1. Consider the following reaction. Which quantity in the reaction profile corresponds to the activation energy for the forward reaction?

A. w
B. x
C. y
D. z
E. None of the above.

2. Which substance below behaves as a Lewis acid?

A. Fe³⁺
B. NH₃
C. CN⁻
D. F₂
E. H₂O
3. Which one of the following reactions will have a formation constant \(K_f\) with the largest value?

A. \([\text{Ni(H}_2\text{O)}_6]^2+\text{(aq)}+6 \text{L(aq)}\rightarrow[\text{Co(L)}_6]^2+\text{(aq)}+6 \text{H}_2\text{O(l)}\), where \(\text{L} = \text{NH}_3\)

B. \([\text{Ni(H}_2\text{O)}_6]^2+\text{(aq)}+6 \text{L(aq)}\rightarrow[\text{Co(L)}_6]^2+\text{(aq)}+6 \text{H}_2\text{O(l)}\), where \(\text{L} = \text{CH}_3\text{CH}_2\text{NH}_2\)

C. \([\text{Ni(H}_2\text{O)}_6]^2+\text{(aq)}+3 \text{L(aq)}\rightarrow[\text{Co(L)}_3]^2+\text{(aq)}+6 \text{H}_2\text{O(l)}\), where \(\text{L} = \text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2\)

D. \([\text{Ni(H}_2\text{O)}_6]^2+\text{(aq)}+3 \text{L(aq)}\rightarrow[\text{Co(L)}_3]^2+\text{(aq)}+6 \text{H}_2\text{O(l)}\), where \(\text{L} = \text{NH}_2\text{CH}_2\text{CH}_2\text{NH}_2\)

E. \([\text{Ni(H}_2\text{O)}_6]^2+\text{(aq)}+2 \text{L(aq)}\rightarrow[\text{Co(L)}_2]^2+\text{(aq)}+6 \text{H}_2\text{O(l)}\), where \(\text{L} = \text{NH}_2\text{CH}_2\text{CH}_2\text{NHCH}_2\text{CH}_2\text{NH}_2\)

4. Which of the following reactions would lead to a net decrease in the entropy of the system?

1. \(\text{C}_2\text{H}_4 (g) + \text{Cl}_2(g) \rightarrow \text{C}_2\text{H}_4\text{Cl}_2 (g)\)

2. \(n \text{C}_2\text{H}_4 (g) \rightarrow (-\text{CH}_2-\text{CH}_2-)_n (s)\) (formation of polyethylene)

3. \(\text{Ni(s)} + 4 \text{CO (g)} \rightarrow \text{Ni(CO)}_4 (g)\)

4. \(\text{NH}_3 (g) + \text{H}_2\text{O (l)} \rightarrow \text{NH}_4\text{OH (aq)}\)

A. 1, 2, 3, and 4
B. 1, 3, and 4 only
C. 1, 2, and 3 only
D. 2, 3, and 4 only
E. 2 and 4 only

5. What are the oxidation state and the coordination number of the central metal ion in \([\text{Rh(NH}_3)_4]\text{Cl}(\text{NO}_3)_2\)?

<table>
<thead>
<tr>
<th></th>
<th>Oxidation State</th>
<th>Coordination Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>+1</td>
<td>8</td>
</tr>
<tr>
<td>B.</td>
<td>+2</td>
<td>6</td>
</tr>
<tr>
<td>C.</td>
<td>+3</td>
<td>6</td>
</tr>
<tr>
<td>D.</td>
<td>+3</td>
<td>8</td>
</tr>
<tr>
<td>E.</td>
<td>+2</td>
<td>5</td>
</tr>
</tbody>
</table>

6. Data were collected for the reaction \(X \rightarrow Y\) at two different temperatures, and then plotted below as lines A and B. Which of the following statements is true?

i. the reaction is first-order

ii. the reaction is second-order

iii. data for line A was obtained at the higher temperature

iv. data for line B was obtained at the higher temperature

A. i and iii only
B. i and iv only
C. ii and iii only
D. ii and iv only
E. There is not information given to answer the question.

7. Natural rubber is too soft and reactive for practical applications. What does vulcanization of natural rubber entail?

A. conversion of an addition polymer to a condensation polymer
B. conversion of an condensation polymer to an addition polymer
C. crosslinking polymer chains
D. increasing the molecular weight of a condensation polymer
E. decreasing the molecular weight of an addition polymer
8. The half-life of $^{239}$Pu is 24,000 years. What fraction of the $^{239}$Pu present in nuclear wastes generated today (2013) will be present in the year 3000?

A. 0.09  
B. 0.92  
C. 1.09  
D. 0.97  
E. 0.90

9. Consider the following equilibria:

$$\text{H}_3\text{AsO}_4 \rightleftharpoons \text{H}_2\text{AsO}_4^- + \text{H}^+ \quad (K_{\text{a1}})$$
$$\text{H}_2\text{AsO}_4^- \rightleftharpoons \text{HAsO}_4^{2-} + \text{H}^+ \quad (K_{\text{a2}})$$
$$\text{HAsO}_4^{2-} \rightleftharpoons \text{AsO}_4^{3-} + \text{H}^+ \quad (K_{\text{a3}})$$

What would happen if 5 drops of concentrated HCl are added to this system?

A. $K_{\text{a1}}$ would increase  
B. $[\text{AsO}_4^{3-}]$ would decrease  
C. $[\text{H}_2\text{AsO}_4]$ would decrease  
D. Both A and B  
E. Both A and C

10. A voltaic cell is built using a copper electrode in 1 M CuSO$_4$ solution combined with a silver electrode in 1 M AgNO$_3$ solution at 298K. If the cell operates spontaneously to deliver energy, which of the following statements are true?

1. The standard cell potential is 1.14 volts.  
2. Electrons will flow from the copper electrode to the silver electrode.  
3. The copper electrode will gain in mass as the cell continues to operate over time.

A. 1 only  
B. 2 only  
C. 3 only  
D. 1 and 3 only  
E. 2 and 3 only

11. Which of the following substances, when dissolved in water, will form basic solutions?

$$\text{NH}_4\text{Cl} \quad \text{Co(NO}_3)_3 \quad \text{K}_2\text{CO}_3 \quad \text{NaF}$$

A. NH$_4$Cl and Co(NO$_3)_3$ only  
B. K$_2$CO$_3$ and NH$_4$Cl only  
C. NaF only  
D. NaF and K$_2$CO$_3$ only  
E. NH$_4$Cl only

12. The d-d transition of the [Ti(H$_2$O)$_6$]$^{2+}$ ion has an absorption maximum of about 500 nm. What is the crystal field splitting energy in this complex?

A. $3.98 \times 10^{-19}$ J  
B. $5.67 \times 10^{-18}$ J  
C. $9.12 \times 10^{-17}$ J  
D. $3.89 \times 10^{-16}$ J  
E. $2.44 \times 10^{-15}$ J

13. Given the data in the table below, which of the ions below is the strongest base?

<table>
<thead>
<tr>
<th>Substance</th>
<th>Equilibrium Constant</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCN</td>
<td>$K_a$</td>
<td>$4.0 \times 10^{-4}$</td>
</tr>
<tr>
<td>CH$_3$COOH</td>
<td>$K_a$</td>
<td>$1.8 \times 10^{-5}$</td>
</tr>
<tr>
<td>HClO</td>
<td>$K_a$</td>
<td>$3.2 \times 10^{-8}$</td>
</tr>
<tr>
<td>HS</td>
<td>$K_b$</td>
<td>$1.8 \times 10^{-7}$</td>
</tr>
</tbody>
</table>

A. cyanide ion, CN$^-$  
B. nitrate ion, NO$_3^-$  
C. acetate ion, CH$_3$COO$^-$  
D. hypochlorite ion, ClO$^-$  
E. hydrogen sulfide ion, HS$^-$
14. Which one of the following is likely to be the monomer unit of a polymer synthesized by addition polymerization?
   A. H₂N(CH₂)₆NH₂
   B. (CH₃)₂SiCl₂
   C. CH₃CH=CH₂
   D. CH₃COOH
   E. CH₃CH₂OH

15. A 0.1 M solution of NH₃ is used to titrate a 25ml sample of 0.1 M HCl. What is the approximate pH at the equivalence point? \([K_b(NH_3) = 1.8 \times 10^{-5}]\)
   A. 1
   B. 5
   C. 7
   D. 11
   E. 13

16. The decomposition of H₂O₂ to form O₂ and H₂O is first-order in H₂O₂. A solution originally at 0.600 M H₂O₂ is found to be 0.075 M after 54 min. What is the half-life for the reaction?
   A. 6.8 min
   B. 18 min
   C. 14 min
   D. 28 min
   E. 36 min

17. Given the following table of thermodynamic data, which sentence is true about the vaporization of TiCl₄ in the following reaction?
   \[ \text{TiCl}_4(l) \rightarrow \text{TiCl}_4(g) \]

<table>
<thead>
<tr>
<th>Substance</th>
<th>ΔH° (kJ/mol)</th>
<th>S° (J/mol • K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TiCl₄ (g)</td>
<td>-763.2</td>
<td>354.9</td>
</tr>
<tr>
<td>TiCl₄ (l)</td>
<td>-804.2</td>
<td>221.9</td>
</tr>
</tbody>
</table>

   A. The reaction is spontaneous at all temperatures.
   B. The reaction is spontaneous at low temperature and nonspontaneous at high temperature.
   C. The reaction is non-spontaneous at low temperature and spontaneous at high temperature.
   D. The reaction is nonspontaneous at all temperatures.
   E. There is not enough information given to draw a conclusion.

18. The \(K_a\) for nitrous acid HNO₂ is \(4.5 \times 10^{-4}\) at 298 K. What is the value of \(G\) (at 298 K) when \([HNO_2] = 0.200 \text{ M}, [NO_2^-] = 0.100 \text{ M} \text{ and } [H^+] = 0.100 \text{ M}\)?
   A. 19.1 kJ/mol
   B. 17.5 kJ/mol
   C. 11.7 kJ/mol
   D. 7.48 kJ/mol
   E. \(-19.1\) kJ/mol

19. According to molecular orbital theory, what is the bond order in the O₂⁻ ion?
   A. 1
   B. 3
   C. 2
   D. 2.5
   E. 1.5
20. Which of the following decreases when solid Ba(OH)₂ is added to a saturated solution of BaCO₃? (Ksp = 5.1 x 10⁻⁹)
   A. [Ba²⁺]
   B. [CO₃²⁻]
   C. [OH⁻]
   D. pH
   E. Both A and B

21. What is the most probable mode of decay of ^40Cl?
   A. α emission
   B. β emission
   C. positron emission
   D. neutron emission
   E. electron capture

22. If you want to dope Si to make a p-type semiconductor, which element would you choose?
   A. B
   B. P
   C. Ge
   D. Se
   E. Te

23. What is the equilibrium constant for the following reaction? (Ksp for CdS(s) = 8.0 x 10⁻²⁸ and Kf for [Cd(CN)₄]²⁻ = 7.1 x 10¹⁶)
   \[ \text{CdS(s) + 4 CN}^{-} (aq) \rightleftharpoons [\text{Cd(CN)}₄]²⁻ (aq) + \text{S}²⁻ (aq) \]
   A. 1.1 x 10⁻⁴⁴
   B. 8.0 x 10⁻²⁸
   C. 5.7 x 10⁻¹¹
   D. 7.1 x 10¹⁶
   E. 8.9 x 10⁴³

24. What will be the emf of the cell shown below when [Sn²⁺] = 0.5 M and [Cu²⁺] = 0.8 M at 298K?
   A. −0.474 V
   B. −0.486 V
   C. +0.492 V
   D. +0.486 V
   E. +0.464 V
25. Consider the following reaction:

\[ \text{S}_2\text{O}_8^{2-}(\text{aq}) + 3 \text{I}^{-}(\text{aq}) \rightarrow 2 \text{SO}_4^{2-}(\text{aq}) + \text{I}_3^{-}(\text{aq}) \]

When the rate of disappearance of I\(^-\) is 0.10 M s\(^{-1}\), what is the rate of appearance of S\(\text{O}_4^{2-}\)?

A. 0.30 M s\(^{-1}\)
B. 0.20 M s\(^{-1}\)
C. 0.15 M s\(^{-1}\)
D. 0.10 M s\(^{-1}\)
E. 0.07 M s\(^{-1}\)

26. Under standard conditions, which species is capable of oxidizing Fe\(^{2+}\)(aq)?

A. Ag\(^+\) (aq)
B. Cl\(^-\) (aq)
C. Fe (s)
D. Mg\(^2+\) (aq)
E. Cu (s)

27. Calculate the pH of a solution that is 0.222 M in nitrous acid (HNO\(_2\)) and 0.278 M in potassium nitrite (KNO\(_2\)). The acid dissociation constant of nitrous acid is \(4.5 \times 10^{-4}\).

A. 3.22
B. 3.33
C. 3.44
D. 2.00
E. 1.32

28. Which of the following compounds would be paramagnetic?

A. [Zn(NH\(_3\))\(_4\)]Cl\(_2\)
B. CaSO\(_4\)
C. [Cu(H\(_2\)O)\(_4\)]Br
D. [Co(NH\(_3\))\(_6\)]Cl\(_3\) (low spin)
E. K[FeCl\(_4\)]

29. The semiconductor band gap energy determines the color of an LED. If the band gap energy is 2.4 eV, what color does the LED appear? (1 eV = 1.6 \(\times\) 10\(^{-19}\) J)

A. red
B. orange
C. yellow
D. green
E. blue

30. [Ni(OH\(_2\))\(_6\)]\(^{2+}\) is green while [Ni(NH\(_3\))\(_6\)]\(^{2+}\) is blue. Which of the following statements is correct?

A. [Ni(OH\(_2\))\(_6\)]\(^{2+}\) absorbs green light and [Ni(NH\(_3\))\(_6\)]\(^{2+}\) absorbs blue light.
B. The crystal field splitting energy \(\Delta\) is smaller for [Ni(OH\(_2\))\(_6\)]\(^{2+}\) than for [Ni(NH\(_3\))\(_6\)]\(^{2+}\).
C. If [Ni(OH\(_2\))\(_6\)]\(^{2+}\) is a high spin complex and [Ni(NH\(_3\))\(_6\)]\(^{2+}\) is a low spin complex, both compounds are diamagnetic.
D. The different colors are due to the chelate effect.
E. The different colors are due to the different oxidation states of nickel.
31. The strongest force holding CaBr₂ together as a solid is
A. London dispersion force.
B. ion-dipole force
C. ionic interactions
D. dipole-dipole force
E. covalent bonding

32. Which of the following solids will have the highest melting point?
A. Ar (s)
B. H₂O (s)
C. CO₂ (s)
D. SiO₂ (s)
E. Hg (s)

33. Consider the species N₂⁻, N₂, and N₂⁺. Which of these species will be paramagnetic according to molecular orbital theory?
A. N₂ and N₂⁻ only
B. N₂⁺ and N₂ only
C. N₂⁻ and N₂⁺ only
D. N₂⁺ only
E. N₂⁻ only

34. The overall reaction for the gas phase oxidation of HBr by O₂ is shown below, along with the proposed mechanism.

Overall: 4 HBr(g) + O₂(g) → 2 H₂O (g) + 2 Br₂ (g)

Step 1: HBr(g) + O₂(g) → HOOBr(g)
Step 2: HOOBr(g) + HBr(g) → 2 HOBr(g)
Step 3: HOBr(g) + HBr(g) → H₂O(g) + Br₂(g)

The experimentally determined rate law is rate = k [HBr][O₂]. Which of the following statement(s) is true?
A. Step 1 is rate-determining.
B. Step 2 is rate-determining.
C. HOOBr is a catalyst.
D. HOBr is a catalyst.
E. Both A and C.

35. Which of these compounds will be colorless?
A. [Co(CN)₆]³⁻
B. [Cr(NH₃)₆]³⁺
C. [Ni(OH₂)₆]²⁺
D. [Cu(OH₂)₆]⁺
E. [Ti(NH₃)₆]²⁺
Three energy diagrams are shown below. They correspond to Al, C(diamond), and GaAs, not necessarily in that order. Match each energy diagram to the correct compound.

<table>
<thead>
<tr>
<th>DIAGRAM I</th>
<th>DIAGRAM II</th>
<th>DIAGRAM III</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. C (diamond)</td>
<td>GaAs</td>
<td>Al</td>
</tr>
<tr>
<td>B. GaAs</td>
<td>C (diamond)</td>
<td>Al</td>
</tr>
<tr>
<td>C. C (diamond)</td>
<td>Al</td>
<td>GaAs</td>
</tr>
<tr>
<td>D. GaAs</td>
<td>Al</td>
<td>C (diamond)</td>
</tr>
<tr>
<td>E. Al</td>
<td>GaAs</td>
<td>C (diamond)</td>
</tr>
</tbody>
</table>

Which of the following is the cathodic reaction in the electrolysis of aqueous LiF?

A. \( \text{Li}^+(aq) + e^- \rightarrow \text{Li}(s) \)
B. \( \text{Li}(s) \rightarrow \text{Li}^+(aq) + e^- \)
C. \( 2 \text{F}^-(aq) \rightarrow \text{F}_2(g) + 2 e^- \)
D. \( 2 \text{H}_2\text{O}(l) + 2 e^- \rightarrow \text{H}_2(g) + 2 \text{OH}^- (aq) \)
E. \( 2 \text{H}_2\text{O}(l) \rightarrow \text{O}_2(g) + 4 \text{H}^+(aq) + 4 e^- \)

How much energy is released in the following fusion reaction?

\[ ^{3}\text{H} + ^{3}\text{H} \rightarrow ^{4}\text{He} + ^{1}\text{n} \]

Use atomic and particle masses of \(^3\text{H} = 2.0140 \text{ amu}, ^3\text{H} = 3.01603 \text{ amu}, ^4\text{He} = 4.00260 \text{ amu}, \text{and } ^1\text{n} = 1.008665 \text{ amu}. \)

A. \(4.0 \times 10^{15} \text{ J} \)
B. \(2.9 \times 10^{12} \text{ J} \)
C. \(2.8 \times 10^{-9} \text{ J} \)
D. \(2.8 \times 10^{-12} \text{ J} \)
E. \(4.0 \times 10^{-15} \text{ J} \)

What is the molar solubility of \( \text{La(IO}_3\text{)}_3(s) \) in water at 298K? \( K_{sp} = 6.1 \times 10^{-12} \)

A. \(6.9 \times 10^{-4} \text{ moles/liter} \)
B. \(9.1 \times 10^{-5} \text{ moles/liter} \)
C. \(3.3 \times 10^{-5} \text{ moles/liter} \)
D. \(5.5 \times 10^{-10} \text{ moles/liter} \)
E. \(1.4 \times 10^{-6} \text{ moles/liter} \)