Chem1C Second Midterm
Spring 2006 (Kahn)

Your lab TA’s name

Your full name _______________
Your PERM # _______________

Your signature _______________

Grading Rubric:

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Total (60) ____________

Comments by the grader: ____________________________________________

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1) **Radioactivity.**

Common household smoke detectors use Americium isotope 241 as a source for $\alpha$-particles that, in the absence of smoke, ionize air. One $\alpha$-particle has enough energy to ionize about hundred thousand nitrogen and oxygen molecules, resulting in a small steady ion current flow through the detector. Smoke particles absorb and deflect $\alpha$-particles causing loss of the ion current, which will be sensed by the detector. Which of the nuclear reactions below correctly describes the process that generates $\alpha$-particles from americium-241?

1) $^{241}_{95}\text{Am} + \frac{1}{0}n \rightarrow ^{242}_{95}\text{Am} + 0^+e + \bar{\nu}_e$

2) $^{241}_{95}\text{Am} \rightarrow ^{241}_{96}\text{Cm} + \frac{0}{-1}e + \bar{\nu}_e$

3) $^{241}_{95}\text{Am} \rightarrow ^{237}_{93}\text{Np} + \frac{4}{2}\text{He}$

4) $^{241}_{94}\text{Pu} \rightarrow ^{241}_{95}\text{Am} + \frac{0}{-1}e + \bar{\nu}_e$

5) $^{241}_{95}\text{Am} + \frac{1}{0}n \rightarrow ^{111}_{47}\text{Ag} + ^{131}_{53}\text{I} + \frac{0}{0}\gamma$

$\alpha$-particle is the helium nucleus. See assigned problems in the syllabus if you got this wrong.

2) **Transition metal complexes.**

Consider the four complexes of Cr$^{3+}$ with four different ligands: aqua, ammine, chloro, and cyano. In each complex, six identical ligands are bound to the central metal atom, i.e. we have hexaaquachromium(III) cation, hexaamminechromium(III) cation, hexachlorochromate(III) anion, and hexacyanochromate(III) anion. Identify one correct statement about these complexes.

1) **All four complexes are paramagnetic**

2) Solutions of all four complexes appear visually similar

3) The hexaammine complex is octahedral but the hexaaqua complex is tetrahedral because the ammine ligand is a stronger ligand than the aqua ligand

4) The observation that the addition of ammonia to the hexachlorochromate(III) complex leads to the increased electrical conductivity of the solution can be explained by postulating that the energy splitting between the $e_g$ and $t_{2g}$ level is smaller in the hexaamminechromium(III) complex than in the hexachlorochromate(III) complex

5) When the positive charge of hexaamminechromium(III) cation is neutralized by the sulfate counterion, a highly corrosive solution known as the cleaning solution is obtained

Cr$^{3+}$ has three d-electrons ($3d^3$), there is no way to pair these up.
3) Liquids, Solids, Gases and Solutions. Identify an incorrect statement.

1) Ice melts at a temperature where the liquid water and solid ice have identical vapor pressures

2) The superheating is a phenomenon in which the liquid achieves temperatures above its normal boiling temperature at the normal pressure

3) The enthalpy change that occurs when one mole of liquid is converted into one mole of vapor at the boiling point is called the heat of fusion

4) The temperature of the boiling banana oil remains constant as long as the pressure above the boiling liquid solution is constant

5) Dissolved nonvolatile molecules reduce the vapor pressure of the volatile solvent

That would be called the heat of vaporization

4) Transition Metals and Coordination Compounds. Identify an incorrect statement

1) Soluble coordination complexes of copper(I) tend to have four ligands and have intense blue color

2) Potassium permanganate can readily oxidize many organic molecules and for safety, permanganate and glycerol should not be stored in the same chemical cabinet.

3) Both Co$^{3+}$ and Ni$^{2+}$ can have linkage isomers with SCN$^{-}$ as a ligand

4) There is one and only one pair of mirror isomers possible for the [Pt(H$_2$O)$_2$(CN)$_2$Br$_2$] complex

5) For the same ligand, a tetrahedral complex typically absorbs light more toward the red end of the spectrum as compared to the octahedral complex

Copper(I) tends to have four ligands but solutions of its coordination complexes are colorless because Cu$^{+}$ has d$^{10}$ electronic configuration. Many Cu(II) coordination complexes have intense blue color.
5) Properties of solutions. Identify a correct statement.

1) In order to calculate the mass percent composition of the solution from the mole fraction of the solute, the molecular weight of the solute and the density of the pure solvent must be known.

2) Solubility of most solids in water depends significantly on the atmospheric pressure

3) Henry’s law allows to calculate the vapor pressure above the open container with dissolved solid if we know the Henry’s constant and the mole fraction of the solid in the solution

4) **Solubility of most gases in liquids decreases as the temperature is increased**

5) Ferrofluids are true solutions of paramagnetic \([\text{Fe(NH}_3\text{)}_4\text{(H}_2\text{O})_2]^2^+\) ions in water

*Try serving warm Champagne in your next party if you do not believe it.*

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6) Miscellaneous definition. Identify an incorrect definition.

1) Geometric isomers are species with the same formulas and same bonds but with different positions of atoms (e.g. with respect to the central atom) and with different chemical properties

2) **Reduction is a process by which protons from the acid attack metals, causing the metal to rust**

3) Chelate is a ligand that can form more than one bond with the metal atom

4) Ideal binary solution of two liquids is a solution that obeys the relationship

$$P_{\text{solution}} = \chi_A P_A^0 + \chi_B P_B^0$$

5) Lysis is a process in which bacteria burst open when placed in a solution that is hypotonic when compared to the interior of the bacteria

*Acid turns \(\text{Me}^0\) into \(\text{Me}^{n^+}\), which is the oxidation of the metal.*
Problem Solving

7) Methanol (CH$_3$OH) is a toxic chemical that has a normal boiling point of 64.7 °C, density of 0.792 g/cm$^3$, and the heat of vaporization of 35.2 kJ/mol. Mount Everest is the tallest mountain on the Earth. With its atmospheric pressure of 240 torr and the temperature during the winter of −36 °C it is a dangerous place to be. Calculate the vapor pressure of methanol on top of Mount Everest knowing that the boiling point of methanol there is +36 °C.
The normal atmospheric pressure at the sea level is 760 torr. (8 pts)

\[
\ln \left( \frac{P_{\text{boil}}}{P_{\text{vap}}} \right)_{\text{Everest}} = \frac{\Delta H_{\text{vap}}}{R} \left( \frac{1}{T_{\text{Everest}}} - \frac{1}{T_{\text{boil}}} \right)
\]

\[
\ln 240 - \ln P_{\text{vap}} = 4.162
\]

\[
P_{\text{vap}} = 3.73 \text{ Torr (0.0049 atm)}
\]

8) Nuclear batteries are devices that harness the energy of nuclear reactions to generate heat or electricity. They provide powerful and long-lasting sources of electricity and are sometimes used to power space probes. One promising nuclear battery technology is based on tritium (T, or T$^3$H$^3$), the radioactive isotope of hydrogen. Tritium has a natural half-life of 12 years and decays by the β-decay

Government scientists working with tritium batteries dissolved 0.36 grams of tritium gas T$^3$ in 900 grams of water in May 25, 1982 and misplaced the closed bottle in their top-secret laboratory. The bottle was found yesterday by an illegal immigrant cleaning the lab. What is the mole fraction of T$^3$ in the bottle today? (8 pts)

\[
\Delta t = 24 \text{ years} = 2 \times \tau_{0.5};
\]

after 12 years, 0.18 grams remains, after 24 years 0.09 grams remains

\[
M_n(T^3) = 6 \text{ g/mol}; \quad M_n(H_2O) = 18 \text{ g/mol}
\]

\[
n(T^3) = 0.09 \text{ g} / 6 \text{ g mol}^{-1} = 0.015 \text{ mol} T^3; \quad n(H_2O) = 900 \text{ g} H_2O / 18 \text{ g mol}^{-1} = 50 \text{ mol} H_2O
\]

\[
\chi_{T^3} = \frac{n(T^3)}{n(T^3) + n(H_2O)} = \frac{0.015}{0.015 + 50} = 0.0003
\]
9) Imagine that you have just synthesized a novel compound that is bright pink liquid at room temperature and can be pulled toward strong magnets. Propose and describe an experiment, including analysis of your data, that allows determination of the heat of vaporization of this liquid. (6 pts)

To determine $\Delta H_{\text{vap}}$ for any liquid regardless of its color or magnetic properties, a plot of $\ln P_{\text{vap}}$ versus $1/T$ should be constructed. Thus, one needs to measure the vapor pressure of the liquid at different temperatures and make a plot where $\ln P$ is on the Y-axis and $1/T$ is on the X-axis (note: temperature should be in Kelvins, but pressure can be in any units due to the way logarithms work). Once we have the plot, calculate the slope, which is equal to $-\Delta H_{\text{vap}}/R$.

Partial credit if the use of Clausius-Clapeyron equation was correctly invoked

10) Consider the phase diagram of carbon dioxide (below) and answer the following questions (8 pts)

   a) What phases are designated by letters A-D (2 pts).

   A: Solid  
   B: Supercritical region  
   C: Gas  
   D: Liquid

   b) What is the freezing temperature of carbon dioxide at normal pressure (about 1 bar) (2 pts)

   A little bit below 200 K

   c) What are the two main differences in phase properties of water and carbon dioxide that emerge from the comparison of this diagram with the water diagram that you learned in this course? (4 pts)

   1) $\text{CO}_2$ phase diagram has positive solid/liquid slope. $\text{H}_2\text{O}$ has negative solid/liquid slope. Applying pressure to liquid $\text{CO}_2$ will cause $\text{CO}_2$ to freeze but applying pressure to solid $\text{H}_2\text{O}$ will cause ice to melt.

   2) At normal pressure, $\text{H}_2\text{O}$ exists as liquid between 0 °C and 100 °C but $\text{CO}_2$ at normal pressure does not exist as liquid.