



**AP<sup>®</sup> Chemistry**  
**2006 Free-Response Questions**  
**Form B**

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**DO NOT DETACH FROM BOOK.**

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# 2

## STANDARD REDUCTION POTENTIALS IN AQUEOUS SOLUTION AT 25°C

Half-reaction			$E^\circ(\text{V})$
$\text{F}_2(\text{g}) + 2\text{e}^-$	$\rightarrow$	$2\text{F}^-$	2.87
$\text{Co}^{3+} + \text{e}^-$	$\rightarrow$	$\text{Co}^{2+}$	1.82
$\text{Au}^{3+} + 3\text{e}^-$	$\rightarrow$	$\text{Au}(\text{s})$	1.50
$\text{Cl}_2(\text{g}) + 2\text{e}^-$	$\rightarrow$	$2\text{Cl}^-$	1.36
$\text{O}_2(\text{g}) + 4\text{H}^+ + 4\text{e}^-$	$\rightarrow$	$2\text{H}_2\text{O}(\text{l})$	1.23
$\text{Br}_2(\text{l}) + 2\text{e}^-$	$\rightarrow$	$2\text{Br}^-$	1.07
$2\text{Hg}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Hg}_2^{2+}$	0.92
$\text{Hg}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Hg}(\text{l})$	0.85
$\text{Ag}^+ + \text{e}^-$	$\rightarrow$	$\text{Ag}(\text{s})$	0.80
$\text{Hg}_2^{2+} + 2\text{e}^-$	$\rightarrow$	$2\text{Hg}(\text{l})$	0.79
$\text{Fe}^{3+} + \text{e}^-$	$\rightarrow$	$\text{Fe}^{2+}$	0.77
$\text{I}_2(\text{s}) + 2\text{e}^-$	$\rightarrow$	$2\text{I}^-$	0.53
$\text{Cu}^+ + \text{e}^-$	$\rightarrow$	$\text{Cu}(\text{s})$	0.52
$\text{Cu}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Cu}(\text{s})$	0.34
$\text{Cu}^{2+} + \text{e}^-$	$\rightarrow$	$\text{Cu}^+$	0.15
$\text{Sn}^{4+} + 2\text{e}^-$	$\rightarrow$	$\text{Sn}^{2+}$	0.15
$\text{S}(\text{s}) + 2\text{H}^+ + 2\text{e}^-$	$\rightarrow$	$\text{H}_2\text{S}(\text{g})$	0.14
$2\text{H}^+ + 2\text{e}^-$	$\rightarrow$	$\text{H}_2(\text{g})$	0.00
$\text{Pb}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Pb}(\text{s})$	-0.13
$\text{Sn}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Sn}(\text{s})$	-0.14
$\text{Ni}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Ni}(\text{s})$	-0.25
$\text{Co}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Co}(\text{s})$	-0.28
$\text{Cd}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Cd}(\text{s})$	-0.40
$\text{Cr}^{3+} + \text{e}^-$	$\rightarrow$	$\text{Cr}^{2+}$	-0.41
$\text{Fe}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Fe}(\text{s})$	-0.44
$\text{Cr}^{3+} + 3\text{e}^-$	$\rightarrow$	$\text{Cr}(\text{s})$	-0.74
$\text{Zn}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Zn}(\text{s})$	-0.76
$2\text{H}_2\text{O}(\text{l}) + 2\text{e}^-$	$\rightarrow$	$\text{H}_2(\text{g}) + 2\text{OH}^-$	-0.83
$\text{Mn}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Mn}(\text{s})$	-1.18
$\text{Al}^{3+} + 3\text{e}^-$	$\rightarrow$	$\text{Al}(\text{s})$	-1.66
$\text{Be}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Be}(\text{s})$	-1.70
$\text{Mg}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Mg}(\text{s})$	-2.37
$\text{Na}^+ + \text{e}^-$	$\rightarrow$	$\text{Na}(\text{s})$	-2.71
$\text{Ca}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Ca}(\text{s})$	-2.87
$\text{Sr}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Sr}(\text{s})$	-2.89
$\text{Ba}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Ba}(\text{s})$	-2.90
$\text{Rb}^+ + \text{e}^-$	$\rightarrow$	$\text{Rb}(\text{s})$	-2.92
$\text{K}^+ + \text{e}^-$	$\rightarrow$	$\text{K}(\text{s})$	-2.92
$\text{Cs}^+ + \text{e}^-$	$\rightarrow$	$\text{Cs}(\text{s})$	-2.92
$\text{Li}^+ + \text{e}^-$	$\rightarrow$	$\text{Li}(\text{s})$	-3.05

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# ADVANCED PLACEMENT CHEMISTRY EQUATIONS AND CONSTANTS

## ATOMIC STRUCTURE

$$E = h\nu \quad c = \lambda\nu$$

$$\lambda = \frac{h}{m\nu} \quad p = m\nu$$

$$E_n = \frac{-2.178 \times 10^{-18}}{n^2} \text{ joule}$$

## EQUILIBRIUM

$$K_a = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]}$$

$$K_b = \frac{[\text{OH}^-][\text{HB}^+]}{[\text{B}]}$$

$$K_w = [\text{OH}^-][\text{H}^+] = 1.0 \times 10^{-14} \text{ @ } 25^\circ\text{C}$$

$$= K_a \times K_b$$

$$\text{pH} = -\log [\text{H}^+], \text{pOH} = -\log [\text{OH}^-]$$

$$14 = \text{pH} + \text{pOH}$$

$$\text{pH} = \text{p}K_a + \log \frac{[\text{A}^-]}{[\text{HA}]}$$

$$\text{pOH} = \text{p}K_b + \log \frac{[\text{HB}^+]}{[\text{B}]}$$

$$\text{p}K_a = -\log K_a, \text{p}K_b = -\log K_b$$

$$K_p = K_c(RT)^{\Delta n},$$

where  $\Delta n$  = moles product gas – moles reactant gas

## THERMOCHEMISTRY/KINETICS

$$\Delta S^\circ = \sum S^\circ \text{ products} - \sum S^\circ \text{ reactants}$$

$$\Delta H^\circ = \sum \Delta H_f^\circ \text{ products} - \sum \Delta H_f^\circ \text{ reactants}$$

$$\Delta G^\circ = \sum \Delta G_f^\circ \text{ products} - \sum \Delta G_f^\circ \text{ reactants}$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

$$= -RT \ln K = -2.303 RT \log K$$

$$= -n \mathcal{F} E^\circ$$

$$\Delta G = \Delta G^\circ + RT \ln Q = \Delta G^\circ + 2.303 RT \log Q$$

$$q = mc\Delta T$$

$$C_p = \frac{\Delta H}{\Delta T}$$

$$\ln[\text{A}]_t - \ln[\text{A}]_0 = -kt$$

$$\frac{1}{[\text{A}]_t} - \frac{1}{[\text{A}]_0} = kt$$

$$\ln k = \frac{-E_a}{R} \left( \frac{1}{T} \right) + \ln A$$

$E$  = energy

$v$  = velocity

$\nu$  = frequency

$n$  = principal quantum number

$\lambda$  = wavelength

$m$  = mass

$p$  = momentum

Speed of light,  $c = 3.0 \times 10^8 \text{ m s}^{-1}$

Planck's constant,  $h = 6.63 \times 10^{-34} \text{ J s}$

Boltzmann's constant,  $k = 1.38 \times 10^{-23} \text{ J K}^{-1}$

Avogadro's number =  $6.022 \times 10^{23} \text{ mol}^{-1}$

Electron charge,  $e = -1.602 \times 10^{-19} \text{ coulomb}$

1 electron volt per atom =  $96.5 \text{ kJ mol}^{-1}$

## Equilibrium Constants

$K_a$  (weak acid)

$K_b$  (weak base)

$K_w$  (water)

$K_p$  (gas pressure)

$K_c$  (molar concentrations)

$S^\circ$  = standard entropy

$H^\circ$  = standard enthalpy

$G^\circ$  = standard free energy

$E^\circ$  = standard reduction potential

$T$  = temperature

$n$  = moles

$m$  = mass

$q$  = heat

$c$  = specific heat capacity

$C_p$  = molar heat capacity at constant pressure

$E_a$  = activation energy

$k$  = rate constant

$A$  = frequency factor

Faraday's constant,  $\mathcal{F} = 96,500 \text{ coulombs per mole of electrons}$

Gas constant,  $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$   
 $= 0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1}$   
 $= 8.31 \text{ volt coulomb mol}^{-1} \text{ K}^{-1}$

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## GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

$$\left( P + \frac{n^2 a}{V^2} \right) (V - nb) = nRT$$

$$P_A = P_{total} \times X_A, \text{ where } X_A = \frac{\text{moles A}}{\text{total moles}}$$

$$P_{total} = P_A + P_B + P_C + \dots$$

$$n = \frac{m}{M}$$

$$K = ^\circ\text{C} + 273$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$D = \frac{m}{V}$$

$$u_{rms} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{M}}$$

$$KE \text{ per molecule} = \frac{1}{2} m v^2$$

$$KE \text{ per mole} = \frac{3}{2} RT$$

$$\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}}$$

molarity,  $M$  = moles solute per liter solution

molality = moles solute per kilogram solvent

$$\Delta T_f = iK_f \times \text{molality}$$

$$\Delta T_b = iK_b \times \text{molality}$$

$$\pi = iMRT$$

$$A = abc$$

$P$  = pressure

$V$  = volume

$T$  = temperature

$n$  = number of moles

$D$  = density

$m$  = mass

$v$  = velocity

$u_{rms}$  = root-mean-square speed

$KE$  = kinetic energy

$r$  = rate of effusion

$M$  = molar mass

$\pi$  = osmotic pressure

$i$  = van't Hoff factor

$K_f$  = molal freezing-point depression constant

$K_b$  = molal boiling-point elevation constant

$A$  = absorbance

$a$  = molar absorptivity

$b$  = path length

$c$  = concentration

$Q$  = reaction quotient

$I$  = current (amperes)

$q$  = charge (coulombs)

$t$  = time (seconds)

$E^\circ$  = standard reduction potential

$K$  = equilibrium constant

## OXIDATION-REDUCTION; ELECTROCHEMISTRY

$$Q = \frac{[C]^c [D]^d}{[A]^a [B]^b}, \text{ where } a A + b B \rightarrow c C + d D$$

$$I = \frac{q}{t}$$

$$E_{\text{cell}} = E_{\text{cell}}^\circ - \frac{RT}{n\mathcal{F}} \ln Q = E_{\text{cell}}^\circ - \frac{0.0592}{n} \log Q @ 25^\circ\text{C}$$

$$\log K = \frac{nE^\circ}{0.0592}$$

$$\text{Gas constant, } R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$$

$$= 0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1}$$

$$= 8.31 \text{ volt coulomb mol}^{-1} \text{ K}^{-1}$$

$$\text{Boltzmann's constant, } k = 1.38 \times 10^{-23} \text{ J K}^{-1}$$

$$K_f \text{ for H}_2\text{O} = 1.86 \text{ K kg mol}^{-1}$$

$$K_b \text{ for H}_2\text{O} = 0.512 \text{ K kg mol}^{-1}$$

$$1 \text{ atm} = 760 \text{ mm Hg}$$

$$= 760 \text{ torr}$$

$$\text{STP} = 0.000^\circ\text{C and } 1.000 \text{ atm}$$

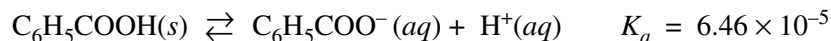
$$\text{Faraday's constant, } \mathcal{F} = 96,500 \text{ coulombs per mole of electrons}$$

**2006 AP<sup>®</sup> CHEMISTRY FREE-RESPONSE QUESTIONS (Form B)****CHEMISTRY****Section II****(Total time—90 minutes)****Part A****Time—40 minutes****YOU MAY USE YOUR CALCULATOR FOR PART A.**

CLEARLY SHOW THE METHOD USED AND THE STEPS INVOLVED IN ARRIVING AT YOUR ANSWERS. It is to your advantage to do this, since you may obtain partial credit if you do and you will receive little or no credit if you do not. Attention should be paid to significant figures.

Be sure to write all your answers to the questions on the lined pages following each question in the goldenrod booklet. Do NOT write your answers on the lavender insert.

Answer Question 1 below. The Section II score weighting for this question is 20 percent.



1. Benzoic acid,  $\text{C}_6\text{H}_5\text{COOH}$ , dissociates in water as shown in the equation above. A 25.0 mL sample of an aqueous solution of pure benzoic acid is titrated using standardized 0.150 M NaOH.
  - (a) After addition of 15.0 mL of the 0.150 M NaOH, the pH of the resulting solution is 4.37. Calculate each of the following.
    - (i)  $[\text{H}^+]$  in the solution
    - (ii)  $[\text{OH}^-]$  in the solution
    - (iii) The number of moles of NaOH added
    - (iv) The number of moles of  $\text{C}_6\text{H}_5\text{COO}^-(aq)$  in the solution
    - (v) The number of moles of  $\text{C}_6\text{H}_5\text{COOH}$  in the solution
  - (b) State whether the solution at the equivalence point of the titration is acidic, basic, or neutral. Explain your reasoning.

In a different titration, a 0.7529 g sample of a mixture of solid  $\text{C}_6\text{H}_5\text{COOH}$  and solid NaCl is dissolved in water and titrated with 0.150 M NaOH. The equivalence point is reached when 24.78 mL of the base solution is added.

- (c) Calculate each of the following.
  - (i) The mass, in grams, of benzoic acid in the solid sample
  - (ii) The mass percentage of benzoic acid in the solid sample

## 2006 AP<sup>®</sup> CHEMISTRY FREE-RESPONSE QUESTIONS (Form B)

Answer EITHER Question 2 OR Question 3 below. Only one of these two questions will be graded. If you start both questions, be sure to cross out the question you do not want graded. The Section II score weighting for the question you choose is 20 percent.

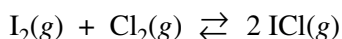
2. Answer the following questions about voltaic cells.

- (a) A voltaic cell is set up using  $\text{Al}/\text{Al}^{3+}$  as one half-cell and  $\text{Sn}/\text{Sn}^{2+}$  as the other half-cell. The half-cells contain equal volumes of solutions and are at standard conditions.
- Write the balanced net-ionic equation for the spontaneous cell reaction.
  - Determine the value, in volts, of the standard potential,  $E^\circ$ , for the spontaneous cell reaction.
  - Calculate the value of the standard free-energy change,  $\Delta G^\circ$ , for the spontaneous cell reaction. Include units with your answer.
  - If the cell operates until  $[\text{Al}^{3+}]$  is  $1.08\text{ M}$  in the  $\text{Al}/\text{Al}^{3+}$  half-cell, what is  $[\text{Sn}^{2+}]$  in the  $\text{Sn}/\text{Sn}^{2+}$  half-cell?
- (b) In another voltaic cell with  $\text{Al}/\text{Al}^{3+}$  and  $\text{Sn}/\text{Sn}^{2+}$  half-cells,  $[\text{Sn}^{2+}]$  is  $0.010\text{ M}$  and  $[\text{Al}^{3+}]$  is  $1.00\text{ M}$ . Calculate the value, in volts, of the cell potential,  $E_{\text{cell}}$ , at  $25^\circ\text{C}$ .

3. Answer the following questions about the thermodynamics of the reactions represented below.



- Is reaction X, represented above, spontaneous under standard conditions? Justify your answer with a calculation.
- Calculate the value of the equilibrium constant,  $K_{\text{eq}}$ , for reaction X at  $25^\circ\text{C}$ .
- What effect will an increase in temperature have on the equilibrium constant for reaction X? Explain your answer.
- Explain why the standard entropy change is greater for reaction Y than for reaction X.
- Above what temperature will the value of the equilibrium constant for reaction Y be greater than 1.0? Justify your answer with calculations.
- For the vaporization of solid iodine,  $\text{I}_2(\text{s}) \rightarrow \text{I}_2(\text{g})$ , the value of  $\Delta H_{298}^\circ$  is  $62\text{ kJ mol}^{-1}$ . Using this information, calculate the value of  $\Delta H_{298}^\circ$  for the reaction represented below.



# STOP

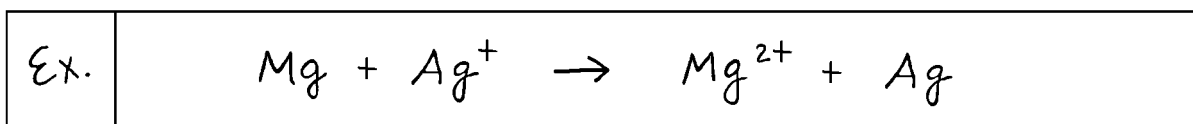
If you finish before time is called, you may check your work on this part only.  
Do not turn to the other part of the test until you are told to do so.

**2006 AP<sup>®</sup> CHEMISTRY FREE-RESPONSE QUESTIONS (Form B)****CHEMISTRY****Part B****Time—50 minutes****NO CALCULATORS MAY BE USED FOR PART B.**

Answer Question 4 below. The Section II score weighting for this question is 15 percent.

4. Write the formulas to show the reactants and the products for any FIVE of the laboratory situations described below. Answers to more than five choices will not be graded. In all cases, a reaction occurs. Assume that solutions are aqueous unless otherwise indicated. Represent substances in solution as ions if the substances are extensively ionized. Omit formulas for any ions or molecules that are unchanged by the reaction. You need not balance the equations.

Example: A strip of magnesium is added to a solution of silver nitrate.



- (a) Solid calcium carbonate is strongly heated.
- (b) A strip of magnesium metal is placed in a solution of iron(II) chloride.
- (c) Boron trifluoride gas is mixed with ammonia gas.
- (d) Excess concentrated hydrochloric acid is added to a solution of nickel(II) nitrate.
- (e) Solid ammonium chloride is added to a solution of potassium hydroxide.
- (f) Propanal is burned in air.
- (g) A strip of aluminum foil is placed in liquid bromine.
- (h) Solid copper(II) sulfide is strongly heated in air.

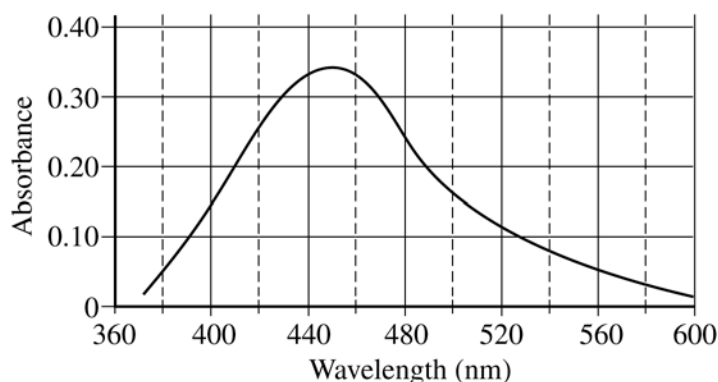


## 2006 AP<sup>®</sup> CHEMISTRY FREE-RESPONSE QUESTIONS (Form B)

Your responses to the rest of the questions in this part of the examination will be graded on the basis of the accuracy and relevance of the information cited. Explanations should be clear and well organized. Examples and equations may be included in your responses where appropriate. Specific answers are preferable to broad, diffuse responses.

Answer BOTH Question 5 below AND Question 6 printed on page 11. Both of these questions will be graded. The Section II score weighting for these questions is 30 percent (15 percent each).

5. A student carries out an experiment to determine the equilibrium constant for a reaction by colorimetric (spectrophotometric) analysis. The production of the red-colored species  $\text{FeSCN}^{2+}(aq)$  is monitored.
- (a) The optimum wavelength for the measurement of  $[\text{FeSCN}^{2+}]$  must first be determined. The plot of absorbance,  $A$ , versus wavelength,  $\lambda$ , for  $\text{FeSCN}^{2+}(aq)$  is given below. What is the optimum wavelength for this experiment? Justify your answer.

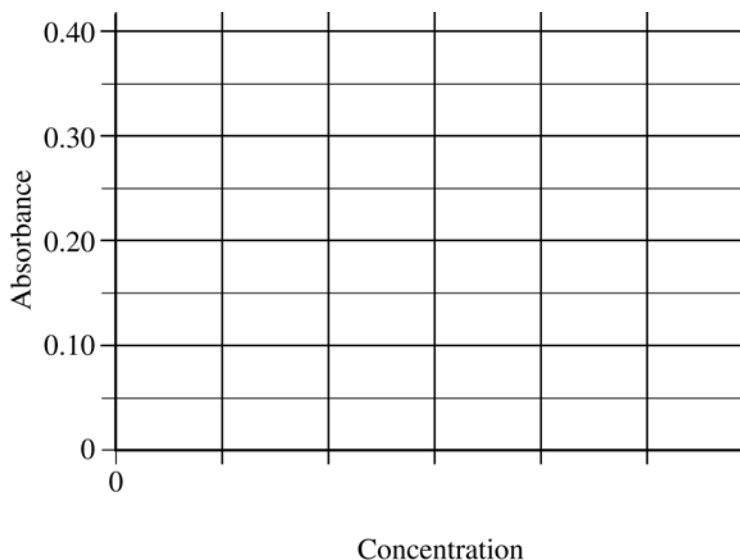


- (b) A calibration plot for the concentration of  $\text{FeSCN}^{2+}(aq)$  is prepared at the optimum wavelength. The data below give the absorbances measured for a set of solutions of known concentration of  $\text{FeSCN}^{2+}(aq)$ .

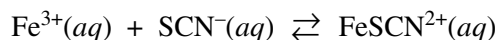
Concentration (mol L <sup>-1</sup> )	Absorbance
$1.1 \times 10^{-4}$	0.030
$3.0 \times 10^{-4}$	0.065
$8.0 \times 10^{-4}$	0.160
$12 \times 10^{-4}$	0.239
$18 \times 10^{-4}$	0.340

**2006 AP<sup>®</sup> CHEMISTRY FREE-RESPONSE QUESTIONS (Form B)**

- (i) Draw a Beer's law calibration plot of all the data on the grid below. Indicate the scale on the horizontal axis by labeling it with appropriate values.



- (ii) An  $\text{FeSCN}^{2+}(\text{aq})$  solution of unknown concentration has an absorbance of 0.300. Use the plot you drew in part (i) to determine the concentration, in moles per liter, of this solution.
- (c) The purpose of the experiment is to determine the equilibrium constant for the reaction represented below.



- (i) Write the equilibrium-constant expression for  $K_c$ .
- (ii) The student combines solutions of  $\text{Fe}(\text{NO}_3)_3$  and  $\text{KSCN}$  to produce a solution in which the initial concentrations of  $\text{Fe}^{3+}(\text{aq})$  and  $\text{SCN}^{-}(\text{aq})$  are both  $6.0 \times 10^{-3} \text{ M}$ . The absorbance of this solution is measured, and the equilibrium  $\text{FeSCN}^{2+}(\text{aq})$  concentration is found to be  $1.0 \times 10^{-3} \text{ M}$ . Determine the value of  $K_c$ .
- (d) If the student's equilibrium  $\text{FeSCN}^{2+}(\text{aq})$  solution of unknown concentration fades to a lighter color before the student measures its absorbance, will the calculated value of  $K_c$  be too high, too low, or unaffected? Justify your answer.

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6. The species represented above all have the same number of chlorine atoms attached to the central atom.
- (a) Draw the Lewis structure (electron-dot diagram) of each of the four species. Show all valence electrons in your structures.
- (b) On the basis of the Lewis structures drawn in part (a), answer the following questions about the particular species indicated.
- (i) What is the  $\text{Cl} - \text{Ge} - \text{Cl}$  bond angle in  $\text{GeCl}_4$ ?
  - (ii) Is  $\text{SeCl}_4$  polar? Explain.
  - (iii) What is the hybridization of the I atom in  $\text{ICl}_4^-$ ?
  - (iv) What is the geometric shape formed by the atoms in  $\text{ICl}_4^+$ ?

## 2006 AP<sup>®</sup> CHEMISTRY FREE-RESPONSE QUESTIONS (Form B)

Answer EITHER Question 7 OR Question 8 below. Only one of these two questions will be graded. If you start both questions, be sure to cross out the question you do not want graded. The Section II score weighting for the question you choose is 15 percent.

7. Account for each of the following observations in terms of atomic theory and/or quantum theory.
- (a) Atomic size decreases from Na to Cl in the periodic table.
  - (b) Boron commonly forms molecules of the type  $\text{BX}_3$ . These molecules have a trigonal planar structure.
  - (c) The first ionization energy of K is less than that of Na.
  - (d) Each element displays a unique gas-phase emission spectrum.
8. Use chemical and physical principles to account for each of the following.
- (a) An aluminum container filled with an aqueous solution of  $\text{CuSO}_4$  eventually developed a leak. Include a chemical equation with your answer.
  - (b) The inside of a metal container was cleaned with steam and immediately sealed. Later, the container imploded.
  - (c) Skin feels cooler after rubbing alcohol has been applied to it.
  - (d) The redness and itching of the skin caused by ant bites (injections of methanoic acid,  $\text{HCO}_2\text{H}$ ) can be relieved by applying a paste made from water and baking soda (solid sodium hydrogen carbonate). Include a chemical equation with your answer.

**STOP**

**END OF EXAM**