is equal</td>
</tr>
</tbody>
</table>

Answer: B
Outcome: D1.8k
### 15. Which of the following pairs of chemical compounds can act as a buffer system?

A. HCl(aq) and NaOH(aq)  
B. HCl(aq) and H₂SO₄(aq)  
C. CH₃COOH(aq) and HCl(aq)  
D. CH₃COOH(aq) and NaCH₃COO(aq)

Answer: D  
Outcome: D1.8k

### 16. Which of the following rows identifies the direction of the shift in equilibrium and the effect on the pH of the system when a small quantity of hydrochloric acid is added to the equilibrium system above?

<table>
<thead>
<tr>
<th>Row</th>
<th>Direction of Shift</th>
<th>Effect on pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>Toward the products</td>
<td>No change</td>
</tr>
<tr>
<td>B.</td>
<td>Toward the products</td>
<td>Decrease</td>
</tr>
<tr>
<td>C.</td>
<td>Toward the reactants</td>
<td>No change</td>
</tr>
<tr>
<td>D.</td>
<td>Toward the reactants</td>
<td>Decrease</td>
</tr>
</tbody>
</table>

Answer: C  
Outcome: D1.3k, D1.8k, D1.3s
Use the following information to answer numerical-response question 5.

A student was asked to investigate a factor that would affect the value of $K_a$ for a weak acid. The student made the following hypothesis.

*The value of $K_a$ is dependent upon the initial concentration of the weak acid.*

<table>
<thead>
<tr>
<th>Nine Possible Reagents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1   0.10 mol/L HCl(aq)</td>
</tr>
<tr>
<td>2   0.10 mol/L HOCl(aq)</td>
</tr>
<tr>
<td>3   0.10 mol/L HClO₄(aq)</td>
</tr>
<tr>
<td>4   0.20 mol/L HCl(aq)</td>
</tr>
<tr>
<td>5   0.20 mol/L HOCl(aq)</td>
</tr>
<tr>
<td>6   0.20 mol/L HClO₄(aq)</td>
</tr>
<tr>
<td>7   0.30 mol/L HCl(aq)</td>
</tr>
<tr>
<td>8   0.30 mol/L HOCl(aq)</td>
</tr>
<tr>
<td>9   0.30 mol/L HClO₄(aq)</td>
</tr>
</tbody>
</table>

**Numerical Response**

5. The **best** reagents to use to test this hypothesis are numbered ____\_, ____\_, and ____\_.

(Record all **three digits** of your answer in **any order** in the numerical-response section on the answer sheet.)

Answer 258, any order
Outcome: A1.1s
Use the following information to answer question 17.

A student titrated an unknown sample of an aqueous acid with aqueous sodium hydroxide. The student graphed the data as shown in the diagram below.

The graph of the student’s titration data shows the titration of a \( i \) acid with a strong base, and on the graph, buffering occurs at \( ii \).

The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>( i )</th>
<th>( ii )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>strong</td>
<td>region II only</td>
</tr>
<tr>
<td>B.</td>
<td>strong</td>
<td>regions II and IV</td>
</tr>
<tr>
<td>C.</td>
<td>weak</td>
<td>region II only</td>
</tr>
<tr>
<td>D.</td>
<td>weak</td>
<td>regions II and IV</td>
</tr>
</tbody>
</table>

Answer: C  
Outcome: D1.3s
18. If the pH of a solution changes from 2 to 4, then the hydronium ion concentration
   A. is doubled
   B. is halved
   C. increases by a factor of 100
   D. decreases by a factor of 100

Answer: D
Outcome: D2.1k

Numerical Response

6. The hydroxide ion concentration in a solution with a pH of 3.50, expressed in
   scientific notation, is \( a \times 10^{-b} \) mol/L. The values of \( a, b, c, \) and \( d \) are
   \( a, b, c, \) and \( d \).

   (Record all four digits of your answer in the numerical-response section on the answer sheet.)

Answer: 3211
Outcome: D2.1k

Numerical Response

7. The \( K_b \) for the ethanoate ion, \( \text{CH}_3\text{COO}^-\text{(aq)} \), expressed in scientific notation, is \( a \times 10^{-b} \) mol/L.
   The values of \( a, b, c, \) and \( d \) are
   \( a, b, c, \) and \( d \).

   (Record all four digits of your answer in the numerical-response section on the answer sheet.)

Answer: 5610
Outcome: D2.2k
If hydrogen sulfide gas, $\text{H}_2\text{S}(g)$, is released into the atmosphere, it dissolves in atmospheric water to form aqueous hydrosulfuric acid, $\text{H}_2\text{S}(aq)$. The ionization of aqueous hydrosulfuric acid can be represented by the following equilibrium equation.

$$\text{H}_2\text{S}(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{HS}^-(aq) + \text{H}_3\text{O}^+(aq)$$

19. If the concentration of a sample of aqueous hydrosulfuric acid is 0.050 mol/L, then the hydronium ion concentration, $\text{H}_3\text{O}^+(aq)$, is $i$ and the pOH of the solution is $ii$.

The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>$i$</th>
<th>$ii$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>$5.0 \times 10^{-2}$ mol/L</td>
<td>1.30</td>
</tr>
<tr>
<td>B.</td>
<td>$5.0 \times 10^{-2}$ mol/L</td>
<td>9.82</td>
</tr>
<tr>
<td>C.</td>
<td>$6.7 \times 10^{-5}$ mol/L</td>
<td>1.30</td>
</tr>
<tr>
<td>D.</td>
<td>$6.7 \times 10^{-5}$ mol/L</td>
<td>9.82</td>
</tr>
</tbody>
</table>

Answer: D
Outcome: D2.1k, D2.2k, D2.3k
Hydrangea flowers are usually white, but can be pink, purple, or blue. The exact colour depends on the concentration of aluminium ions, \( \text{Al}^{3+}(aq) \), accumulated by the plant. Aluminium occurs naturally in the soil as aluminium hydroxide, \( \text{Al(OH)}_3(s) \), which dissociates in the water in the soil, as represented by the following equilibrium equation.

**Aluminium Hydroxide Equilibrium System**

\[
\text{Al(OH)}_3(s) \rightleftharpoons \text{Al}^{3+}(aq) + 3 \text{OH}^-(aq) + \text{energy} \quad K_c = 4.6 \times 10^{-33}
\]

20. At equilibrium, compared to the rate of the reverse reaction, the rate of the forward reaction is _____ and the pH of the solution over time would _____.

The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>(i)</th>
<th>(ii)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>greater</td>
<td>decrease</td>
</tr>
<tr>
<td>B.</td>
<td>greater</td>
<td>remain constant</td>
</tr>
<tr>
<td>C.</td>
<td>equal</td>
<td>decrease</td>
</tr>
<tr>
<td>D.</td>
<td>equal</td>
<td>remain constant</td>
</tr>
</tbody>
</table>

Answer: D
Outcome: D1.1k
8. The pOH of a solution of aluminium hydroxide was measured to be 4.86. The hydronium ion, H$_3$O$^+$ (aq), concentration of this solution, expressed in scientific notation, is $a.b \times 10^{cd}$. The values of $a$, $b$, $c$, and $d$ are ______, ______, ______, and ______.

(Record all four digits of your answer in the numerical-response section on the answer sheet.)

Answer: 7210
Outcome: D2.2k

Use the following information to answer question 21.

Household bleach contains sodium hypochlorite, which is a weak base with a $K_b$ of $2.5 \times 10^{-7}$. The ionization of sodium hypochlorite can be represented by the following equilibrium equation.

$$\text{OCl}^- (aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{HOCl}(aq) + \text{OH}^- (aq)$$

21. The pOH of a 0.0125 mol/L solution of sodium hypochlorite is

A. 1.90
B. 4.25
C. 8.51
D. 9.75

Answer: B
Outcome: D2.2k
Use the following information to answer questions 22 to 24.

One of the chemicals responsible for the odour of fish is methylamine, CH$_3$NH$_2$(aq). Methylamine is a weak base and reacts with water as represented by the following equation.

\[
\text{CH}_3\text{NH}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{CH}_3\text{NH}_3^+(\text{aq}) + \text{OH}^- (\text{aq})
\]

\[K_b = 4.4 \times 10^{-4}\]

22. Which of the following rows identifies a Brønsted–Lowry base and a conjugate acid–base pair in the equation above?

<table>
<thead>
<tr>
<th>Row</th>
<th>Brønsted–Lowry Base</th>
<th>Conjugate Acid–Base Pair</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>CH$_3$NH$_3^+$ (aq)</td>
<td>H$_2$O(l) and OH$^-$ (aq)</td>
</tr>
<tr>
<td>B.</td>
<td>CH$_3$NH$_3^+$ (aq)</td>
<td>CH$_3$NH$_2$(aq) and OH$^-$ (aq)</td>
</tr>
<tr>
<td>C.</td>
<td>CH$_3$NH$_2$(aq)</td>
<td>H$_2$O(l) and OH$^-$ (aq)</td>
</tr>
<tr>
<td>D.</td>
<td>CH$_3$NH$_2$(aq)</td>
<td>CH$_3$NH$_2$(aq) and OH$^-$ (aq)</td>
</tr>
</tbody>
</table>

Answer: C  
Outcome: D1.5k, D1.7k

23. The value of the $K_a$ for the conjugate acid of methylamine is $i$, and the conjugate acid is classified as $ii$.

The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>$i$</th>
<th>$ii$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>$2.3 \times 10^{-11}$</td>
<td>weak and monoprotic</td>
</tr>
<tr>
<td>B.</td>
<td>$2.3 \times 10^{-11}$</td>
<td>strong and polyprotic</td>
</tr>
<tr>
<td>C.</td>
<td>$4.4 \times 10^{-18}$</td>
<td>weak and monoprotic</td>
</tr>
<tr>
<td>D.</td>
<td>$4.4 \times 10^{-18}$</td>
<td>strong and polyprotic</td>
</tr>
</tbody>
</table>

Answer: A  
Outcome: D1.6k, D2.2k
24. The OH\(^-\)(aq) concentration in a 0.50 mol/L solution of methylamine is

A. \(3.0 \times 10^{-2}\) mol/L
B. \(1.5 \times 10^{-2}\) mol/L
C. \(8.8 \times 10^{-4}\) mol/L
D. \(2.2 \times 10^{-4}\) mol/L

Answer: B
Outcome: D2.2k

Use the following information to answer numerical-response question 9.

\[ \text{CN}^- (aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{HCN}(aq) + \text{OH}^-(aq) \quad K_b = 1.6 \times 10^{-5} \]

**Numerical Response**

9. If the pH of a solution of NaCN(aq) is 8.71, then the equilibrium concentration of \(\text{CN}^-\)(aq), expressed in scientific notation, is \(a.b \times 10^{-c}\) mol/L. The values of \(a, b,\) and \(c\) are \(\_\_\_\_, \_\_\_,\) and \(\_\_\_.\)

(Record all three digits of your answer in the numerical-response section on the answer sheet.)

Answer: 166
Outcome: D2.2k, D2.3k
The equilibrium-law expression for an industrial method of producing ethanol is shown below.

\[
K_c = \frac{[C_2H_5OH(g)]}{[C_2H_4(g)] [H_2O(g)]}
\]

At equilibrium, a 5000 L reaction vessel contains 115 mol of C\(_2\)H\(_4\)(g) and 110 mol of H\(_2\)O(g).

25. Under these conditions, the equilibrium concentration of C\(_2\)H\(_5\)OH(g) is

A. \(1.69 \times 10^{-6}\) mol/L
B. \(1.52 \times 10^{-1}\) mol/L
C. \(7.50 \times 10^1\) mol/L
D. \(5.92 \times 10^5\) mol/L

Answer: B
Outcome: D2.3k
Use the following information to answer numerical-response question 10 and question 26.

A technician injected PCl₃(g) and NH₃(g) into a 1.00 L reaction vessel, closed the vessel, and allowed the reaction to reach equilibrium, as represented by the following equation.

\[
\text{PCl}_3(g) + 3 \text{NH}_3(g) \rightleftharpoons \text{P(NH}_2\text{)}_3(g) + 3 \text{HCl}(g) + \text{energy}
\]

The technician then changed the reaction conditions and allowed a new equilibrium to be established. The graph below represents both the establishment of the original equilibrium and the changes to the equilibrium system.

### Equilibrium System

![Equilibrium System](image)

**Numerical Response**

10. The value of the equilibrium constant at time \( p \) on the graph is ________.  

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

   Answer: 4.00  
   Outcome: D2.3k, D2.3s
26. *The change in the reaction conditions represented by time q on the graph is the result of [**i**], and the value of the new equilibrium constant at time r will [**ii**].*

The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>i</th>
<th>ii</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>increasing the temperature of the system</td>
<td>increase</td>
</tr>
<tr>
<td>B.</td>
<td>increasing the temperature of the system</td>
<td>decrease</td>
</tr>
<tr>
<td>C.</td>
<td>decreasing the temperature of the system</td>
<td>increase</td>
</tr>
<tr>
<td>D.</td>
<td>decreasing the temperature of the system</td>
<td>decrease</td>
</tr>
</tbody>
</table>

Answer: C
Outcome: D1.3k, D1.3s, D2.3s

*Use the following information to answer numerical-response question 11.*

Methane gas, CH₄(g), can be produced in a laboratory by reacting carbon disulfide, CS₂(g), and hydrogen gas, H₂(g), as represented by the following equation.

\[ \text{CS}_2(g) + 4 \text{H}_2(g) \rightleftharpoons \text{CH}_4(g) + 2 \text{H}_2\text{S}(g) \]

Initially, at a temperature of 90 °C, 0.18 mol/L CS₂(g) and 0.31 mol/L H₂(g) are present in a closed container. When equilibrium is established, 0.13 mol/L CS₂(g) is present.

**Numerical Response**

11. The concentration of hydrogen gas present in the container at equilibrium is _________ mol/L.

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

Answer: 0.11
Outcome: D2.3k, D2.3s
Toluene, C<sub>7</sub>H<sub>8</sub>(g), is an important organic solvent and can be produced as represented by the following equilibrium equation.

\[ C_7H_{14}(g) + \text{energy} \rightleftharpoons C_7H_8(g) + 3H_2(g) \]

A technician placed 3.00 mol of C<sub>7</sub>H<sub>14</sub>(g) into an empty 1.00 L flask. The flask was then stoppered and allowed to reach equilibrium. At equilibrium, 1.20 mol of H<sub>2</sub>(g) was present in the flask.

27. The value of the equilibrium constant is

A. 0.185
B. 0.266
C. 0.798
D. 1.15

Answer: B
Outcome: D2.3k, D2.3s
A technician added CS\(_2\)(g), H\(_2\)(g), CH\(_4\)(g), and H\(_2\)S(g) to an empty 1.00 L container at 960 °C and allowed the contents of the container to reach equilibrium, as represented by the following equation.

\[
\text{CS}_2(g) + 4 \text{H}_2(g) \rightleftharpoons \text{CH}_4(g) + 2 \text{H}_2\text{S}(g)
\]

The technician records the following data.

<table>
<thead>
<tr>
<th>Initial concentration (mol/L)</th>
<th>CS(_2)(g)</th>
<th>H(_2)(g)</th>
<th>CH(_4)(g)</th>
<th>H(_2)S(g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equilibrium concentration (mol/L)</td>
<td>1.25</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
</tbody>
</table>

28. The equilibrium concentration of H\(_2\)(g) is _i_ mol/L, and the equilibrium concentration of H\(_2\)S(g) is _ii_ mol/L.

The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th><em>i</em></th>
<th><em>ii</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>3.25</td>
<td>2.50</td>
</tr>
<tr>
<td>B.</td>
<td>3.25</td>
<td>5.50</td>
</tr>
<tr>
<td>C.</td>
<td>1.00</td>
<td>2.50</td>
</tr>
<tr>
<td>D.</td>
<td>1.00</td>
<td>5.50</td>
</tr>
</tbody>
</table>

Answer: D
Outcome: D2.3k, D2.3s
A student observes a system at equilibrium between a silver nitrate solution and copper solid. The net ionic equation for this equilibrium is shown below.

\[ 2 \text{Ag}^+(\text{aq}) + \text{Cu}(s) \rightleftharpoons 2 \text{Ag}(s) + \text{Cu}^{2+}(\text{aq}) + 54.1 \text{kJ} \]

<table>
<thead>
<tr>
<th>Materials Involved in Shifting Equilibrium</th>
<th>Direction of Equilibrium Shift</th>
<th>Qualitative Observation After Shift in Equilibrium</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Hot plate</td>
<td>5  Toward products</td>
<td>7  Solution turns lighter blue</td>
</tr>
<tr>
<td>2  Ice water bath</td>
<td>6  Toward reactants</td>
<td>8  Solution turns darker blue</td>
</tr>
<tr>
<td>3  Concentrated NaCl(aq)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4  Concentrated AgNO₃(aq)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Numerical Response**

12. Using the numbers above, choose one material that would result in a shift in equilibrium and match it with the direction of the equilibrium shift and with a qualitative observation that would confirm this shift. (There is more than one correct answer.)

<table>
<thead>
<tr>
<th>Number:</th>
<th>Material chosen</th>
<th>Direction of equilibrium shift</th>
<th>Qualitative observation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Record all three digits of your answer in the numerical-response section on the answer sheet.)

Answer: 167, 258, 367, 458
Outcome: D1.3k, D1.1s
Volcanoes on Io, one of Jupiter’s moons, emit hydrogen sulfide gas, H$_2$S(g), and sulfur dioxide gas, SO$_2$(g). The gases can react as represented by the following equilibrium equation.

\[
16 \text{H}_2\text{S(g)} + 8 \text{SO}_2(g) \rightleftharpoons 16 \text{H}_2\text{O(g)} + 3 \text{S}_8(g) + 332.2 \text{kJ}
\]

1. The enthalpy diagram that could represent the reaction above is

Answer: A
Outcome: A2.3k, A2.3s
The oxidation number of sulfur in

\( \text{H}_2\text{S(g)} \) is \( +/− \) \underline{\hspace{1cm}} \ (Record in the \textit{first} column)

\( \text{SO}_2\text{(g)} \) is \( +/− \) \underline{\hspace{1cm}} \ (Record in the \textit{second} column)

\( \text{S}_8\text{(g)} \) is \( +/− \) \underline{\hspace{1cm}} \ (Record in the \textit{third} column)

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

Answer: 240
Outcome: B1.2k
Most automobile engines are cooled by a mixture of antifreeze and water. Antifreezes are added to the water to prevent the cooling system in an engine from freezing in cold weather. Many compounds can be used for this purpose.

### Compounds Used as an Antifreeze

<table>
<thead>
<tr>
<th>Compound</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common name</td>
<td>wood alcohol</td>
<td>ethylene glycol</td>
<td>glycerol</td>
<td>propylene glycol</td>
</tr>
<tr>
<td>IUPAC name</td>
<td>methanol</td>
<td>ethane-1,2-diol</td>
<td>propane-1,2,3-triol</td>
<td>propane-1,2-diol</td>
</tr>
<tr>
<td>Specific heat capacity (J/g°C)</td>
<td>2.52</td>
<td>2.40</td>
<td>2.41</td>
<td>2.50</td>
</tr>
<tr>
<td>Viscosity (relative to water, water = 1.00)</td>
<td>0.64</td>
<td>17.8</td>
<td>648</td>
<td>52</td>
</tr>
<tr>
<td>Density (g/mL)</td>
<td>0.79</td>
<td>1.11</td>
<td>1.26</td>
<td>1.04</td>
</tr>
</tbody>
</table>

2. If a 1.25 kg sample of pure antifreeze was heated by 16.5 °C when 52.0 kJ of energy was added, then the sample is most likely to be

   A. methanol
   B. ethane-1,2-diol
   C. propane-1,2-diol
   D. propane-1,2,3-triol

   Answer: A
   Outcome: A1.1k, A1.3s
3. The two compounds that belong to the same homologous series are numbered

A. 1 and 2  
B. 2 and 3  
C. 2 and 4  
D. 3 and 4  

Answer: C  
Outcome: C1.6k
Use the following additional information to answer numerical-response question 2.

A student took a 25.0 mL sample of Compound 1 and poured it into a tube, as illustrated in the diagram. They measured the time it took for the marble to fall the distance indicated in the diagram and repeated this procedure for each remaining compound, with identical equipment, and with all measurements made at the same temperature.

Variables
1. Number of carbon atoms
2. Number of hydroxyl groups
3. Density of the liquid
4. Viscosity of the liquid
5. Volume of the liquid
6. Time for the marble to travel the distance
7. Distance the marble travelled
8. Temperature of the liquid

Numerical Response

2. In the experiment described above,

the responding variable is numbered

one controlled variable is numbered

another controlled variable is numbered

and a third controlled variable is numbered

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

Answer: 6578, 6587, 6785, 6758, 6857, 6875
Outcome: C1.1s
If ethylene glycol, C\(_2\)H\(_6\)O\(_2\)(aq), is ingested, enzymes in the body convert it to glycolic acid, C\(_2\)H\(_4\)O\(_3\)(aq), as represented by the following unbalanced incomplete half-reaction.

\[
\text{C}_2\text{H}_6\text{O}_2(\text{aq}) \xrightarrow{\text{enzymes}} \text{C}_2\text{H}_4\text{O}_3(\text{aq})
\]

The buildup of glycolic acid (\(K_a = 1.5 \times 10^{-4}\)) causes acidosis, a serious medical condition.

4. The oxidation number of carbon in ethylene glycol is
   
   A. \(-2\)  
   B. \(-1\)  
   C. \(+1\)  
   D. \(+2\)

   Answer: B  
   Outcome: B1.2k

5. *If the half-reaction above is balanced in an acidic solution, the H\(^+\)(aq) will appear on the side of the equation with the \(i\) and will have a coefficient of \(ii\).*

   The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>(i)</th>
<th>(ii)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>reactants</td>
<td>2</td>
</tr>
<tr>
<td>B.</td>
<td>reactants</td>
<td>4</td>
</tr>
<tr>
<td>C.</td>
<td>products</td>
<td>2</td>
</tr>
<tr>
<td>D.</td>
<td>products</td>
<td>4</td>
</tr>
</tbody>
</table>

   Answer: D  
   Outcome: B1.7k
Use the following additional information to answer question 6 and 7.

The glycolic acid produced can react with the $\text{H}_2\text{PO}_4^-(aq)/\text{HPO}_4^{2-}(aq)$ buffer that is present in cellular fluid.

6. Which of the following rows identifies the Brønsted–Lowry base that will first react with the glycolic acid and the extent of that reaction?

<table>
<thead>
<tr>
<th>Row</th>
<th>Brønsted–Lowry Base</th>
<th>Extent of the Reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>$\text{H}_2\text{PO}_4^-(aq)$</td>
<td>&lt;50%</td>
</tr>
<tr>
<td>B.</td>
<td>$\text{H}_2\text{PO}_4^-(aq)$</td>
<td>&gt;50%</td>
</tr>
<tr>
<td>C.</td>
<td>$\text{HPO}_4^{2-}(aq)$</td>
<td>&lt;50%</td>
</tr>
<tr>
<td>D.</td>
<td>$\text{HPO}_4^{2-}(aq)$</td>
<td>&gt;50%</td>
</tr>
</tbody>
</table>

Answer: D
Outcome: D1.5k, D1.6k

Use the following additional information to answer question 7.

During acidosis, the pH of the blood may change from 7.40 to 7.25.

7. Which of the following rows identifies the $[\text{OH}^-\text{(aq)}]$ at a pH of 7.25 and compares it to the $[\text{OH}^-\text{(aq)}]$ at a pH of 7.40?

<table>
<thead>
<tr>
<th>Row</th>
<th>$[\text{OH}^-\text{(aq)}]$ at pH of 7.25</th>
<th>Compared to $[\text{OH}^-\text{(aq)}]$ at pH of 7.40</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>$1.8 \times 10^{-7}$</td>
<td>Less at a pH of 7.25</td>
</tr>
<tr>
<td>B.</td>
<td>$1.8 \times 10^{-7}$</td>
<td>Greater at a pH of 7.25</td>
</tr>
<tr>
<td>C.</td>
<td>$5.6 \times 10^{-8}$</td>
<td>Less at a pH of 7.25</td>
</tr>
<tr>
<td>D.</td>
<td>$5.6 \times 10^{-8}$</td>
<td>Greater at a pH of 7.25</td>
</tr>
</tbody>
</table>

Answer: A
Outcome: D2.1k, D2.2k
Sorbic acid, \( \text{C}_5\text{H}_7\text{COOH}(\text{aq}) \), is used as a preservative in wine as it inhibits the growth of fungi and bacteria. Its structure can be represented by the following line diagram.

\[
\begin{align*}
\text{HO} & \quad K_a = 1.7 \times 10^{-5}
\end{align*}
\]

8. Which of the following rows identifies a classification and a functional group for sorbic acid?

<table>
<thead>
<tr>
<th>Row</th>
<th>Classification</th>
<th>Functional Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>Aromatic</td>
<td>Ester linkage</td>
</tr>
<tr>
<td>B.</td>
<td>Aromatic</td>
<td>Carboxyl</td>
</tr>
<tr>
<td>C.</td>
<td>Aliphatic</td>
<td>Ester linkage</td>
</tr>
<tr>
<td>D.</td>
<td>Aliphatic</td>
<td>Carboxyl</td>
</tr>
</tbody>
</table>

Answer: D
Outcome: C1.3k, C1.4k, C1.3s

9. Sorbic acid can react with excess \( \text{Br}_2(\text{l}) \) in \( \text{i} \) and the number of different inorganic products produced is \( \text{ii} \).

The statement above is completed by the information in row

<table>
<thead>
<tr>
<th>Row</th>
<th>\text{i}</th>
<th>\text{ii}</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>an addition reaction</td>
<td>two</td>
</tr>
<tr>
<td>B.</td>
<td>an addition reaction</td>
<td>zero</td>
</tr>
<tr>
<td>C.</td>
<td>a substitution reaction</td>
<td>two</td>
</tr>
<tr>
<td>D.</td>
<td>a substitution reaction</td>
<td>zero</td>
</tr>
</tbody>
</table>

Answer: B
Outcome: C2.2k
10. The pH of a 0.020 mol/L solution of sorbic acid is
   
   A. 6.47  
   B. 4.77  
   C. 3.23  
   D. 1.70  
   
   Answer: C  
   Outcome: D2.2k

**Numerical Response**

3. The value of \( K_b \) for the sorbate ion is \( a \cdot b \times 10^{-cd} \). The values of \( a, b, c, \) and \( d \) are \( \frac{a}{b}, \frac{b}{c}, \frac{c}{d} \), and \( \frac{d}{a} \).

(Record all four digits of your answer in the numerical-response section on the answer sheet.)

Answer: 5910  
Outcome: D2.2k

*Use the following additional information to answer question 11.*

Sorbic acid can react with the bicarbonate ion that is also present in wine. The reaction can be represented by the following equilibrium equation.

\[
\text{C}_5\text{H}_7\text{COOH}(aq) + \text{HCO}_3^-(aq) \rightleftharpoons \text{C}_5\text{H}_7\text{COO}^-(aq) + \text{H}_2\text{CO}_3(aq)
\]

11. Which of the following rows identifies the extent of reaction and a conjugate acid–base pair?

<table>
<thead>
<tr>
<th>Row</th>
<th>Extent of Reaction</th>
<th>Conjugate Acid–Base Pair</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>Reactants Favoured</td>
<td>( \text{HCO}_3^-(aq), \text{C}_5\text{H}_7\text{COO}^-(aq) )</td>
</tr>
<tr>
<td>B.</td>
<td>Reactants Favoured</td>
<td>( \text{C}_5\text{H}_7\text{COOH}(aq), \text{C}_5\text{H}_7\text{COO}^-(aq) )</td>
</tr>
<tr>
<td>C.</td>
<td>Products Favoured</td>
<td>( \text{HCO}_3^-(aq), \text{C}_5\text{H}_7\text{COO}^-(aq) )</td>
</tr>
<tr>
<td>D.</td>
<td>Products Favoured</td>
<td>( \text{C}_5\text{H}_7\text{COOH}(aq), \text{C}_5\text{H}_7\text{COO}^-(aq) )</td>
</tr>
</tbody>
</table>

Answer: D  
Outcome: D1.6k, D1.7k