



## **AP<sup>®</sup> Chemistry 2004 Free-Response Questions**

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DO NOT DETACH FROM BOOK.

# PERIODIC TABLE OF THE ELEMENTS

1 <b>H</b> 1.0079																	2 <b>He</b> 4.0026
3 <b>Li</b> 6.941	4 <b>Be</b> 9.012											5 <b>B</b> 10.811	6 <b>C</b> 12.011	7 <b>N</b> 14.007	8 <b>O</b> 16.00	9 <b>F</b> 19.00	10 <b>Ne</b> 20.179
11 <b>Na</b> 22.99	12 <b>Mg</b> 24.30											13 <b>Al</b> 26.98	14 <b>Si</b> 28.09	15 <b>P</b> 30.974	16 <b>S</b> 32.06	17 <b>Cl</b> 35.453	18 <b>Ar</b> 39.948
19 <b>K</b> 39.10	20 <b>Ca</b> 40.08	21 <b>Sc</b> 44.96	22 <b>Ti</b> 47.90	23 <b>V</b> 50.94	24 <b>Cr</b> 52.00	25 <b>Mn</b> 54.938	26 <b>Fe</b> 55.85	27 <b>Co</b> 58.93	28 <b>Ni</b> 58.69	29 <b>Cu</b> 63.55	30 <b>Zn</b> 65.39	31 <b>Ga</b> 69.72	32 <b>Ge</b> 72.59	33 <b>As</b> 74.92	34 <b>Se</b> 78.96	35 <b>Br</b> 79.90	36 <b>Kr</b> 83.80
37 <b>Rb</b> 85.47	38 <b>Sr</b> 87.62	39 <b>Y</b> 88.91	40 <b>Zr</b> 91.22	41 <b>Nb</b> 92.91	42 <b>Mo</b> 95.94	43 <b>Tc</b> (98)	44 <b>Ru</b> 101.1	45 <b>Rh</b> 102.91	46 <b>Pd</b> 106.42	47 <b>Ag</b> 107.87	48 <b>Cd</b> 112.41	49 <b>In</b> 114.82	50 <b>Sn</b> 118.71	51 <b>Sb</b> 121.75	52 <b>Te</b> 127.60	53 <b>I</b> 126.91	54 <b>Xe</b> 131.29
55 <b>Cs</b> 132.91	56 <b>Ba</b> 137.33	57 <b>*La</b> 138.91	72 <b>Hf</b> 178.49	73 <b>Ta</b> 180.95	74 <b>W</b> 183.85	75 <b>Re</b> 186.21	76 <b>Os</b> 190.2	77 <b>Ir</b> 192.2	78 <b>Pt</b> 195.08	79 <b>Au</b> 196.97	80 <b>Hg</b> 200.59	81 <b>Tl</b> 204.38	82 <b>Pb</b> 207.2	83 <b>Bi</b> 208.98	84 <b>Po</b> (209)	85 <b>At</b> (210)	86 <b>Rn</b> (222)
87 <b>Fr</b> (223)	88 <b>Ra</b> 226.02	89 <b>†Ac</b> 227.03	104 <b>Rf</b> (261)	105 <b>Db</b> (262)	106 <b>Sg</b> (263)	107 <b>Bh</b> (262)	108 <b>Hs</b> (265)	109 <b>Mt</b> (266)	110 <b>§</b> (269)	111 <b>§</b> (272)	112 <b>§</b> (277)	§Not yet named					

\*Lanthanide Series

58 <b>Ce</b> 140.12	59 <b>Pr</b> 140.91	60 <b>Nd</b> 144.24	61 <b>Pm</b> (145)	62 <b>Sm</b> 150.4	63 <b>Eu</b> 151.97	64 <b>Gd</b> 157.25	65 <b>Tb</b> 158.93	66 <b>Dy</b> 162.50	67 <b>Ho</b> 164.93	68 <b>Er</b> 167.26	69 <b>Tm</b> 168.93	70 <b>Yb</b> 173.04	71 <b>Lu</b> 174.97
90 <b>Th</b> 232.04	91 <b>Pa</b> 231.04	92 <b>U</b> 238.03	93 <b>Np</b> 237.05	94 <b>Pu</b> (244)	95 <b>Am</b> (243)	96 <b>Cm</b> (247)	97 <b>Bk</b> (247)	98 <b>Cf</b> (251)	99 <b>Es</b> (252)	100 <b>Fm</b> (257)	101 <b>Md</b> (258)	102 <b>No</b> (259)	103 <b>Lr</b> (260)

†Actinide Series

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

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

GO ON TO THE NEXT PAGE.

# ADVANCED PLACEMENT CHEMISTRY EQUATIONS AND CONSTANTS

## ATOMIC STRUCTURE

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

$$\lambda = \frac{h}{mv} \quad p = mv$$

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

## 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

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

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

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

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

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

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

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

$$q = mc\Delta T$$

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

$$\ln[A]_t - \ln[A]_0 = -kt$$

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

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

$$E = \text{energy} \quad v = \text{velocity}$$

$$\nu = \text{frequency} \quad n = \text{principal quantum number}$$

$$\lambda = \text{wavelength} \quad m = \text{mass}$$

$$p = \text{momentum}$$

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

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

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

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

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

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

## 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 coulombs per mole of electrons

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

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

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

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## GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

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

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

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

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

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

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

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

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

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

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

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

molarity,  $M$  = moles solute per liter solution

molality = moles solute per kilogram solvent

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

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

$$\pi = MRT$$

$$A = abc$$

$P$  = 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

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

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

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

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

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

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

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

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

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

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

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

$= 760 \text{ torr}$

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

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

# 2004 AP<sup>®</sup> CHEMISTRY FREE-RESPONSE QUESTIONS

## CHEMISTRY

### Section II

(Total time—90 minutes)

#### Part A

Time—40 minutes

**YOU MAY USE YOUR CALCULATOR FOR PART A.**

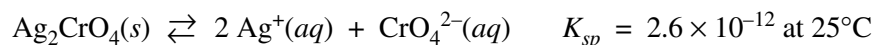
CLEARLY SHOW THE METHOD USED AND THE STEPS INVOLVED IN ARRIVING AT YOUR ANSWERS. It is to your advantage to do this, since you may obtain partial credit if you do and you will receive little or no credit if you do not. Attention should be paid to significant figures.

Be sure to write all your answers to the questions on the lined pages following each question in the booklet with the pink cover. Do NOT write your answers on the green insert.

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

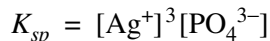
1. Answer the following questions relating to the solubilities of two silver compounds,  $\text{Ag}_2\text{CrO}_4$  and  $\text{Ag}_3\text{PO}_4$ .

Silver chromate dissociates in water according to the equation shown below.



- (a) Write the equilibrium-constant expression for the dissolving of  $\text{Ag}_2\text{CrO}_4(s)$ .
- (b) Calculate the concentration, in  $\text{mol L}^{-1}$ , of  $\text{Ag}^+(aq)$  in a saturated solution of  $\text{Ag}_2\text{CrO}_4$  at  $25^\circ\text{C}$ .
- (c) Calculate the maximum mass, in grams, of  $\text{Ag}_2\text{CrO}_4$  that can dissolve in 100. mL of water at  $25^\circ\text{C}$ .
- (d) A 0.100 mol sample of solid  $\text{AgNO}_3$  is added to a 1.00 L saturated solution of  $\text{Ag}_2\text{CrO}_4$ . Assuming no volume change, does  $[\text{CrO}_4^{2-}]$  increase, decrease, or remain the same? Justify your answer.

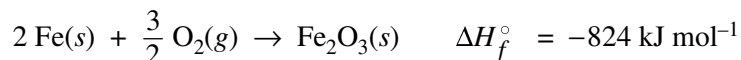
In a saturated solution of  $\text{Ag}_3\text{PO}_4$  at  $25^\circ\text{C}$ , the concentration of  $\text{Ag}^+(aq)$  is  $5.3 \times 10^{-5} \text{ M}$ . The equilibrium-constant expression for the dissolving of  $\text{Ag}_3\text{PO}_4(s)$  in water is shown below.



- (e) Write the balanced equation for the dissolving of  $\text{Ag}_3\text{PO}_4$  in water.
- (f) Calculate the value of  $K_{sp}$  for  $\text{Ag}_3\text{PO}_4$  at  $25^\circ\text{C}$ .
- (g) A 1.00 L sample of saturated  $\text{Ag}_3\text{PO}_4$  solution is allowed to evaporate at  $25^\circ\text{C}$  to a final volume of 500. mL. What is  $[\text{Ag}^+]$  in the solution? Justify your answer.

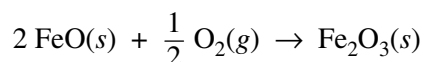
## 2004 AP<sup>®</sup> CHEMISTRY FREE-RESPONSE QUESTIONS

Answer EITHER Question 2 below OR Question 3 printed on page 8. 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. Iron reacts with oxygen to produce iron(III) oxide, as represented by the equation above. A 75.0 g sample of Fe(s) is mixed with 11.5 L of O<sub>2</sub>(g) at 2.66 atm and 298 K.
- (a) Calculate the number of moles of each of the following before the reaction begins.
    - (i) Fe(s)
    - (ii) O<sub>2</sub>(g)
  - (b) Identify the limiting reactant when the mixture is heated to produce Fe<sub>2</sub>O<sub>3</sub>(s). Support your answer with calculations.
  - (c) Calculate the number of moles of Fe<sub>2</sub>O<sub>3</sub>(s) produced when the reaction proceeds to completion.
  - (d) The standard free energy of formation,  $\Delta G_f^\circ$ , of Fe<sub>2</sub>O<sub>3</sub>(s) is  $-740. \text{ kJ mol}^{-1}$  at 298 K.
    - (i) Calculate the standard entropy of formation,  $\Delta S_f^\circ$ , of Fe<sub>2</sub>O<sub>3</sub>(s) at 298 K. Include units with your answer.
    - (ii) Which is more responsible for the spontaneity of the formation reaction at 298 K, the standard enthalpy of formation,  $\Delta H_f^\circ$ , or the standard entropy of formation,  $\Delta S_f^\circ$ ? Justify your answer.

The reaction represented below also produces iron(III) oxide. The value of  $\Delta H^\circ$  for the reaction is  $-280. \text{ kJ}$  per mole of Fe<sub>2</sub>O<sub>3</sub>(s) formed.



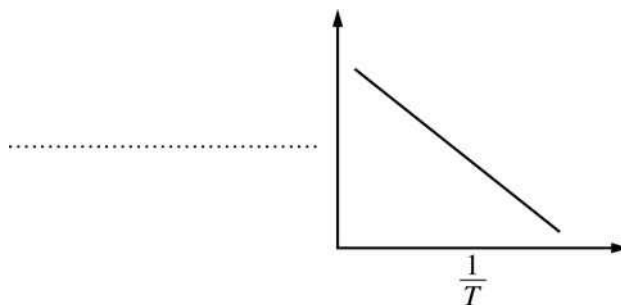
- (e) Calculate the standard enthalpy of formation,  $\Delta H_f^\circ$ , of FeO(s).

## 2004 AP<sup>®</sup> CHEMISTRY FREE-RESPONSE QUESTIONS

3. The first-order decomposition of a colored chemical species, X, into colorless products is monitored with a spectrophotometer by measuring changes in absorbance over time. Species X has a molar absorptivity constant of  $5.00 \times 10^3 \text{ cm}^{-1} \text{ M}^{-1}$  and the path length of the cuvette containing the reaction mixture is 1.00 cm. The data from the experiment are given in the table below.

[X] (M)	Absorbance	Time (min)
?	0.600	0.0
$4.00 \times 10^{-5}$	0.200	35.0
$3.00 \times 10^{-5}$	0.150	44.2
$1.50 \times 10^{-5}$	0.075	?

- Calculate the initial concentration of the colored species.
- Calculate the rate constant for the first-order reaction using the values given for concentration and time. Include units with your answer.
- Calculate the number of minutes it takes for the absorbance to drop from 0.600 to 0.075.
- Calculate the half-life of the reaction. Include units with your answer.
- Experiments were performed to determine the value of the rate constant for this reaction at various temperatures. Data from these experiments were used to produce the graph below, where  $T$  is temperature. This graph can be used to determine the activation energy,  $E_a$ , of the reaction.
  - Label the vertical axis of the graph.
  - Explain how to calculate the activation energy from this graph.



## S T O P

**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.**



# 2004 AP<sup>®</sup> CHEMISTRY FREE-RESPONSE QUESTIONS

## CHEMISTRY

### Part B

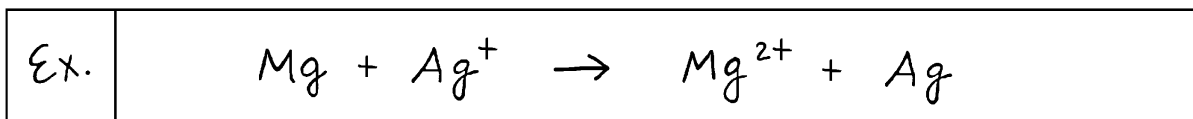
Time—50 minutes

**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.



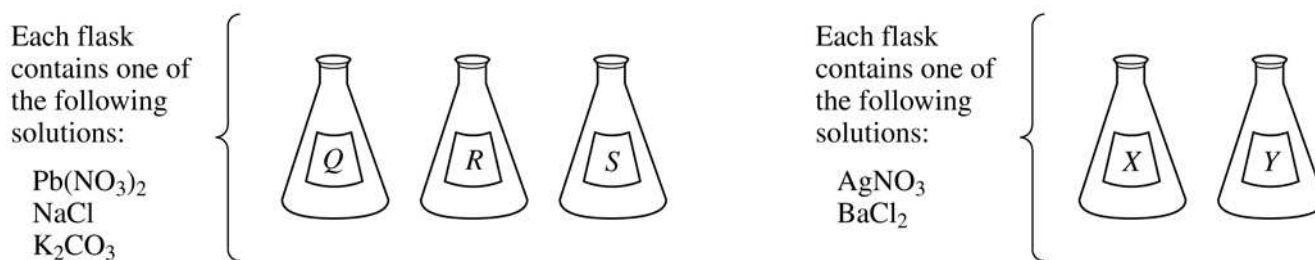
- (a) A solution of copper(II) sulfate is spilled onto a sheet of freshly polished aluminum metal.
- (b) Dimethyl ether is burned in air.
- (c) A 0.1 *M* nitrous acid solution is added to the same volume of a 0.1 *M* sodium hydroxide solution.
- (d) Hydrogen iodide gas is bubbled into a solution of lithium carbonate.
- (e) An acidic solution of potassium dichromate is added to a solution of iron(II) nitrate.
- (f) Excess concentrated aqueous ammonia is added to a solution of nickel(II) bromide.
- (g) A solution of sodium phosphate is added to a solution of aluminum nitrate.
- (h) Concentrated hydrochloric acid is added to a solution of sodium sulfide.

## 2004 AP<sup>®</sup> CHEMISTRY FREE-RESPONSE QUESTIONS

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.

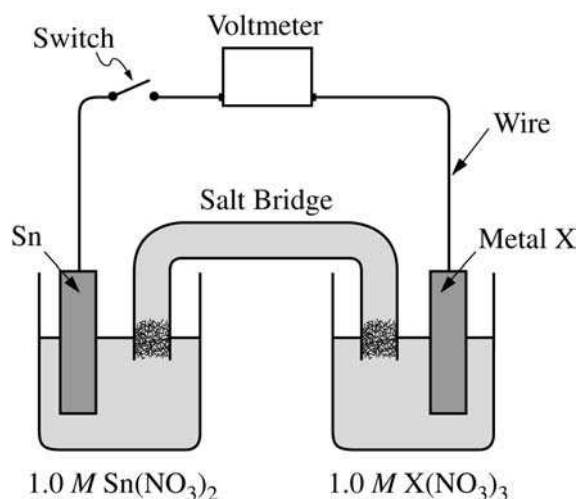
Answer BOTH Question 5 below AND Question 6 printed on page 11. Both of these questions will be graded. The Section II score weighting for these questions is 30 percent (15 percent each).

5. In a laboratory class, a student is given three flasks that are labeled  $Q$ ,  $R$ , and  $S$ . Each flask contains one of the following solutions:  $1.0\text{ M Pb(NO}_3)_2$ ,  $1.0\text{ M NaCl}$ , or  $1.0\text{ M K}_2\text{CO}_3$ . The student is also given two flasks that are labeled  $X$  and  $Y$ . One of these flasks contains  $1.0\text{ M AgNO}_3$ , and the other contains  $1.0\text{ M BaCl}_2$ . This information is summarized in the diagram below.

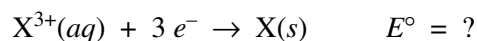
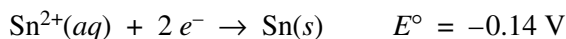


- (a) When the student combined a sample of solution  $Q$  with a sample of solution  $X$ , a precipitate formed. A precipitate also formed when samples of solutions  $Q$  and  $Y$  were combined.
- Identify solution  $Q$ .
  - Write the chemical formulas for each of the two precipitates.
- (b) When solution  $Q$  is mixed with solution  $R$ , a precipitate forms. However, no precipitate forms when solution  $Q$  is mixed with solution  $S$ .
- Identify solution  $R$  and solution  $S$ .
  - Write the chemical formula of the precipitate that forms when solution  $Q$  is mixed with solution  $R$ .
- (c) The identity of solution  $X$  and solution  $Y$  are to be determined using only the following solutions:  $1.0\text{ M Pb(NO}_3)_2$ ,  $1.0\text{ M NaCl}$ , and  $1.0\text{ M K}_2\text{CO}_3$ .
- Describe a procedure to identify solution  $X$  and solution  $Y$ .
  - Describe the observations that would allow you to distinguish between solution  $X$  and solution  $Y$ .
  - Explain how the observations would enable you to distinguish between solution  $X$  and solution  $Y$ .

# 2004 AP<sup>®</sup> CHEMISTRY FREE-RESPONSE QUESTIONS



6. An electrochemical cell is constructed with an open switch, as shown in the diagram above. A strip of Sn and a strip of an unknown metal, X, are used as electrodes. When the switch is closed, the mass of the Sn electrode increases. The half-reactions are shown below.



- In the diagram above, label the electrode that is the cathode. Justify your answer.
- In the diagram above, draw an arrow indicating the direction of the electron flow in the external circuit when the switch is closed.
- If the standard cell potential,  $E_{\text{cell}}^{\circ}$ , is +0.60 V, what is the standard reduction potential, in volts, for the  $\text{X}^{3+}/\text{X}$  electrode?
- Identify metal X.
- Write a balanced net-ionic equation for the overall chemical reaction occurring in the cell.
- In the cell, the concentration of  $\text{Sn}^{2+}$  is changed from 1.0 M to 0.50 M, and the concentration of  $\text{X}^{3+}$  is changed from 1.0 M to 0.10 M.
  - Substitute all the appropriate values for determining the cell potential,  $E_{\text{cell}}$ , into the Nernst equation. (Do not do any calculations.)
  - On the basis of your response in part (f) (i), will the cell potential,  $E_{\text{cell}}$ , be greater than, less than, or equal to the original  $E_{\text{cell}}^{\circ}$ ? Justify your answer.

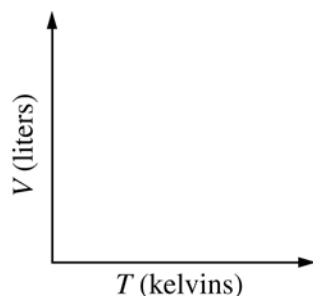
## 2004 AP<sup>®</sup> CHEMISTRY FREE-RESPONSE QUESTIONS

Answer EITHER Question 7 below OR Question 8 printed on page 13. 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.

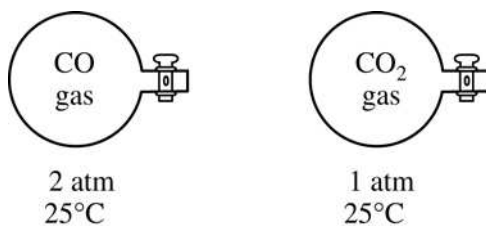
7. Use appropriate chemical principles to account for each of the following observations. In each part, your response must include specific information about both substances.
- (a) At 25°C and 1 atm,  $F_2$  is a gas, whereas  $I_2$  is a solid.
  - (b) The melting point of  $NaF$  is 993°C, whereas the melting point of  $CsCl$  is 645°C.
  - (c) The shape of the  $ICl_4^-$  ion is square planar, whereas the shape of the  $BF_4^-$  ion is tetrahedral.
  - (d) Ammonia,  $NH_3$ , is very soluble in water, whereas phosphine,  $PH_3$ , is only moderately soluble in water.

## 2004 AP<sup>®</sup> CHEMISTRY FREE-RESPONSE QUESTIONS

8. Answer the following questions about carbon monoxide,  $\text{CO}(g)$ , and carbon dioxide,  $\text{CO}_2(g)$ . Assume that both gases exhibit ideal behavior.
- (a) Draw the complete Lewis structure (electron-dot diagram) for the  $\text{CO}$  molecule and for the  $\text{CO}_2$  molecule.
  - (b) Identify the shape of the  $\text{CO}_2$  molecule.
  - (c) One of the two gases dissolves readily in water to form a solution with a pH below 7. Identify the gas and account for this observation by writing a chemical equation.
  - (d) A 1.0 mole sample of  $\text{CO}(g)$  is heated at constant pressure. On the graph below, sketch the expected plot of volume versus temperature as the gas is heated.



- (e) Samples of  $\text{CO}(g)$  and  $\text{CO}_2(g)$  are placed in 1 L containers at the conditions indicated in the diagram below.



- (i) Indicate whether the average kinetic energy of the  $\text{CO}_2(g)$  molecules is greater than, equal to, or less than the average kinetic energy of the  $\text{CO}(g)$  molecules. Justify your answer.
- (ii) Indicate whether the root-mean-square speed of the  $\text{CO}_2(g)$  molecules is greater than, equal to, or less than the root-mean-square speed of the  $\text{CO}(g)$  molecules. Justify your answer.
- (iii) Indicate whether the number of  $\text{CO}_2(g)$  molecules is greater than, equal to, or less than the number of  $\text{CO}(g)$  molecules. Justify your answer.

**END OF EXAMINATION**