Final Exam
200 points total

Name: _________________________________________________________________

Remember:

• You can use notes on one side of one sheet of paper.

• A periodic table and sheet of equations is provided.

• Turn in the note sheet with your exam.

• Significant figures will be included in points for each numerical problem.

• Point values for each question appear in parentheses in the margins

My signature below means that I agree to uphold the Honor Principle in
taking this exam.
Signature: _______________________________________________________________

Please wait to start your quiz until everyone is seated and the instructor
tells you to begin. There are useful tables and equations on the first pages of the exam.

Good Luck!
Useful Equations, Constants, and Conversion Factors

R = 8.31451 J mol⁻¹ K⁻¹
= 0.082058 L atm mol⁻¹ K⁻¹

ΔS = ∫ dqrev/T

ΔS = n c_p ln T_f/T_i

ΔS_vap = ΔH_vap/T_vap

ΔS_fus = ΔH_fus/T_fus

ΔG = ΔH – T ΔS

ΔG = ΔG^* + RT ln Q

ΔG^* = –RT ln K

S = k ln Ω

F = 96,485.31 C/mol

K_c = K_p (RT)^–Δn

T (K) = T (°C) + 273.15

pH = – log [H₃O⁺]

pK_a = – log K_a

K_w = 10⁻¹⁴ = [OH⁻][H₃O⁺]

pH = pK_a – log [HA]/[A⁻]

ΔG = – n F Δε

ΔG^o = – n F Δε^o

Δε^o = Δε^o_cathode – Δε^o_anode

Δε = Δε^o – RT/ n F ln Q

Δε = Δε^o – 0.0592V/ n log Q

µ (D) = \frac{R (Å)}{0.2082 Å D⁻¹} δ

For grader’s use only:________
Useful Data

Information about Water

$C_p$ of liquid water at 298 K = 4.178 J/g K or 75.29 J/mol K

$\Delta H_{vap}$ of water at 100°C = 40.66 kJ/mol

$\Delta H_{fus}$ of water at 0°C = 6.007 kJ/mol

Density of water at 298 K = 0.99707 g/mL

Thermodynamic Data

<table>
<thead>
<tr>
<th></th>
<th>$\Delta H^\circ f$</th>
<th>$S^\circ$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe (s)</td>
<td>0 kJ/mol</td>
<td>27.28 J/mol K</td>
</tr>
<tr>
<td>Fe$_2$O$_2$ (s)</td>
<td>–824.2</td>
<td>87.40</td>
</tr>
<tr>
<td>Al (s)</td>
<td>0</td>
<td>28.33</td>
</tr>
<tr>
<td>Al$_2$O$_3$ (s)</td>
<td>–1675.5</td>
<td>50.92</td>
</tr>
<tr>
<td>H$_2$O (l)</td>
<td>–285.83</td>
<td>69.91</td>
</tr>
<tr>
<td>H$_2$O (g)</td>
<td>–241.82</td>
<td>188.72</td>
</tr>
</tbody>
</table>
1. Consider the following galvanic cell diagram:

\[
\text{Zn} \quad \text{Zn}^{2+} \quad \text{Ni}^{2+} \quad \text{Ni (s)}
\]

(8)
Complete the following sketch of the galvanic cell by filling in each blank label to identify the following components. There may be MORE THAN ONE THING in each blank box!

<table>
<thead>
<tr>
<th>Salt Bridge</th>
<th>direction of electron flow</th>
<th>anode</th>
<th>cathode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni (s)</td>
<td>Zn (s)</td>
<td>Ni$^{2+}$ (aq)</td>
<td>Zn$^{2+}$ (aq)</td>
</tr>
</tbody>
</table>

*For grader's use only:_______*
1. Continued… \[ \text{Zn} \mid \text{Zn}^{2+} \mid \parallel \text{Ni}^{2+} \mid \text{Ni (s)} \]

(2) Write the half-reaction that will occur at the cathode:

(2) Write the half-reaction that will occur at the anode:

(2) Write the overall cell reaction:

(4) What voltage would you expect to read for this cell, at 25° C, 1 atm, and with 1 M solutions of the metal cations? Show a calculation.

(4) What is \( \Delta G^\circ \) for the cell reaction? Show a calculation.

(4) What voltage would you expect to read, if the cell operated long enough for the concentration of Zn\(^{2+}\) ions to increase by 50.0% and the concentration of Ni\(^{2+}\) ions to decrease by 50.0%?
2. On the last day of class, you observed the thermite reaction of Iron (II) oxide and aluminum metal:

\[ \text{Fe}_2\text{O}_3 (s) + \text{Al} (s) \rightarrow \text{Al}_2\text{O}_3 (s) + \text{Fe} (s) \]

For this reaction identify the following:

(2) Oxidizing Agent:

(2) Reducing Agent:

Write the balanced

(1) Oxidation half-reaction:

(1) Reduction half-reaction:

(2) Net reaction:

(6) For a typical demonstration, 50.0 g of Fe₂O₃ are combined with 15.0 g Al. What mass of Fe metal can be produced by the reaction?
2. Continued \[ \text{Fe}_2\text{O}_3 (s) + \text{Al} (s) \rightarrow \text{Al}_2\text{O}_3 (s) + \text{Fe} (s) \]

(3) Calculate the \( \Delta H^\circ \) for the thermite reaction.

(3) Calculate \( \Delta S^\circ \)

(3) Calculate \( \Delta G \) for the reaction at 298 K

(3) Which things contribute to a spontaneous reaction?

- entropy change of the system
- enthalpy change of the system
- entropy change of the surroundings

(2) Is it possible to change the spontaneity of the reaction? If so, how?

(3) What does the value of \( \Delta G^\circ \) predict for the equilibrium constant of the reaction?

(2) What does the value of K predict about the relative amounts of products and reactants at equilibrium?
2. Continued \[ \text{Fe}_2\text{O}_3 (s) + \text{Al} (s) \rightarrow \text{Al}_2\text{O}_3 (s) + \text{Fe} (s) \]

(3) How many kJ of heat are evolved in the typical demonstration, with 50.0 g of \( \text{Fe}_2\text{O}_3 \) and 15.0 g of Al?

(5) If all the heat evolved in the thermite reaction was used to melt the snow that surrounded the demonstration, how many grams of snow would have melted? The heat of fusion of water at 0º C is 6.007 kJ/mol.
3. Circle the correct responses for each question. There may be MORE THAN ONE correct answer. You will receive a point for each letter that is correctly circled and for each that is correctly left uncircled. It is not in your best interest to guess blindly!

(4) A solution containing a mixture of Cu$^{2+}$, Ni$^{2+}$, and Ag$^{+}$ ions is placed in a beaker. When a strip of tin metal is added to the solution, what happens?
A. Nothing.
B. Cu solid will spontaneously form.
C. Ni solid will spontaneously form.
D. Ag solid will spontaneously form.

(4) For the reaction \(\text{HCO}_3^- + \text{OH}^- \rightleftharpoons \text{CO}_3^{2-} + \text{H}_2\text{O}\) the equilibrium constant \(K_c\) is
A. \(1/K_b\) of carbonate ion
B. \(K_b\) of hydrogen carbonate ion
C. \(K_a/K_w\) of \(\text{HCO}_3^-\)
D. \(K_w/K_a\) of \(\text{H}_2\text{CO}_3\)

(4) Which of the following substances can reduce Fe$^{2+}$ ions to Fe metal?
A. F$_2$
B. Mg
C. H$_2$
D. Li

(4) If a monoprotic weak base solution is titrated to the equivalence point with strong acid, the solution that results is
A. A buffer solution with pH = pK$_a$ of the conjugate acid.
B. A salt solution with pH < 7.
C. A solution of the conjugate acid of the weak base.
D. A salt solution with neutral pH.

(4) Which of the following salts is basic in aqueous solution?
A. NaCH$_3$COO
B. NH$_4$Cl
C. KCl
D. Ba(OH)$_2$
3. Multiple Choice, continued.

(4) Which of the following solutions would you expect to be a buffer solution?
A. Final solution obtained when 1.00 L of 0.20 M acetic acid is thoroughly mixed with 1.00 L of 0.20 M sodium acetate solution.
B. Final solution obtained when a 1.00 L of 0.20 M acetic acid is mixed with 1.00 L of 0.10 M HCl.
C. Final solution obtained when a 1.00 L of 0.20 M acetic acid is mixed with 1.00 L of 0.10 M NaOH.
D. Final solution obtained when a 1.00 L of 0.20 M sodium acetate is mixed with 1.00 L of 0.10 M HCl.

(4) Consider the solubility of CaF₂. For which of the following solutions would you expect a solubility of CaF₂ LESS than the solubility in pure water?
A. 1.0 M CaCl₂.
B. 1.0 M HCl.
C. 1.0 M NaF.
D. 1.0 M NaOH

(4) Which of the following substances do you expect to be highly soluble in pure water?
A. AgNO₃
B. NH₃
C. Ag₂CO₃
D. CH₃COOH

(4) A metal hydroxide solid, MOH, is dissolved in water to form a saturated solution with a pH of 9.68. Which of the following statements are true of the solution?
A. The concentration of H₃O⁺ is greater than the concentration of OH⁻.
B. The K_sp of the metal hydroxide is $2.3 \times 10^{-9}$.
C. There is solid MOH present in the bottom of the beaker.
D. Addition of strong acid would increase the solubility of MOH.
3. Still More Multiple Choice, continued.

(4) Which of the following reaction would you expect to have a large equilibrium constant?
   A. \( \text{CH}_3\text{COOH} + \text{OH}^- \rightarrow \text{CH}_3\text{COO}^- + \text{H}_2\text{O} \)
   B. \( \text{CH}_3\text{COO}^- + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{COOH} + \text{OH}^- \)
   C. \( \text{OH}^- + \text{H}_3\text{O}^+ \rightarrow 2 \text{H}_2\text{O} \)
   D. \( \text{CH}_3\text{COOH} + \text{H}_2\text{O} \rightarrow \text{CH}_3\text{COO}^- + \text{H}_3\text{O}^+ \)

(4) What kind of attractions must be overcome to boil water?
   A. Covalent bonds between hydrogen and oxygen atoms.
   B. Ionic bonds between OH\(^-\) and H\(^+\) ions.
   C. Intermolecular hydrogen bonds.
   D. Vapor pressure.

(4) Two identical flasks at 25º C are filled with gas at 1 atm, one containing Xe and the other containing N\(_2\). Which of the following statements are true about the gases?
   A. The molecules of both gases have the same root mean square speed.
   B. The molecules of both gases have the same average kinetic energy.
   C. The two flasks contain the same number of particles of gas.
   D. The molecules of each gas are attracted to one another by London Forces.

(4) For the following graph of the change in free energy vs. temperature, which of the statements below is true?

\[ \Delta G \]
\[ \text{T} \]

A. The process is endothermic with decreasing entropy.
B. The process is exothermic with increasing entropy.
C. The process is endothermic with increasing entropy.
D. The process is exothermic with decreasing entropy.
4. Limestone consists primarily of CaCO$_3$, which has a K$_{sp}$ of $8.7 \times 10^{-9}$. If a limestone pebble, with a mass of 1.83 g was dropped in a swimming pool with a volume of $1.5 \times 10^5$ L, at 25º C and pH 7, what would happen?

(15)

You can assume several things in formulating your answer:

The reaction of the carbonate ion as a weak base is negligible.

There are no other sources of Ca$^{2+}$ or CO$_3^{-2}$ ions in the water, aside from the pebble.

There is infinite time available to establish equilibrium.

Circle ONE answer at the bottom of the page and show a complete and clear calculation to support your answer.

The pebble would

- partially dissolve, until equilibrium was reached
- dissolve completely
- remain unchanged.

For grader's use only:_______
5. Based on your performance in Chem 5 this term, you are hired by Dartmouth's office of Environmental Health and Safety. In helping to disposed of unwanted chemicals in a disused lab, you find a bottle labeled only "Waste". You measure the pH of the liquid and find that it is 9.08. Suspecting it is a buffer or weak base solution, you decide to titrate it. Your results are shown below.

<table>
<thead>
<tr>
<th>Titration with acid</th>
<th>Titration with base</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 mL waste solution</td>
<td>100 mL waste solution</td>
</tr>
<tr>
<td>titrated with 0.10 M HCl</td>
<td>titrated with 0.10 M NaOH</td>
</tr>
</tbody>
</table>

(16) What do your results tell you about the solution in the "Waste" bottle? Circle ALL statements below that are correct, without guessing!

- It is a strong base
- It is a buffer
- It is monoprotic
- It is a weak base

- The concentration is about 0.1 M
- It could contain a pyridinium salt
- The concentration is about 0.05 M
- It has a pK_b of about 5

- It could be used to make a buffer of pH ~ 5
- It has a pK_b of about 9
- It could be used to make a buffer of pH ~ 3
- The concentration can't be estimated from these data

- It could contain an ammonium salt
- It could contain pyridine.
- It has nearly zero buffer capacity
- It could contain hydrocyanic acid

For grader's use only:_______
6. Choose FIVE of the following things to calculate or answer. Show your work and be clear and complete.

(10) Calculate the pH of a solution made by adding 0.50 mole of hypochlorous acid, HClO, and 0.50 mole of sodium chlorate, NaClO, and 0.010 mole of hydrochloric acid, HCl, to enough water to make 1.0 L of solution.

(10) A 2.00 g sample of gas occupies a volume of 1.09 L at 28º C and 702 torr. What is the molar mass of the gas?
6. Continued…Choose FIVE

(10) Draw Lewis structures of the following substances and write formal charges for each atom. Show all important resonance forms.

SO$_2$

CO$_3$$^-$$^2$

XeF$_2$

(10) Calculate the entropy change of the system for 1.00 g of water

when it melts at the normal melting point:
when it boils at the normal boiling point:

Show clear calculations below. You may find useful thermodynamic information at the beginning of the exam.
6. Continued…Choose FIVE

(10) Balance the following redox reaction, in acidic solution.

\[ \text{Fe}^{2+} (aq) + \text{MnO}_4^- (aq) \rightarrow \text{Fe}^{3+} (aq) + \text{Mn}^{2+} (aq) \]

(10) A mixture of 6.0 moles of H\(_2\) and 6.0 moles of CO\(_2\) is placed in a 10.0 L container and heated to 750º C. For the reaction below, K\(_c\) is 0.77 at 750º C. Calculate the concentration of H\(_2\), CO\(_2\), H\(_2\)O and CO in the mixture, when equilibrium is established.

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