Please read the following instructions before starting to work on this exam.

1. Each multiple-choice and short answer question should be answered on an answer sheet.
2. Write the answer and question number clearly on the answer sheet.
3. You may use an approved calculator.
4. Potentially useful information:

### PERIODIC TABLE OF THE ELEMENTS

| 1A  | 2A  | 3B  | 4B  | 5B  | 6B  | 7B  | 8B  | 8B  | 8B  | 1B  | 2B  | 3A  | 4A  | 5A  | 6A  | 7A  | 8A  |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| H  | He | Li  | Be  | B  | C  | N  | O  | F  | Ne | Na  | Mg  | Al  | Si  | P  | S  | Cl  | Ar  |
| K  | Ca  | Sc  | Ti  | V  | Cr  | Mn  | Fe  | Co  | Ni  | Cu  | Zn  | Ga  | Ge  | As  | Se  | Br  | Kr  |
| 39.10 | 40.08 | 44.96 | 47.90 | 50.94 | 52.00 | 54.94 | 56.96 | 58.93 | 58.71 | 63.55 | 65.39 | 69.72 | 72.61 | 74.92 | 78.96 | 79.90 | 83.80 |
| Rb  | Sr  | Y  | Zr  | Nb  | Mo  | Tc  | Ru  | Rh  | Pd  | Ag  | Cd  | In  | Sn  | Sb  | Te  | I  | Xe  |
| 85.47 | 87.62 | 88.91 | 91.22 | 92.91 | 95.41 | 99.00 | 101.1 | 102.9 | 106.4 | 107.9 | 112.4 | 114.8 | 118.7 | 121.8 | 126.9 | 131.3 |
| Cs  | Ba  | La  | Hf  | Ta  | W  | Re  | Os  | Ir  | Pt  | Au  | Hg  | Tl  | Pb  | Bi  | Po  | At  | Rn  |
| 132.9 | 137.3 | 138.9 | 178.5 | 181.0 | 183.8 | 186.2 | 186.9 | 187.2 | 196.5 | 197.0 | 200.6 | 204.2 | 207.2 | 209.0 | 210.0 | 222.0 |
| Fr  | Ra  | Ac  | U  | Np  | Pu  | Am  | Cm  | Bk  | Cf  | Es  | Fm  | Md  | No  | Lr  | Rf  | Db  | Sg  |
| 223 | 226.0 | 227.0 | 231(281) | 232(282) | 238(282) | 239(282) | 244(282) | 247(282) | 253(282) | 257(282) | 261(282) | 262(282) | 268(282) | 277(282) | 285(282) |
| Formulæ: | \( t_{1/2} = (ln2/k) \), \( ln2 = 0.693 \) | \( v = \sqrt{R(1/n_1^2 - 1/n_2^2)} \), \( R = 3.29 \times 10^{15} \) Hz | \( \Delta E^0 = E^0(\text{cathode}) - E^0(\text{anode}) \) | \( \Delta G^0 = -nFE^0 \) | \( \Delta E = \Delta E^0 - (0.05916/n)\log Q \) |
| Constants: | \( R = 8.314 \) J / mol K | \( \Delta H_f^0(\text{kJ/mol}) \) | \( S^0(\text{J/K-mol}) \) | | | | | | | | | | | | | | |
| 1 atm = 760 Torr | O\(_2\)(g) | 205 | | | | | | | | | | | | | | |
| = 1.01 \times 10^5 Pa | H\(_2\)(g) | 130.7 | | | | | | | | | | | | | | |
| = 0.0821 L atm / K mol | H\(_2\)O(g) | -241.8 | | | | | | | | | | | | | | |
| = 8.314 L kPa / K mol | CO(g) | -110.5 | | | | | | | | | | | | | | |
| c = 2.99 \times 10^8 m/s | CO\(_2\)(g) | -393.5 | | | | | | | | | | | | | | |
| h = 6.63 \times 10^{-34} J·s | C\(_2\)H\(_5\)OH(g) | -235.1 | | | | | | | | | | | | | | |
| h = 1.05 \times 10^{-34} J·s | F = 96,500 Coulombs/mole | | | | | | | | | | | | | | |
| Ag\(^+\)(aq) + e\(^-\) \rightarrow Ag(s) | E\(^0\) = 0.80 V | | | | | | | | | | | | | | |
| Cu\(^2+\)(aq) + 2e\(^-\) \rightarrow Cu(s) | E\(^0\) = 0.34 V | | | | | | | | | | | | | | |

**Thermodynamic Data**
Part I: Multiple-choice questions (60%)

1. The Claus reactions, shown below, are used to generate elemental sulfur from hydrogen sulfide.

\[ \text{Fe}_2\text{O}_3 \rightarrow 2\text{SO}_2 + 2\text{H}_2\text{O} \]
\[ \text{SO}_2 + 2\text{H}_2\text{S} \rightarrow 3\text{S} + 2\text{H}_2\text{O} \]

How much sulfur (in grams) is produced from 10.1 grams of O\(_2^\text{2}\)?

a. 16.0 g
b. 20.2 g
c. 32.1 g
d. 48.1 g
e. none of these

2. In an isothermal process, the pressure on one mole of an ideal monatomic gas suddenly changes from 7.50 atm to 2.20 atm at 25°C. Calculate q.

a. -3.04 kJ
b. -1.70 kJ
c. 0
d. 1.70 kJ
e. 3.04 kJ

3. Which of the following is true concerning vapor pressure?

a. Solids do not have vapor pressures.
b. Gases generally have lower vapor pressures than both liquids and solids.
c. Solids generally have lower vapor pressures than both liquids and gases.
d. Liquids generally have lower vapor pressures than both solids and gases.
e. There is no general trend for vapor pressures among solids, liquids, and gases.
4. Which of the following atomic symbols is incorrect?
   a. 14
      8N
   b. 32
      15P
   c. 14
      6C
   d. 39
      19K
   e. 37
      17Cl

5. Calculate the pH of the following aqueous solution. Choose your answer from the following pH ranges:
   0.5 M H₂S (pKₐ₁ = 7.00; pKₐ₂ = 12.89)
   a. pH 0.00 - 2.99
   b. pH 3.00 - 5.99
   c. pH 6.00 - 8.99
   d. pH 9.00 - 10.99
   e. pH 11.00 - 14.00

6. How many of the following molecules or ions are linear?
   \[
   \text{NH}_3 \quad \text{NH}_4^+ \quad \text{HCN} \quad \text{CO}_2 \quad \text{O}_3 \quad \text{NO}_2
   \]
   a. 0
   b. 1
   c. 2
   d. 3
   e. 4

7. The hybridization of the central atom in XeCl₃⁺ is:
   a. sp
   b. sp²
   c. sp³
   d. dsp³
   e. d²sp³
8. The following questions refer to the hypothetical reaction
A + B \rightarrow \text{products}. The kinetics data given can be analyzed to
answer the questions.

<table>
<thead>
<tr>
<th>[A]₀ (mol/L)</th>
<th>[B]₀ (mol/L)</th>
<th>Rate of decrease of [A] (M/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0</td>
<td>5.0</td>
<td>X</td>
</tr>
<tr>
<td>10.0</td>
<td>5.0</td>
<td>2X</td>
</tr>
<tr>
<td>5.0</td>
<td>10.0</td>
<td>2X</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>[B] (mol/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0</td>
<td>100</td>
</tr>
<tr>
<td>20.0</td>
<td>100</td>
</tr>
<tr>
<td>30.0</td>
<td>100</td>
</tr>
</tbody>
</table>

Determine the magnitude of the pseudo-rate constant (k') if
the magnitude of X in the rate data is \(8.5 \times 10^{-3}\).

a. 0.31
b. 0.86
c. \(1.2 \times 10^{-2}\)
d. \(1.63 \times 10^{-3}\)
e. \(4.3 \times 10^{-3}\)

9. Suppose you are studying coordination compounds of Co(II)
with the ligand pyridine (py, \(\text{C}_5\text{H}_5\text{N}\), molar mass = 79.10).
You isolate a crystalline compound, and since the only
available anions are \(\text{Cl}^-\) and \(\text{NO}_3^-\), you hypothesize the
empirical formula of the coordination compound must be
\(\text{Co(II)}_w(\text{py})_x(\text{Cl})_y(\text{NO}_3)_z\).

Analysis of the data from a titration indicates that a
0.1000-g sample of the complex contains 0.708 g of py.
Further analysis shows that 0.1000 g of the complex contains
a 0.0132 g of cobalt and 0.0160 g of
chloride. What is the empirical formula of the complex?

a. \(\text{Co}_2(\text{py})_5(\text{Cl})_2(\text{NO}_3)_2\)
b. \(\text{Co(py)}_4(\text{NO}_3)_2\)
c. \(\text{Co(py)}_6(\text{Cl})(\text{NO}_3)\)
d. \(\text{Co}_3(\text{py})_8(\text{Cl})_2(\text{NO}_3)_4\)
e. \(\text{Co(ppy)}_4\text{Cl}_2\)
10. Based on the phase diagram shown below, which of the following statements are correct?

![Phase Diagram]

I. Sublimation occurs at a point in the transformation that occurs along a straight line from point A to point F.
II. C and E represent points where the gas and liquid phases are in equilibrium.
III. $\Delta H_{vap}$ can be measured at point B.
IV. Molecules at point D have a greater average kinetic energy than those at point F.
V. The temperature at point E is called the critical temperature of the compound.

a. I, II, IV
b. II, V
c. II, IV, V
d. I, II, III
e. I, III, IV

11. A gas expands isothermally and irreversibly. $\Delta S_{surr}$ is

a. less than zero.
b. equal to zero.
c. greater than zero.
d. More information is needed.

12. Calculate the solubility of $\text{Ag}_2\text{CrO}_4$ [$K_{sp} = 9.0 \times 10^{-12}$] in a $1.0 \times 10^{-2}$ M $\text{AgNO}_3$ solution.

a. $1.3 \times 10^{-4}$ mol/L
b. $2.3 \times 10^{-8}$ mol/L
c. $9.0 \times 10^{-8}$ mol/L
d. $9.0 \times 10^{-10}$ mol/L
e. none of these
13. In the titration of 250.0 mL of 0.20 M $\text{H}_3\text{PO}_4$ with 0.10 M NaOH, the pH of the solution after addition of some NaOH is 4.66. Which of the following phosphate-containing species is present in the largest amount? For $\text{H}_3\text{PO}_4$, $K_\text{a1} = 7.5 \times 10^{-3}$, is $K_\text{a2} = 6.2 \times 10^{-8}$, and is $K_\text{a3} = 4.8 \times 10^{-13}$

a. $\text{PO}_4^{3-}$

b. $\text{HPO}_4^{2-}$

c. $\text{H}_2\text{PO}_4^-$

d. $\text{H}_3\text{PO}_4$

e. none of these

14. What are the oxidation numbers of the central metal atom in the following coordination compounds? $\text{K}_3[\text{Fe(CN)}_6]$, $[\text{Cr(NH}_3)_4\text{Br}_2]\text{Br}$, $[\text{Ni(H}_2\text{O})_6]\text{Cl}_2$, $\text{Na}_2[\text{TaF}_7]$ are

a. -3, 1, 2, 5

b. 3, 3, 2, 7

c. -3, 3, 2, 5

d. 3, 3, 2, 5

e. 3, 3, 3, 5

15. Which of the following will not produce a buffered solution?

a. 50 mL of 0.2 M $\text{Na}_2\text{CO}_3$ and 5 mL of 1.0 M HCl

b. 100 mL of 0.1 M $\text{NaHCO}_3$ and 25 mL of 0.2 M HCl

c. 100 mL of 0.1 M $\text{Na}_2\text{CO}_3$ and 50 mL of 0.1 M HCl

d. 100 mL of 0.1 M $\text{Na}_2\text{CO}_3$ and 75 mL of 0.2 M HCl

e. 100 mL of 0.1 M $\text{Na}_2\text{CO}_3$ and 50 mL of 0.1 M NaOH

16. Metallic sodium crystallizes in a body-centered cubic lattice. The length of an edge of the unit cell is 0.430 nm. The radius of the sodium atom in this crystal is

a. 0.152 nm.

b. 0.186 nm.

c. 0.304 nm.

d. 0.372 nm.

e. none of these
17. How many moles of Fe(OH)$_2$ ($K_{sp} = 1.8 \times 10^{-15}$) dissolve in one liter of water buffered at pH = 12.00?

a. $8.0 \times 10^{-6}$  
b. $4.0 \times 10^{-8}$  
c. $1.8 \times 10^{-9}$  
d. $1.8 \times 10^{-11}$  
e. $5.0 \times 10^{-12}$

18. A concentration cell is constructed using two Ni electrodes with Ni$^{2+}$ concentrations of 1.0 M and $1.00 \times 10^{-4}$ M in the two half-cells. The reduction potential of Ni$^{2+}$ is -0.23 V. Calculate the potential of the cell at 25°C.

a. -0.368 V  
b. -0.132 V  
c. +0.059 V  
d. +0.118 V  
e. +0.132 V

19. If the reaction $2\text{HI} \rightarrow \text{H}_2 + \text{I}_2$ is second order, which of the following will yield a linear plot?

a. $\ln [\text{HI}]$ vs time  
b. $[\text{HI}]$ vs time  
c. $1/[\text{HI}]$ vs time  
d. $\log [\text{HI}]$ vs time

20. In which of the following changes is the work done by the system the largest at 25°C?

a. an isothermal free expansion of an ideal gas from 1 to 10 liters  
b. an isothermal expansion of an ideal gas from 1 to 10 liters against an opposing pressure of 5 atm  
c. an isothermal reversible expansion of an ideal gas from 1 to 10 liters  
d. an isothermal expansion of an ideal gas from 1 to 10 liters against an opposing pressure of 1 atm  
e. the work is the same for all these processes
Part II. Short answer questions (40%)

1. A solution contains 0.10 M Ag⁺ and 0.1 M Ba²⁺. Potassium sulfate is added slowly.
   a. Which solid, Ag₂SO₄ or BaSO₄, precipitates first? __1__
   b. What is the concentration of barium ions in the solution when Ag₂SO₄ first precipitate? __2__
   c. Can you use this technique (selective precipitation of sulfate salts) separate Ag⁺ and Ba²⁺? __3__

   \[ K_{sp}(Ag₂SO₄) = 1.20 \times 10^{-5}, \ K_{sp}(BaSO₄) = 1.08 \times 10^{-10} \]

2. CO(g) results from the partial oxidation of ethanol in an fuel cell. Write the chemical reaction for the reaction of ethanol (C₂H₅OH) into CO(g).

   \[ 1C₂H₅OH(g) + 4 \rightarrow 3CO(g) + 5 \] (I)

   a. Assume \( \Delta H_I \) and \( \Delta S_I \) do not change with temperature; evaluate the expression for \( \Delta G_I \) as a function of \( T \) for reaction (I).

   \[ \Delta H_I \quad 5 \quad \Delta S_I \quad 6 \quad \Delta G_I \quad 7 \]

   b. Write the chemical reaction for the combustion of ethanol (C₂H₅OH) into CO₂(g).

   \[ 1C₂H₅OH(g) + 8 \rightarrow 9CO₂(g) + 10 \] (II)

   c. Assume \( \Delta H_{II} \) and \( \Delta S_{II} \) do not change with temperature; evaluate the expression for \( \Delta G_{II} \) as a function of \( T \) for reaction (II). (You need to calculate \( \Delta H_{II} \) and \( \Delta S_{II} \)).

   \[ \Delta G_{II} \quad 11 \]

   d. At what temperature(s) is the production of CO(g) favor over CO₂(g) for the combustion of propane? __12__
3. The reaction of solid dimethylhydrazine, \((\text{CH}_3)_2\text{N}_2\text{H}_2\), and liquefied dinitrogen tetroxide, \(\text{N}_2\text{O}_4\), has been investigated as a rocket fuel; the reaction produces gaseous carbon dioxide \((\text{CO}_2)\), nitrogen \((\text{N}_2)\), and water vapor \((\text{H}_2\text{O})\), which are ejected as exhaust gases. In a controlled experiment, solid dimethylhydrazine reacted with excess dinitrogen tetroxide and the gases were collected in a closed vessel until a pressure of 3.00 atm and temperature of 400.0 K were reached. What are the partial pressures of \(\text{CO}_2\), \(\text{N}_2\)?

Pressure of \(\text{CO}_2\) 
Pressure of \(\text{N}_2\)

4. The following galvanic cell operates at a temperature of 25°C, pressure of 1 atm, and uses potassium nitrate as the solution in the salt bridge.

a. Label cathode and anode.  

b. Identify the half-reactions in each half cell.

c. Write the balanced chemical reaction.

d. Calculate \(\Delta E_0\) for this cell.