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Introduction

The questions presented in this booklet are from the January 2009 Chemistry 30 Diploma Examination. This material, along with the program of studies, Subject Bulletin, Assessment Highlights, and January 2009 Diploma Examination Results, can provide insights that assist you with decisions relative to instructional programming.

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1. The activation energy for the forward, catalyzed reaction is

A. II minus I
B. III minus I
C. IV minus II
D. IV minus III
Use the following information to answer the next question.

Incomplete combustion in motor vehicles may lead to the formation of carbon monoxide gas, which is a health hazard in high concentrations. Carbon monoxide gas is converted to carbon dioxide gas in a catalytic converter before being emitted from the motor vehicle. This conversion is represented by the equation below.

$$2 \text{CO}(g) + \text{O}_2(g) \rightleftharpoons 2 \text{CO}_2(g)$$

2. The addition of a catalyst to the reaction represented by the equation above would ____ \(i\) ____ the energy transferred during the reaction and would ____ \(ii\) ____ the value of the equilibrium constant.

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>increase</td>
<td>increase</td>
</tr>
<tr>
<td>B.</td>
<td>increase</td>
<td>not change</td>
</tr>
<tr>
<td>C.</td>
<td>not change</td>
<td>increase</td>
</tr>
<tr>
<td>D.</td>
<td>not change</td>
<td>not change</td>
</tr>
</tbody>
</table>

Use the following information to answer the next question.

Honey has a high concentration of fructose, \(\text{C}_6\text{H}_{12}\text{O}_6\text{(s)}\). Fructose has the same molecular formula as glucose but a different structural formula.

3. If 1.50 mmol of fructose is burned in a calorimeter that contains 250.0 g of water and the temperature increases by 3.85 °C, then the molar enthalpy of combustion of fructose is

A. \(-6.05 \times 10^{-3}\) kJ/mol
B. \(-9.68 \times 10^{-2}\) kJ/mol
C. \(-4.03\) kJ/mol
D. \(-2.69 \times 10^{3}\) kJ/mol
A technician performed an experiment to determine the molar enthalpy of combustion of propane in a soldering torch, as represented in the diagram below.

4. If the experimental value of the molar enthalpy of combustion of propane in the technician’s calorimetry experiment is significantly different from the theoretical value, then the technician could reduce the discrepancy in the data by

A. using a glass beaker to hold the water  
B. creating an enclosing shield around the apparatus  
C. raising the aluminium calorimeter above the flame  
D. decreasing the mass of water in the aluminium calorimeter
5. *During a combustion reaction, energy is ______ the surroundings because the products have ______ potential energy than the reactants.*

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>released to</td>
<td>lower</td>
</tr>
<tr>
<td>B.</td>
<td>released to</td>
<td>higher</td>
</tr>
<tr>
<td>C.</td>
<td>absorbed from</td>
<td>lower</td>
</tr>
<tr>
<td>D.</td>
<td>absorbed from</td>
<td>higher</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Chemicals</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{O}_2(\text{g}) )</td>
</tr>
<tr>
<td>( \text{CO}(\text{g}) )</td>
</tr>
<tr>
<td>( \text{CO}_2(\text{g}) )</td>
</tr>
</tbody>
</table>

**Numerical Response**

1. Match the chemicals numbered above with the statements given below.

The reactants of photosynthesis are: ______ and ______.

Record in the first column

The products of complete hydrocarbon combustion in an open system are: ______ and ______.

Record in the third column

(Record your answer in the numerical-response section on the answer sheet.)
6. *The reaction represented in the diagram above is __i__, and if the energy was included as a term in the balanced equation, it would be a __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>exothermic</td>
<td>reactant</td>
</tr>
<tr>
<td>B.</td>
<td>exothermic</td>
<td>product</td>
</tr>
<tr>
<td>C.</td>
<td>endothermic</td>
<td>reactant</td>
</tr>
<tr>
<td>D.</td>
<td>endothermic</td>
<td>product</td>
</tr>
</tbody>
</table>
The bombardier beetle can release a chemical solution when threatened. Glands in the beetle produce hydrogen peroxide and hydroquinone, \( \text{C}_6\text{H}_4(\text{OH})_2(\text{aq}) \), which are combined to produce the reaction represented by the overall equation below.

\[
\text{C}_6\text{H}_4(\text{OH})_2(\text{aq}) + \text{H}_2\text{O}_2(\text{aq}) \rightarrow \text{C}_6\text{H}_4\text{O}_2(\text{aq}) + 2 \text{H}_2\text{O}(\text{l})
\]

The equations listed below represent reactions that are related to the production of the chemical solution.

**Equations**

1. \( \text{C}_6\text{H}_4(\text{OH})_2(\text{aq}) \rightarrow \text{C}_6\text{H}_4\text{O}_2(\text{aq}) + \text{H}_2(\text{g}) \) \( \Delta H = +177.4 \text{ kJ} \)
2. \( \text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow \text{H}_2\text{O}_2(\text{aq}) \) \( \Delta H = -191.2 \text{ kJ} \)
3. \( \text{H}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g}) \rightarrow \text{H}_2\text{O}(\text{g}) \) \( \Delta H = -241.8 \text{ kJ} \)
4. \( \text{H}_2\text{O}(\text{g}) \rightarrow \text{H}_2\text{O}(\text{l}) \) \( \Delta H = -43.8 \text{ kJ} \)

7. The enthalpy change for the overall equation is
   - A. +83.0 kJ
   - B. -202.6 kJ
   - C. -299.4 kJ
   - D. -585.0 kJ

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

\[
\text{C}_6\text{H}_4\text{O}_2(\text{aq}) + 2 \text{H}^+(\text{aq}) + 2 \text{e}^- \rightarrow \text{C}_6\text{H}_4(\text{OH})_2(\text{aq}) \quad E^\circ = +0.70 \text{ V}
\]

8. Which of the following substances would oxidize \( \text{C}_6\text{H}_4(\text{OH})_2(\text{aq}) \)?
   - A. \( \text{Ag}^+(\text{aq}) \)
   - B. \( \text{Cu}^{2+}(\text{aq}) \)
   - C. \( \text{Ag}(\text{s}) \)
   - D. \( \text{Cu}(\text{s}) \)
Use the following information to answer the next two questions.

Nitrogen can react with oxygen to form a variety of oxides as represented by the following equations.

\[
\begin{align*}
N_2(g) + O_2(g) + 182.6 \text{ kJ} & \rightarrow 2 \text{ NO}(g) \\
N_2(g) + 2 \text{ O}_2(g) + 66.4 \text{ kJ} & \rightarrow 2 \text{ NO}_2(g) \\
2N_2(g) + O_2(g) + 163.2 \text{ kJ} & \rightarrow 2 \text{ N}_2\text{O}(g) \\
N_2(g) + 2 \text{ O}_2(g) + 11.1 \text{ kJ} & \rightarrow \text{ N}_2\text{O}_4(g)
\end{align*}
\]

**Numerical Response**

2. The oxidation number of nitrogen in

- NO(g) is _________ (Record in the first column)
- NO\(_2\)(g) is _________ (Record in the second column)
- N\(_2\)O(g) is _________ (Record in the third column)
- N\(_2\)O\(_4\)(g) is _________ (Record in the fourth column)

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

Use the following additional information to answer the next question.

1. NO(g)  3. N\(_2\)O(g)  2. NO\(_2\)(g)  4. N\(_2\)O\(_4\)(g)

**Numerical Response**

3. The nitrogen oxides, listed in order of increasing enthalpy of formation, are _____, _____, _____, and ______.

(Record all four digits of your answer in the numerical-response section on the answer sheet.)
Use the following information to answer the next three questions.

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

\[
Pb(s) + PbO_2(s) + 4 H^+(aq) + 2 SO_4^{2-}(aq) \rightarrow 2 PbSO_4(s) + 2 H_2O(l) \quad \Delta H = -315.9 \text{ kJ}
\]

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 additional information to answer the next question.

Every car battery is given a CCA (cold cranking amps) rating. A CCA rating of 600 means that the battery is capable of generating 600 A of current for a 30.0 s period at 0 °C.

11. Which of the following values indicates how many coulombs a battery with a CCA rating of 600 produces during 30.0 s of operation?

A. 20.0 C  
B. 600 C  
C. 1.80 \times 10^4 C  
D. 1.74 \times 10^9 C
Use the following information to answer the next two questions.

The electrolysis of aluminium oxide in an electrolytic cell occurs at high temperatures so that the compound is molten.

12. Which of the following equations represents the reduction half-reaction when molten aluminium oxide undergoes electrolysis?

A. $\text{Al}^{3+}(l) \rightarrow \text{Al}(l) + 3 \text{e}^-$
B. $\text{Al}^{3+}(l) + 3 \text{e}^- \rightarrow \text{Al}(l)$
C. $2 \text{O}^2-(l) \rightarrow \text{O}_2(g) + 4 \text{e}^-$
D. $2 \text{O}^2-(l) + 4 \text{e}^- \rightarrow \text{O}_2(g)$

13. During the production of aluminium metal in the electrolytic cell, anions travel toward the ____i____ and electrons travel through 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>cathode</td>
<td>electrolyte to the anode</td>
</tr>
<tr>
<td>B.</td>
<td>cathode</td>
<td>wire to the cathode</td>
</tr>
<tr>
<td>C.</td>
<td>anode</td>
<td>electrolyte to the anode</td>
</tr>
<tr>
<td>D.</td>
<td>anode</td>
<td>wire to the cathode</td>
</tr>
</tbody>
</table>
A student constructs the following standard electrochemical cell in a laboratory at 25.0 °C.

14. If the standard lead reduction half-reaction had been chosen as the reference half-reaction instead of the hydrogen reduction half-reaction, then the electrical potential for this cell would be

   A. +1.14 V
   B. +0.93 V
   C. +0.67 V
   D. +0.46 V
Use the following information to answer the next two questions.

In an experiment to study the reactivity of Pt(s), Rh(s), Sm(s), and Te(s), a student observed the reactions represented by the equations below.

Equation I \[ \text{Pt}^{2+}(aq) \ + \ 2 \text{Rh}(s) \rightarrow \text{Pt}(s) \ + \ 2 \text{Rh}^+(aq) \]
Equation II \[ 2 \text{Te}^+(aq) \ + \ \text{Sm}(s) \rightarrow 2 \text{Te}(s) \ + \ \text{Sm}^{2+}(aq) \]
Equation III \[ \text{Te}^+(aq) \ + \ \text{Rh}(s) \rightarrow \text{no evidence of a reaction} \]

15. Which of the following substances is the strongest reducing agent?
   A. Pt(s)
   B. Rh(s)
   C. Sm(s)
   D. Te(s)

16. Which of the following equations represents a spontaneous reaction?
   A. \[ \text{Te}^+(aq) \ + \ \text{Rh}(s) \rightarrow \text{Te}(s) \ + \ \text{Rh}^+(aq) \]
   B. \[ \text{Sm}^{2+}(aq) \ + \ \text{Pt}(s) \rightarrow \text{Sm}(s) \ + \ \text{Pt}^{2+}(aq) \]
   C. \[ \text{Pt}^{2+}(aq) \ + \ 2 \text{Te}(s) \rightarrow \text{Pt}(s) \ + \ 2 \text{Te}^+(aq) \]
   D. \[ \text{Sm}^{2+}(aq) \ + \ 2 \text{Rh}(s) \rightarrow \text{Sm}(s) \ + \ 2 \text{Rh}^+(aq) \]
A student placed a large piece of zinc into a beaker of hydrochloric acid and collected all of the gas produced. Indicators were also added to monitor the change in pH.

17. Which of the following rows gives the composition of the bubbles and the process through which they were formed?

<table>
<thead>
<tr>
<th>Row</th>
<th>Composition</th>
<th>Process of Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>Cl₂(g)</td>
<td>oxidation of chloride ions</td>
</tr>
<tr>
<td>B.</td>
<td>H₂(g)</td>
<td>reduction of hydrogen ions</td>
</tr>
<tr>
<td>C.</td>
<td>H₂(g)</td>
<td>reduction of water</td>
</tr>
<tr>
<td>D.</td>
<td>O₂(g)</td>
<td>oxidation of water</td>
</tr>
</tbody>
</table>

18. If a student were to build a voltaic cell using solid zinc and hydrochloric acid, which of the following equipment would also be needed?

A. An inert electrode for the cathode and a salt bridge
B. An inert electrode for the cathode and a power source
C. An inert electrode for the anode and a salt bridge
D. An inert electrode for the anode and a power source
Use the following information to answer the next question.

Fireworks usually contain a mixture of explosives and other chemicals. Some of the reactions that occur in a fireworks display are represented by the equations below.

\[
\begin{align*}
\text{I} & \quad 4 \text{Al}(s) + 3 \text{O}_2(g) \rightarrow 2 \text{Al}_2\text{O}_3(s) \\
\text{II} & \quad \text{KClO}_4(s) \rightarrow \text{KCl}(s) + 2 \text{O}_2(g) \\
\text{III} & \quad \text{SrCO}_3(g) \rightarrow \text{SrO}(s) + \text{CO}_2(g) \\
\text{IV} & \quad 2 \text{Mg}(s) + \text{O}_2(g) \rightarrow 2 \text{MgO}(s) \\
\text{V} & \quad \text{Fe}_3\text{O}_4(s) \rightarrow 3 \text{Fe}(s) + 2 \text{O}_2(g)
\end{align*}
\]

19. The equations above that represent a reaction in which the metal is being oxidized are

A. I and IV only  
B. II and III only  
C. I, III, and IV  
D. II, III, and V

Use the following information to answer the next question.

Ammonium nitrate, used to make gunpowder and fireworks, was extracted from animal manure in ancient China. During the explosion of gunpowder or fireworks, the ammonium nitrate reacts violently, as represented by the equation below.

**Explosion of Ammonium Nitrate**

\[2 \text{NH}_4\text{NO}_3(s) \rightarrow 2 \text{N}_2(g) + \text{O}_2(g) + 4 \text{H}_2\text{O}(g)\]

20. During the explosion of ammonium nitrate, hydrogen

A. is oxidized  
B. loses electrons  
C. is the oxidizing agent  
D. has no change in oxidation number
Use the following information to answer the next question.

Methanoic acid, in the presence of a catalyst, can be used to produce electricity in a fuel cell, as represented by the following diagram.

21. The equation that represents the half-reaction that occurs at the cathode of the fuel cell is

A. \( \text{O}_2(g) + 4 \text{H}^+(aq) + 4 \text{e}^- \rightarrow 2 \text{H}_2\text{O}(l) \)

B. \( 2 \text{H}_2\text{O}(l) \rightarrow \text{O}_2(aq) + 4 \text{H}^+(aq) + 4 \text{e}^- \)

C. \( \text{HCOOH}(l) \rightarrow \text{CO}_2(aq) + 2 \text{H}^+(aq) + 2 \text{e}^- \)

D. \( \text{CO}_2(aq) + 2 \text{H}^+(aq) + 2 \text{e}^- \rightarrow \text{HCOOH}(l) \)
Use the following information to answer the next question.

The equation below represents the AlF$_6^{3-}$(aq) reduction half-reaction.

$$\text{AlF}_6^{3-}(aq) + 3 \text{e}^- \rightarrow \text{Al}(s) + 6 \text{F}^-(aq) \quad E^\circ = -2.07 \text{ V}$$

One half-cell in an electrochemical cell contains Al(s) in a F$^-$ (aq) solution. The other half-cell contains Pb(s) in a Pb$^{2+}$(aq) solution. A spontaneous reaction occurs, producing AlF$_6^{3-}$(aq) and Pb(s).

**Numerical Response**

4. The net cell potential for this electrochemical cell is $+/-$ ________ V.

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

Use the following information to answer the next question.

22. If the electrochemical cell in the diagram above produces a flow of electrons in the direction indicated, then M(s) and M$^{2+}$(aq) could be

   A. Fe(s) and Fe$^{2+}$(aq)
   B. Pb(s) and Pb$^{2+}$(aq)
   C. Ni(s) and Ni$^{2+}$(aq)
   D. Cu(s) and Cu$^{2+}$(aq)
Use the following information to answer the next two questions.

<table>
<thead>
<tr>
<th>Statements About Electrochemical Cells</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
</tr>
<tr>
<td>II</td>
</tr>
<tr>
<td>III</td>
</tr>
<tr>
<td>IV</td>
</tr>
<tr>
<td>V</td>
</tr>
<tr>
<td>VI</td>
</tr>
</tbody>
</table>

23. The statements above that correctly describe an electrolytic cell are
   A. I, III, and V
   B. I, IV, and VI
   C. II, III, and VI
   D. II, IV, and V

24. The statements above that correctly describe both an electrolytic cell and a voltaic cell are
   A. I and III
   B. III and VI
   C. IV and V
   D. IV and VI
Use the following information to answer the next question.

Iron metal reacts with hydrochloric acid slowly. The equation for this reaction is

\[ \text{Fe(s)} + 2 \text{HCl(aq)} \rightarrow \text{FeCl}_2(\text{aq}) + \text{H}_2(\text{g}) \]

25. In this reaction, the reducing agent is

A. \( \text{FeCl}_2(\text{aq}) \)
B. \( \text{HCl(aq)} \)
C. \( \text{H}_2(\text{g}) \)
D. \( \text{Fe(s)} \)

Use the following information to answer the next question.

A student drew the structural diagram shown below.

26. The IUPAC name for the structural diagram the student drew is 1-______-2-_______.

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>methyl</td>
<td>ethylbutane</td>
</tr>
<tr>
<td>B.</td>
<td>methyl</td>
<td>ethylcyclobutane</td>
</tr>
<tr>
<td>C.</td>
<td>ethyl</td>
<td>methylbutane</td>
</tr>
<tr>
<td>D.</td>
<td>ethyl</td>
<td>methylcyclobutane</td>
</tr>
</tbody>
</table>
### Numerical Response

5. The organic compound numbered above that

- is an alkene is _________ (Record in the **first** column)
- is an alcohol is _________ (Record in the **second** column)
- contains a triple bond is _________ (Record in the **third** column)
- is cyclic and saturated is _________ (Record in the **fourth** column)

(Record your answer in the numerical-response section on the answer sheet.)
Use the following information to answer the next question.

**Organic Compounds**

1. \[ \text{CH}_3 \]
2. \[ \text{H} \]
   \[ \text{H} \]
   \[ \text{H} \]
   \[ \text{H} \]
   \[ \text{H} \]
   \[ \text{O} \]
   \[ \text{C} \]
   \[ \text{C} \]
   \[ \text{H} \]
3. \[ \text{H} \]
   \[ \text{C} \]
   \[ \text{C} \]
   \[ \text{CH}_3 \]
   \[ \text{C} \]
   \[ \text{C} \]
   \[ \text{H} \]
4. \[ \text{H} \]
   \[ \text{H} \]
   \[ \text{H} \]
   \[ \text{H} \]
   \[ \text{H} \]
   \[ \text{H} \]
   \[ \text{C} \]
   \[ \text{C} \]
   \[ \text{C} \]
   \[ \text{Br} \]
5. \[ \text{H} \]
   \[ \text{H} \]
   \[ \text{O} \]
   \[ \text{H} \]
   \[ \text{O} \]
   \[ \text{H} \]
6. \[ \text{H} \]
   \[ \text{H} \]
   \[ \text{H} \]
   \[ \text{H} \]
   \[ \text{H} \]
   \[ \text{H} \]
   \[ \text{O} \]
   \[ \text{C} \]
   \[ \text{C} \]
   \[ \text{O} \]
   \[ \text{H} \]

**Numerical Response**

6. Match four of the organic compounds numbered above with their classifications below.

   Alkyne __________ (Record in the first column)
   Alcohol __________ (Record in the second column)
   Aromatic __________ (Record in the third column)
   Unsaturated hydrocarbon __________ (Record in the fourth column)

(Record your answer in the numerical-response section on the answer sheet.)
Use the following information to answer the next question.

**Reaction Equation**

\[
\begin{align*}
I & \quad \text{H} & & \text{C} & & \text{O} & & \text{H} \\
& \quad \text{H} & & \text{C} & & \text{O} & & \text{H} \\
\rightarrow & \quad \text{O} & & \text{C} & & \text{O} & & \text{C} & & \text{H} & & \text{H} & & \text{H} & & \text{H} & & \text{H} \\
\end{align*}
\]

**Names and Terms**

<table>
<thead>
<tr>
<th></th>
<th>Name</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Methane</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>Methanol</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>Ethanoate</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>Methanoic acid</td>
<td>9</td>
</tr>
<tr>
<td>5</td>
<td>Methyl methanoate</td>
<td></td>
</tr>
</tbody>
</table>

**Numerical Response**

7. Match a name or a term from the list above with each descriptor given below.

- Name of reactant I __________ (Record in the first column)
- Name of product II __________ (Record in the second column)
- Type of reaction __________ (Record in the third column)
- Classification of product II __________ (Record in the fourth column)

(Record your answer in the numerical-response section on the answer sheet.)
Use the following information to answer the next question.

The following are structural diagrams for four organic compounds with common industrial uses.

1. \[
\text{CH}_2\text{CH}_3
\]

2. \[
\text{Br-CH}_2\text{-CH}_2\text{-Br}
\]

3. \[
\text{H-C-C}=\text{O}
\]

4. \[
\text{CH}_3\text{O} \quad \text{CH}_2=\text{CH-C-C-O-CH}_2\text{-CH}_3
\]

Numerical Response

8. Match each of the structural diagrams above with its classification below.

Aromatic

Carboxylic acid

Unsaturated and aliphatic

Halogenated hydrocarbon

(Record your answer in the numerical-response section on the answer sheet.)
Hexane and hex-1-ene are both colourless liquids. One method used to differentiate between hexane and hex-1-ene is to add a few drops of orange-coloured aqueous bromine to samples of each organic compound.

27. Hexane is ____i____ hydrocarbon, and hex-1-ene is ____ii____ hydrocarbon.

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>a saturated</td>
<td>a saturated</td>
</tr>
<tr>
<td>B.</td>
<td>a saturated</td>
<td>an unsaturated</td>
</tr>
<tr>
<td>C.</td>
<td>an unsaturated</td>
<td>a saturated</td>
</tr>
<tr>
<td>D.</td>
<td>an unsaturated</td>
<td>an unsaturated</td>
</tr>
</tbody>
</table>

28. When aqueous bromine is added to hexane and hex-1-ene in the presence of light, the hexane undergoes ____i____ reaction and the hex-1-ene undergoes ____ii____ 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>an addition</td>
<td>a substitution</td>
</tr>
<tr>
<td>B.</td>
<td>an addition</td>
<td>an addition</td>
</tr>
<tr>
<td>C.</td>
<td>a substitution</td>
<td>a substitution</td>
</tr>
<tr>
<td>D.</td>
<td>a substitution</td>
<td>an addition</td>
</tr>
</tbody>
</table>
Use the following information to answer the next question.

<table>
<thead>
<tr>
<th>Carbon-Containing Compounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  CCl₄(l)</td>
</tr>
<tr>
<td>2  Fe₃C(s)</td>
</tr>
<tr>
<td>3  C₂H₂(g)</td>
</tr>
<tr>
<td>4  C₂H₅OH(l)</td>
</tr>
</tbody>
</table>

Numerical Response

9. The compounds numbered above that can be classified as organic are _____, _____, _____, and _____.

(Record all four digits of your answer in lowest-to-highest numerical order in the numerical-response section on the answer sheet.)
29. An ester functional group is found in
   A. II and III only
   B. II, III, and IV
   C. III only
   D. V only
Use the following information to answer the next two questions.

The concentration of aqueous sodium hypochlorite, NaOCl(aq), in laundry bleach can be determined by titrating a sample of laundry bleach with an iodide solution, as represented by the equation below.

\[ \text{OCl}^- (aq) + 2 \text{H}^+ (aq) + 2 \text{I}^- (aq) \rightleftharpoons \text{Cl}^- (aq) + \text{H}_2\text{O}(l) + \text{I}_2(aq) \]

**Numerical Response**

10. If a student uses 4.25 mL of a 0.0473 mol/L \( \text{I}^- \) solution to titrate a 100.00 mL sample of laundry bleach, then the concentration of \( \text{OCl}^- \) in the laundry bleach is _________ mmol/L.

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

30. The \( K_b \) of \( \text{OCl}^- \) is _______i_____, and \( \text{OCl}^- \) is a weaker base than ______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>2.5 \times 10^{-7}</td>
<td>( \text{PO}_4^{3-} )(aq)</td>
</tr>
<tr>
<td>B.</td>
<td>2.5 \times 10^{-7}</td>
<td>( \text{CH}_3\text{COO}^- )(aq)</td>
</tr>
<tr>
<td>C.</td>
<td>4.0 \times 10^{-8}</td>
<td>( \text{PO}_4^{3-} )(aq)</td>
</tr>
<tr>
<td>D.</td>
<td>4.0 \times 10^{-8}</td>
<td>( \text{CH}_3\text{COO}^- )(aq)</td>
</tr>
</tbody>
</table>
Use the following information to answer the next two questions.

Citric acid, $\text{H}_3\text{C}_6\text{H}_5\text{O}_7\text{(aq)}$, is a weak, polyprotic acid that is found in fruits such as oranges and lemons. Citric acid reacts with water, as represented by the following Brønsted–Lowry equations.

$$\text{H}_3\text{C}_6\text{H}_5\text{O}_7\text{(aq)} + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_2\text{C}_6\text{H}_5\text{O}_7\text{−(aq)} + \text{H}_3\text{O}^+(aq) \quad K_a = 7.4 \times 10^{-4}$$

$$\text{H}_2\text{C}_6\text{H}_5\text{O}_7\text{−(aq)} + \text{H}_2\text{O}(l) \rightleftharpoons \text{C}_6\text{H}_5\text{O}_7^{2−}(aq) + \text{H}_3\text{O}^+(aq) \quad K_a = 1.7 \times 10^{-5}$$

$$\text{HC}_6\text{H}_5\text{O}_7^{2−}(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{C}_6\text{H}_5\text{O}_7^{3−}(aq) + \text{H}_3\text{O}^+(aq) \quad K_a = 4.0 \times 10^{-7}$$

31. The amphiprotic species in the equations above are

A. $\text{H}_3\text{C}_6\text{H}_5\text{O}_7\text{(aq)}$, $\text{HC}_6\text{H}_5\text{O}_7^{2−}(aq)$, and $\text{H}_2\text{O}(l)$

B. $\text{H}_2\text{C}_6\text{H}_5\text{O}_7\text{−(aq)}$, $\text{HC}_6\text{H}_5\text{O}_7^{2−}(aq)$, and $\text{H}_2\text{O}(l)$

C. $\text{H}_3\text{C}_6\text{H}_5\text{O}_7\text{(aq)}$ and $\text{H}_2\text{C}_6\text{H}_5\text{O}_7\text{−(aq)}$

D. $\text{HC}_6\text{H}_5\text{O}_7^{2−}(aq)$ and $\text{C}_6\text{H}_5\text{O}_7^{3−}(aq)$

32. Which of the following statements about $K_a$ and $K_b$ values applies to the equations above?

A. The $K_a$ of $\text{H}_3\text{C}_6\text{H}_5\text{O}_7\text{(aq)}$ is less than the $K_b$ of $\text{HC}_6\text{H}_5\text{O}_7^{2−}(aq)$.

B. The $K_b$ of $\text{HC}_6\text{H}_5\text{O}_7^{2−}(aq)$ is greater than the $K_b$ of $\text{C}_6\text{H}_5\text{O}_7^{3−}(aq)$.

C. The $K_a$ of $\text{H}_2\text{C}_6\text{H}_5\text{O}_7\text{−(aq)}$ is greater than the $K_b$ of $\text{C}_6\text{H}_5\text{O}_7^{3−}(aq)$.

D. The $K_b$ of $\text{H}_2\text{C}_6\text{H}_5\text{O}_7\text{−(aq)}$ is greater than the $K_b$ of $\text{HC}_6\text{H}_5\text{O}_7^{2−}(aq)$.
Use the following information to answer the next two questions.

Lactic acid, $\text{HC}_3\text{H}_5\text{O}_3(\text{aq})$, is produced in human muscle cells when not enough oxygen is supplied to the muscle during heavy physical activity. The equation below represents the Brønsted–Lowry reaction of lactic acid and water.

$$\text{HC}_3\text{H}_5\text{O}_3(\text{aq}) + \text{H}_2\text{O}(l) \rightleftharpoons \text{C}_3\text{H}_5\text{O}_3^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$$

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

<table>
<thead>
<tr>
<th>Row</th>
<th>Brønsted–Lowry Acids</th>
<th>Conjugate Acid–Base Pair</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>$\text{HC}_3\text{H}_5\text{O}_3(\text{aq})$ and $\text{C}_3\text{H}_5\text{O}_3^-(\text{aq})$</td>
<td>$\text{H}_2\text{O}(l)$ and $\text{H}_3\text{O}^+(\text{aq})$</td>
</tr>
<tr>
<td>B.</td>
<td>$\text{HC}_3\text{H}_5\text{O}_3(\text{aq})$ and $\text{C}_3\text{H}_5\text{O}_3^-(\text{aq})$</td>
<td>$\text{C}_3\text{H}_5\text{O}_3^-(\text{aq})$ and $\text{H}_3\text{O}^+(\text{aq})$</td>
</tr>
<tr>
<td>C.</td>
<td>$\text{HC}_3\text{H}_5\text{O}_3(\text{aq})$ and $\text{H}_3\text{O}^+(\text{aq})$</td>
<td>$\text{H}_2\text{O}(l)$ and $\text{H}_3\text{O}^+(\text{aq})$</td>
</tr>
<tr>
<td>D.</td>
<td>$\text{HC}_3\text{H}_5\text{O}_3(\text{aq})$ and $\text{H}_3\text{O}^+(\text{aq})$</td>
<td>$\text{C}_3\text{H}_5\text{O}_3^-(\text{aq})$ and $\text{H}_3\text{O}^+(\text{aq})$</td>
</tr>
</tbody>
</table>

Use the following additional information to answer the next question.

A 100.0 mL sample of lactic acid has a pH of 3.38.

**Numerical Response**

11. The hydroxide ion concentration in this sample of lactic acid, expressed in scientific notation, is $a.b \times 10^{-cd}$ mol/L. 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.)

34. If a 100.0 mL sample of 0.167 mol/L unknown acid has a pH of 2.32 at 25.0 °C, then the $K_a$ is

A. $2.9 \times 10^{-2}$
B. $4.8 \times 10^{-3}$
C. $1.4 \times 10^{-4}$
D. $2.3 \times 10^{-5}$
Use the following information to answer the next question.

A technician placed an amount of the colourless gas dinitrogen tetraoxide into a flask. He closed the flask and allowed the reaction to reach equilibrium. The dinitrogen tetraoxide partially decomposed to form brown-coloured nitrogen dioxide gas. The data collected during the experiment were recorded below.

<table>
<thead>
<tr>
<th></th>
<th>N\textsubscript{2}O\textsubscript{4}(g)</th>
<th>NO\textsubscript{2}(g)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial Concentration (mol/L)</strong></td>
<td>0.700</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>Final Concentration (mol/L)</strong></td>
<td>0.610</td>
<td>0.180</td>
</tr>
</tbody>
</table>

35. The balanced chemical equation and equilibrium constant for the partial decomposition of dinitrogen tetraoxide gas are

A. \( \text{N}_2\text{O}_4(g) \rightleftharpoons \text{NO}_2(g) \quad K_c = 0.295 \)

B. \( \text{N}_2\text{O}_4(g) \rightleftharpoons 2 \text{NO}_2(g) \quad K_c = 0.053 \)

C. \( \text{NO}_2(g) \rightleftharpoons \text{N}_2\text{O}_4(g) \quad K_c = 3.39 \)

D. \( 2 \text{NO}_2(g) \rightleftharpoons \text{N}_2\text{O}_4(g) \quad K_c = 18.8 \)

Use the following information to answer the next question.

When the system represented by the equation below is at equilibrium in a 2.00 L flask at 15.0 °C, the flask contains 1.15 mmol of H\textsubscript{2}(g), 2.13 mmol of I\textsubscript{2}(g), and 3.74 mmol of HI(g).

\[
\text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2 \text{HI}(g)
\]

**Numerical Response**

12. At 15.0 °C, the equilibrium constant is __________.

(Record your **three-digit answer** in the numerical-response section on the answer sheet.)
Use the following information to answer the next two questions.

In blood, the enzyme carbonic anhydrase catalyzes the formation of carbonic acid from aqueous carbon dioxide and water. Carbonic acid and hydrogen carbonate form an important buffer in the blood. Two reactions that occur in the blood are represented by the equations below.

### Reactions in the Blood

**Equation I**  
\[ \text{CO}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}_2\text{CO}_3(\text{aq}) \]

**Equation II**  
\[ \text{H}_2\text{CO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{HCO}_3^- (\text{aq}) + \text{H}_3\text{O}^+(\text{aq}) \]

36. If the concentration of \( \text{CO}_2(\text{aq}) \) in the blood increases, then the equilibria will shift to the ____ _i____ , and the concentration of \( \text{HCO}_3^- (\text{aq}) \) in the blood 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>left</td>
<td>increase</td>
</tr>
<tr>
<td>B.</td>
<td>left</td>
<td>decrease</td>
</tr>
<tr>
<td>C.</td>
<td>right</td>
<td>increase</td>
</tr>
<tr>
<td>D.</td>
<td>right</td>
<td>decrease</td>
</tr>
</tbody>
</table>

37. The equilibrium law expression for the reaction represented by equation II is

A. \[ K_c = \frac{[\text{H}_2\text{CO}_3(\text{aq})][\text{H}_2\text{O}(\text{l})]}{[\text{HCO}_3^- (\text{aq})][\text{H}_3\text{O}^+(\text{aq})]} \]

B. \[ K_c = \frac{[\text{H}_2\text{CO}_3(\text{aq})]}{[\text{HCO}_3^- (\text{aq})][\text{H}_3\text{O}^+(\text{aq})]} \]

C. \[ K_c = \frac{[\text{HCO}_3^- (\text{aq})][\text{H}_3\text{O}^+(\text{aq})]}{[\text{H}_2\text{CO}_3(\text{aq})][\text{H}_2\text{O}(\text{l})]} \]

D. \[ K_c = \frac{[\text{HCO}_3^- (\text{aq})][\text{H}_3\text{O}^+(\text{aq})]}{[\text{H}_2\text{CO}_3(\text{aq})]} \]
At 200 °C, the equilibrium system represented by the following equation and diagram was established.

\[ \text{PCl}_5(g) + \text{energy} \rightleftharpoons \text{PCl}_3(g) + \text{Cl}_2(g) \]

**Equilibrium System**

38. In the equilibrium system represented in the diagram above, equilibrium was initially established at \( i \) \(_{\text{ii}}\), and the stress applied to the system at 14.0 minutes was \( ii \) \(_{\text{ii}}\) in temperature.

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>4.5 min</td>
<td>an increase</td>
</tr>
<tr>
<td>B.</td>
<td>4.5 min</td>
<td>a decrease</td>
</tr>
<tr>
<td>C.</td>
<td>14.0 min</td>
<td>an increase</td>
</tr>
<tr>
<td>D.</td>
<td>14.0 min</td>
<td>a decrease</td>
</tr>
</tbody>
</table>
39. Which of the following graphs represents the titration of a weak, polyprotic base with a strong, monoprotic acid?

A. 

\[
\text{pH} \quad \begin{array}{c}
\text{Volume added (mL)}
\end{array}
\]

B. 

\[
\text{pH} \quad \begin{array}{c}
\text{Volume added (mL)}
\end{array}
\]

C. 

\[
\text{pH} \quad \begin{array}{c}
\text{Volume added (mL)}
\end{array}
\]

D. 

\[
\text{pH} \quad \begin{array}{c}
\text{Volume added (mL)}
\end{array}
\]

40. Which of the following systems could be at equilibrium?

A. A closed bottle of carbonated water
B. A block of ice in a glass of water
C. Water boiling in a kettle
D. A glass of pop
Use the following information to answer the next question.

<table>
<thead>
<tr>
<th>Equations</th>
<th>( K_c ) at 25 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ( \text{H}_2(g) + \text{Br}_2(g) \rightleftharpoons 2 \text{HBr}(g) )</td>
<td>( 5.0 \times 10^{-18} )</td>
</tr>
<tr>
<td>2 ( \text{H}_2(g) + \text{Cl}_2(g) \rightleftharpoons 2 \text{HCl}(g) )</td>
<td>( 2.5 \times 10^{33} )</td>
</tr>
<tr>
<td>3 ( \text{N}_2(g) + \text{O}_2(g) \rightleftharpoons 2 \text{NO}(g) )</td>
<td>( 2.0 \times 10^{-31} )</td>
</tr>
<tr>
<td>4 ( \text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2 \text{HI}(g) )</td>
<td>( 2.5 \times 10^{-1} )</td>
</tr>
</tbody>
</table>

**Numerical Response**

13. When the equations numbered above are ordered from the reaction that produces the **most** products to the reaction that produces the **least** products, the order is

Most, , , , and Least

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

Use the following information to answer the next question.

<table>
<thead>
<tr>
<th>Weak Acids</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 HF(aq)</td>
</tr>
<tr>
<td>2 H(_2)S(aq)</td>
</tr>
<tr>
<td>3 HOCl(aq)</td>
</tr>
<tr>
<td>4 H(_2)SO(_3)(aq)</td>
</tr>
</tbody>
</table>

**Numerical Response**

14. When the weak acids numbered above are ordered from the acid with the **strongest** conjugate base to the acid with the **weakest** conjugate base, the order is

Strongest, , , , and Weakest

(Record all **four digits** of your answer in the numerical-response section on the answer sheet.)
Use the following information to answer the next question.

Pairs of Solutions

<table>
<thead>
<tr>
<th>Pair</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>HCl(aq) and NaOH(aq)</td>
</tr>
<tr>
<td>II</td>
<td>HClO₄(aq) and KClO₄(aq)</td>
</tr>
<tr>
<td>III</td>
<td>H₂SO₄(aq) and LiHSO₄(aq)</td>
</tr>
<tr>
<td>IV</td>
<td>H₃PO₄(aq) and NaH₂PO₄(aq)</td>
</tr>
</tbody>
</table>

41. If each pair of solutions listed above is mixed together in equal amounts, then the pair of solutions that would act as a buffer is

A. I
B. II
C. III
D. IV
Use the following information to answer the first question.

Sour gas contains a significant amount of hydrogen sulfide gas mixed with methane gas. Hydrogen sulfide gas is a colourless, toxic gas that smells like rotten eggs. Hydrogen sulfide gas can be converted to sulfur dioxide gas in a process called flaring, as represented by the equation below.

\[ 2 \text{H}_2\text{S}(g) + 3 \text{O}_2(g) \rightarrow 2 \text{SO}_2(g) + 2 \text{H}_2\text{O}(g) \]

Written Response—10%

1. **a. Determine** the enthalpy change for the flaring process represented by the equation above. (3 marks)

   **b. Sketch** and label a potential energy diagram that represents the enthalpy change for the flaring process. (2 marks)
Use the following information to answer the next question.

Large amounts of ammonia for the production of fertilizers and other consumer goods are made by the Haber process. During the Haber process, hydrogen gas combines with nitrogen gas to produce ammonia gas. This process is carried out in the presence of a catalyst.

**Written Response—10%**

2. a. Write a balanced equilibrium equation for the Haber process. Include the enthalpy change as an energy term in the balanced equation. (3 marks)

b. Describe what happens to the equilibrium position and the value of the equilibrium constant when the temperature of the system is increased from 200 °C to 500 °C. (2 marks)
The copper covering on the hull of a ship, which is the main body of the ship that is in contact with water, corrodes when it is exposed to water and oxygen. To protect against such corrosion on British naval ships, Sir Humphry Davy was the first to use blocks of either zinc, tin, or iron as sacrificial anodes, which were attached to the ship’s hull.

Use the following information to answer the next question.

3. **Explain** how a block of zinc, tin, or iron would prevent the corrosion of the copper on a ship’s hull.

Your response should include
- an explanation of the corrosion of copper
- an explanation of how a block of zinc, tin, or iron protects the copper from corrosion
- relevant balanced equations and $E^\circ_{\text{cell}}$ calculations to support each of your explanations
### Chemistry 30 Diploma Examination January 2009, Part B: Multiple-Choice and Numerical-Response Answers

Key: MC–Multiple Choice; NR–Numerical Response

<table>
<thead>
<tr>
<th>Question</th>
<th>Key</th>
<th>Diff. %</th>
<th>Question</th>
<th>Key</th>
<th>Diff. %</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC1</td>
<td>A</td>
<td>66.3</td>
<td>MC25</td>
<td>D</td>
<td>78.6</td>
</tr>
<tr>
<td>MC2</td>
<td>D</td>
<td>56.9</td>
<td>MC26</td>
<td>D</td>
<td>69.3</td>
</tr>
<tr>
<td>MC3</td>
<td>D</td>
<td>71.6</td>
<td>NR5</td>
<td>1645</td>
<td>87.4</td>
</tr>
<tr>
<td>MC4</td>
<td>B</td>
<td>68.3</td>
<td>NR6</td>
<td>4613/4614</td>
<td>66.1</td>
</tr>
<tr>
<td>MC5</td>
<td>A</td>
<td>67.4</td>
<td>NR7</td>
<td>4586</td>
<td>54.0</td>
</tr>
<tr>
<td>NR1</td>
<td>3435/3453/4335/4353</td>
<td>41.0</td>
<td>NR8</td>
<td>1342/2342</td>
<td>71.8</td>
</tr>
<tr>
<td>MC6</td>
<td>C</td>
<td>81.6</td>
<td>MC27</td>
<td>B</td>
<td>86.7</td>
</tr>
<tr>
<td>MC7</td>
<td>B</td>
<td>62.7</td>
<td>MC28</td>
<td>D</td>
<td>77.5</td>
</tr>
<tr>
<td>MC8</td>
<td>A</td>
<td>54.5</td>
<td>NR9</td>
<td>1346 (any order)</td>
<td>59.5</td>
</tr>
<tr>
<td>NR2</td>
<td>2414</td>
<td>78.6</td>
<td>MC29</td>
<td>A</td>
<td>58.4</td>
</tr>
<tr>
<td>NR3</td>
<td>4231</td>
<td>52.8</td>
<td>NR10</td>
<td>1.01</td>
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*Difficulty—percentage of students answering the question correctly*

*Please note that these are only sample responses, and that other variations of the response may also have received full marks.

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<th>Marks</th>
<th>Sample Response – Analytic Scoring Criteria</th>
<th>Comments</th>
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</table>
| 1.a.     | 3     | \[2 \text{H}_2\text{S}(g) + 3 \text{O}_2(g) \rightarrow 2 \text{SO}_2(g) + 2 \text{H}_2\text{O}(g)\] \[\Delta H^o = \sum n \Delta f H^o_{(\text{products})} - \sum n \Delta f H^o_{(\text{reactants})}\] \[= [(2 \text{ mol})(-296.8 \text{ kJ/mol}) + (2 \text{ mol})(-241.8 \text{ kJ/mol})] - [(2 \text{ mol})(-20.6 \text{ kJ/mol}) + (3 \text{ mol})(0 \text{ kJ/mol})]\] \[= (-1077.2 \text{ kJ}) - (-41.2 \text{ kJ})\] \[= -1036.0 \text{ kJ}\] | • 1 mark for correct method  
• 1 mark for substitution consistent with method  
• 1 mark for correct answer |
| 1.b.     | 2     | \[\text{Combustion of } \text{H}_2\text{S}(g)\] \[\Delta H = -1036.0 \text{ kJ}\] | • 1 mark for correct labels  
• 1 mark for shape of graph consistent with calculation |

**Note:** Can also be labelled reactants and products.

<table>
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<tr>
<th>1</th>
<th>Communication—See Guide</th>
<th>Use Analytic Scoring Guide</th>
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Total possible marks = 6
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<th>Comments</th>
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</table>
| 2.a.     | 3     | $3 \text{H}_2(\text{g}) + \text{N}_2(\text{g}) \rightleftharpoons 2 \text{NH}_3(\text{g}) + 91.8 \text{kJ}$ | • 1 mark for balanced equation  
• 1 mark for the correct heat value  
• 1 mark for the inclusion of the heat term on the correct side |
| 2.b.     | 2     | The equilibrium position would shift toward the reactants because the forward reaction is exothermic, and the $K_c$ value would decrease. | • 1 mark for correct shift in equilibrium consistent with heat term  
• 1 mark for a change in $K_c$ consistent with the shift |
|          | 1     | Communication—See Guide | Use Analytic Scoring Guide |
|          |       | Total possible marks = 4 |          |
### Question 3

**Corrosion Explanation**

The corrosion of copper is the spontaneous oxidation reaction that occurs when copper reacts with water and oxygen. Solid copper is oxidized to Cu\(^{2+}\)(aq).

\[
\begin{align*}
O_2(g) + 2H_2O(l) + 4e^- &\rightarrow 4OH^-(aq) & E^{\circ}_{\text{reduction}} &= +0.40 \text{ V} \\
Cu(s) &\rightarrow Cu^{2+}(aq) + 2e^- & E^{\circ}_{\text{reduction}} &= +0.34 \text{ V}
\end{align*}
\]

\[
O_2(g) + 2H_2O(l) + 2Cu(s) \rightarrow 4OH^-(aq) + 2Cu^{2+}(aq) \\
\text{OR} \rightarrow 2Cu(OH)_2(s)
\]

**Sacrificial Anode Explanation**

The metal found in the sacrificial anode prevents the corrosion of copper because it (Zn, Sn, or Fe) is a stronger reducing agent than copper and the metal undergoes oxidation before the copper.

If both iron and copper are present with water and oxygen, the reaction that occurs is the following.

\[
O_2(g) + 2H_2O(l) + 2Fe(s) \rightarrow 4OH^-(aq) + 2Fe^{2+}(aq) \\
\text{OR} \rightarrow 2Fe(OH)_2(s)
\]