1. Balance the following reaction in acid solution.

\[
\text{H}_2\text{O}_2 + \text{Fe}^{2+} \rightarrow \text{Fe}^{3+} + \text{H}_2\text{O(liq)}
\]

What is the coefficient in front of water?

A. 1  
B. 2  
C. 3  
D. 4  
E. 5

2. Which of the following reactions will proceed spontaneously under standard conditions.

i. \[
\text{H}_2(g) + \text{Ni}^{2+}(\text{aq}) \rightarrow 2 \text{H}^+(\text{aq}) + \text{Ni(s)}
\]

ii. \[
2 \text{Cr(s)} + 3 \text{Zn}^{2+}(\text{aq}) \rightarrow 2 \text{Cr}^{3+}(\text{aq}) + 3 \text{Zn(s)}
\]

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

A. i only  
B. ii only  
C. iii only  
D. i and iii  
E. ii and iii

3. Quartz is the second most abundant mineral in the Earth's continental crust. It has a molecular formula of SiO\text{2}. A solid of this compound would be classified as:

A. Network covalent  
B. Metallic  
C. Atomic  
D. Ionic  
E. Molecular
4. Which of the following process results in a positive entropy change for the system?

A. $2 \text{H}_2 (g) + \text{O}_2 (g) \rightarrow 2 \text{H}_2\text{O} (g)$
B. $\text{NH}_4\text{Cl} (s) \rightarrow \text{NH}_3 (g) + \text{HCl} (g)$
C. $2 \text{Zn} (s) + \text{O}_2 (g) \rightarrow 2 \text{ZnO} (s)$
D. $2 \text{CO} (g) + \text{O}_2 (g) \rightarrow 2 \text{CO}_2 (g)$
E. $\text{N}_2 (g) + 3 \text{H}_2 (g) \rightarrow 2 \text{NH}_3 (g)$

5. How many d electrons are in the chromium ion of $[\text{Cr(H}_2\text{O)}_4\text{Cl}_2]\text{Cl}$?

A. 3
B. 4
C. 5
D. 6
E. 7

6. Which of the following complexes is colorless?

A. $[\text{Cd(H}_2\text{O)}_6]^{2+}$
B. $[\text{Co(H}_2\text{O)}_6]^{2+}$
C. $[\text{V(H}_2\text{O)}_6]^{2+}$
D. $[\text{Fe(H}_2\text{O)}_6]^{2+}$
E. $[\text{Cu(H}_2\text{O)}_4]^{2+}$

7. What is the likely nuclear decay process for $^{35}\text{S}$?

A. $\alpha$ emission
B. $\beta$ emission
C. positron emission
D. electron capture
E. none; this isotope will be stable
8. Consider the following reaction: \( A \rightarrow 5B \). How is the average rate of disappearance of \( A \) related to the average rate of appearance of \( B \)?

A. \( \frac{\Delta [B]}{\Delta t} = 5 \left( \frac{\Delta [A]}{\Delta t} \right) \)

B. \( \frac{\Delta [B]}{\Delta t} = \frac{1}{5} \left( \frac{\Delta [A]}{\Delta t} \right) \)

C. \( \frac{\Delta [B]}{\Delta t} = -5 \left( \frac{\Delta [A]}{\Delta t} \right) \)

D. \( \frac{\Delta [B]}{\Delta t} = -\frac{1}{5} \left( \frac{\Delta [A]}{\Delta t} \right) \)

E. \( \frac{\Delta [B]}{\Delta t} = \left( \frac{\Delta [A]}{\Delta t} \right) \)

9. 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>
10. 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

11. The unit cell shown below can be classified as:

A. Primitive cubic  
B. Body-centered cubic  
C. Face-centered cubic  
D. Hexagonal close-packed  
E. None of the above

12. Which of the following can be considered an allotropic form of carbon?
   i. Diamond  
   ii. Graphite  
   iii. Buckyball  
   iv. Graphene  

A. i only  
B. i and ii  
C. ii and iv  
D. i, ii, and iii  
E. all of the above
13. What is the pH of a 0.020 M solution of Ba(OH)$_2$?

A. 1.7
B. 4.1
C. 7.0
D. 11.3
E. 12.6

14. As part of the process to purify Ni, carbon monoxide, CO, is used to form nickel carbonyl, Ni(CO)$_4$(g) as follows:

Ni(s) + 4 CO(g) ⇌ Ni(CO)$_4$(g)

Using the values for $\Delta G^\circ_f$ below, determine the value for the equilibrium constant for the reaction at 298 K.

<table>
<thead>
<tr>
<th>Substance</th>
<th>CO</th>
<th>Ni(CO)$_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta G^\circ_f$ (kJ/mol)</td>
<td>-137.3</td>
<td>-587.4</td>
</tr>
</tbody>
</table>

A. $3.8 \times 10^{-16}$
B. 0.83
C. 0.98
D. $5.0 \times 10^6$
E. $2.6 \times 10^{15}$

15. What is the equilibrium constant for the following reaction at 25 °C? Note: the answer you get for this is very sensitive to the values you use in the calculation.

Mg(s) + Zn$^{2+}$(aq) ⇌ Mg$^{2+}$(aq) + Zn(s)

A. $1.6 \times 10^3$
B. $6.2 \times 10^{11}$
C. $4.5 \times 10^{23}$
D. $1.4 \times 10^{27}$
E. $2.3 \times 10^{54}$
16. The section of polymer shown below corresponds to Kevlar, a very hard substance used in bulletproof vests. This polymer is made via the condensation reaction between two monomers. Which two of the following molecules are the monomers?

A. I and III
B. I and IV
C. V and VI
D. I and VI
E. III and IV
17. How many faradays (F) of electricity are needed to plate 0.01 mole of Cr metal onto an electrode when a current is passed through potassium dichromate K$_2$Cr$_2$O$_7$(aq) solution?

A. 0.01 F  
B. 0.06 F  
C. 0.03 F  
D. 0.15 F  
E. 0.30 F

18. The pH of a 0.30 M solution of a weak base is 10.66. What is the $K_b$?

A. $1.5 \times 10^{-3}$  
B. $4.6 \times 10^{-4}$  
C. $9.6 \times 10^{-10}$  
D. $6.6 \times 10^{2}$  
E. $7.0 \times 10^{-7}$

19. What is the pH of the resulting solution when 25 mL of 0.10 M NaOH is added to 25 mL of 0.25 M HNO$_3$?

A. 1.12  
B. 4.25  
C. 7.00  
D. 8.65  
E. 12.88

20. Which octahedral transition metal complex would you expect to be diamagnetic? (Hint: Cl$^-$ and H$_2$O are weak field ligands, CN$^-$ and NH$_3$ are strong field ligands.)

A. [Co(H$_2$O)$_6$]$^{2+}$  
B. [Fe(CN)$_6$]$^{3-}$  
C. [Fe(CN)$_6$]$^{4-}$  
D. [Mn(NH$_3$)$_6$]$^{3+}$  
E. [MnCl$_6$]$^{3-}$
21. Which of the following aqueous solutions would have a pH BELOW 7.0?

   i. 0.2 M HF  
   ii. 1.5 M CH₃COONa  
   iii. 3.0 M NH₄Br  
   iv. 0.5 M NH₃  
   v. 0.85 M FeCl₃

A. i, iii, v  
B. ii, iv  
C. i, ii, iii  
D. i only  
E. none of them, they are all basic

22. At high temperature, nitrogen dioxide spontaneously decomposes to nitrogen monoxide and oxygen.

\[ 2 \text{NO}_2 (g) \rightarrow 2 \text{NO} (g) + \text{O}_2 (g) \]

The concentration of NO₂ was monitored as a function of time and the following data was obtained.

If the experiment was repeated with an initial NO₂ concentration of 0.250 M at the same temperature, how long would it take to decompose half of the NO₂?

A. 0.202 sec  
B. 0.566 sec  
C. 1.72 sec  
D. 7.37 sec  
E. 9.31 sec
23. How much energy must be supplied to break a single copper-63 nucleus into separated protons and neutrons if a copper-63 nucleus has a mass of 62.91367 amu?

A. $1.56 \times 10^{16}$ J  
B. $2.60 \times 10^{11}$ J  
C. $4.53 \times 10^{-8}$ J  
D. $8.85 \times 10^{-11}$ J  
E. $9.62 \times 10^{-10}$ J

24. An ancient Egyptian wooden artifact has a $^{14}$C activity of 15 counts/minute. Modern wood has a $^{14}$C activity of 48 counts/minute. What is the age of the Egyptian artifact? (The half-life for $^{14}$C is 5700 years.)

A. 1254 years  
B. 3397 years  
C. 3742 years  
D. 6712 years  
E. 9565 years

25. Calculate the crystal field splitting energy of $[\text{Co(SCN)}_4]^{2-}$, which has a maximum absorbance of 530 nm.

A. $3.75 \times 10^{-22}$ kJ/mol  
B. 154 kJ/mol  
C. 226 kJ/mol  
D. $2.26 \times 10^{-4}$ kJ/mol  
E. 37.5 kJ/mol

26. Consider the species $\text{O}_2$, $\text{O}_2^-$, and $\text{O}_2^{2-}$. Which of these species will be paramagnetic?

A. $\text{O}_2$ and $\text{O}_2^-$ only  
B. $\text{O}_2^-$ and $\text{O}_2^{2-}$ only  
C. $\text{O}_2$ and $\text{O}_2^{2-}$ only  
D. $\text{O}_2$ only  
E. $\text{O}_2^-$ only
27. Which one of the following reactions will have a formation constant ($K_f$) with the largest value?

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

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

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

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

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

28. Consider the following equilibria:

\[
\begin{align*}
\text{H}_3\text{AsO}_4 & \rightleftharpoons \text{H}_2\text{AsO}_4^- + \text{H}^+ \quad (K_{a1}) \\
\text{H}_2\text{AsO}_4^- & \rightleftharpoons \text{HAsO}_4^{2-} + \text{H}^+ \quad (K_{a2}) \\
\text{HAsO}_4^{2-} & \rightleftharpoons \text{AsO}_4^{3-} + \text{H}^+ \quad (K_{a3})
\end{align*}
\]

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

i. $K_{a1}$ would increase

ii. $[\text{AsO}_4^{3-}]$ would decrease

iii. $[\text{H}_3\text{AsO}_4]$ would decrease

A. i only
B. ii only
C. iii only
D. i and ii
E. i and iii

29. According to molecular orbital theory, what is the bond order in the $\text{NO}^+$ ion? (Use MO diagram for small 2s-2p interaction)

A. 1
B. 1.5
C. 2
D. 2.5
E. 3
30. The \([\text{Cr}(\text{H}_2\text{O})_6]^{2+}\) ion has an absorption maximum at about 630 nm. Which of the following complexes absorbs higher energy photons?

i. green \([\text{Ni}(\text{H}_2\text{O})_6]^{2+}\)

ii. orange \([\text{Co}((\text{NH}_3)_6]^{3+}\)

iii. red \([\text{Fe}((\text{NCS})_6]^{3+}\)

A. i
B. ii
C. iii
D. i and ii
E. ii and iii

31. The color and wavelength of light emitted from various LEDs are given below. Which one has the largest band gap?

<table>
<thead>
<tr>
<th>LED composition</th>
<th>Color</th>
<th>Wavelength</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. ZnSe</td>
<td>blue</td>
<td>500 nm</td>
</tr>
<tr>
<td>B. AlGaAs</td>
<td>red</td>
<td>630 nm</td>
</tr>
<tr>
<td>C. GaAsP</td>
<td>orange</td>
<td>610 nm</td>
</tr>
<tr>
<td>D. GaP</td>
<td>yellow</td>
<td>590 nm</td>
</tr>
<tr>
<td>E. InGaN</td>
<td>green</td>
<td>565 nm</td>
</tr>
</tbody>
</table>

32. Put these in order of increasing solubility in water.

i. \(\text{Fe(OH)}_2\) \(K_{sp} = 7.9 \times 10^{-16}\)

ii. \(\text{CoCO}_3\) \(K_{sp} = 1.0 \times 10^{-10}\)

iii. \(\text{Ag}_2\text{CrO}_4\) \(K_{sp} = 1.2 \times 10^{-12}\)

A. i < iii < ii
B. iii < i < ii
C. ii < i < iii
D. iii < ii < i
E. i < ii < iii
33. What is the concentration of Fe$^{3+}$ ions in a saturated solution of Fe(OH)$_3$ at a pOH of 9? $K_{sp}$ of Fe(OH)$_3$ is $1.1 \times 10^{-36}$

A. $1.1 \times 10^{-9}$ M  
B. $4.5 \times 10^{-10}$ M  
C. $4.1 \times 10^{-11}$ M  
D. $1.1 \times 10^{-21}$ M  
E. $3.0 \times 10^{-26}$ M

34. What is the concentration of [Cd$^{2+}$ (aq)] in a solution made by dissolving 0.01 mole of Cd(NO$_3$)$_2$ in 500 mL of a solution of KCN that is 0.45 M at equilibrium? $K_f$ of [Cd(CN)$_4$]$^{2-}$ is $3.0 \times 10^{18}$

A. $1.6 \times 10^{-19}$ M  
B. $3.3 \times 10^{-19}$ M  
C. $3.0 \times 10^{-21}$ M  
D. $7.2 \times 10^{-21}$ M  
E. $6.1 \times 10^{18}$ M

35. 50.0 mL of 0.50 M NaOH is added to a 250 mL buffer solution containing 0.30 M NH$_3$ and 0.36 M NH$_4$Cl. What is the pH of the solution after the addition of the base? $K_b$ of NH$_3$ = $1.8 \times 10^{-5}$

A. 7.26  
B. 8.56  
C. 9.44  
D. 10.08  
E. 12.23
36. Calculate the pH at the equivalence point when 50.0 mL of 0.10 M methylamine (CH₃NH₂) is titrated with a 0.20 M HCl solution.  \( K_b \) of CH₃NH₂ = \( 4.4 \times 10^{-4} \).

A. 4.19  
B. 5.91  
C. 7.00  
D. 8.09  
E. 11.81

37. A slightly bruised apple will rot extensively in 4 days at room temperature (20°C). If it is kept in a refrigerator at 0°C it takes 16 days for the apple to rot to the same extent. What is the activation energy for the reaction that causes rotting?

A. 2.88 kJ/mol  
B. 20.0 kJ/mol  
C. 37.5 kJ/mol  
D. 46.1 kJ/mol  
E. 133 kJ/mol

38. The reaction of hydrogen bromide with oxygen proceeds as follows:

\[
4 \text{HBr(g)} + \text{O}_2(g) \rightarrow 2 \text{H}_2\text{O(g)} + 2 \text{Br}_2(g)
\]

A possible mechanism for the reaction is:

\[
\begin{align*}
\text{HBr(g) + O}_2(g) & \quad \rightleftharpoons \quad \text{HOBr(g)} & \text{step 1} \\
\text{HOBr(g) + HBr(g) & \rightarrow \quad 2\text{HOBr(g)}} & \text{step 2} \\
\text{HOBr(g) + HBr(g) & \rightarrow \quad \text{H}_2\text{O(g) + Br}_2(g)} & \text{step 3}
\end{align*}
\]

If the experimentally observed rate law is rate = \( k [\text{HBr}]^2[\text{O}_2] \), then

A. step one is rate-determining  
B. step two is rate-determining  
C. step three is rate-determining  
D. the overall reaction is second-order  
E. the overall reaction is first-order
39. For the following voltaic cell, which of the following statements is incorrect?

![Voltaic cell diagram]

A. $\Delta G < 0$.
B. The Cu(s) electrode is the cathode.
C. Na$^+$ ions migrate from the salt bridge to the Cu half-cell compartment.
D. Electrons flow towards the Cu electrode.
E. $E_{cell}$ is 0.636 V.

40. In the electrolysis of an aqueous solution containing 1M FeCl$_3$ and 1M CuBr$_2$, what is the initial product formed at the anode?

A. Br$_2$ (aq)
B. Cu (s)
C. Cu$^{2+}$ (aq)
D. Fe (s)
E. Cl$_2$ (g)

End of Exam