



AP[®] Chemistry 2003 Free-Response Questions Form B

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DO NOT DETACH FROM BOOK.

PERIODIC TABLE OF THE ELEMENTS

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

*Lanthanide Series

58 Ce 140.12	59 Pr 140.91	60 Nd 144.24	61 Pm (145)	62 Sm 150.4	63 Eu 151.97	64 Gd 157.25	65 Tb 158.93	66 Dy 162.50	67 Ho 164.93	68 Er 167.26	69 Tm 168.93	70 Yb 173.04	71 Lu 174.97
90 Th 232.04	91 Pa 231.04	92 U 238.03	93 Np 237.05	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (252)	100 Fm (257)	101 Md (258)	102 No (259)	103 Lr (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	2F^-	2.87
$\text{Co}^{3+} + e^-$	\rightarrow	Co^{2+}	1.82
$\text{Au}^{3+} + 3 e^-$	\rightarrow	$\text{Au}(\text{s})$	1.50
$\text{Cl}_2(\text{g}) + 2 e^-$	\rightarrow	2Cl^-	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	2Br^-	1.07
$2 \text{Hg}^{2+} + 2 e^-$	\rightarrow	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	Fe^{2+}	0.77
$\text{I}_2(\text{s}) + 2 e^-$	\rightarrow	2I^-	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	Cu^+	0.15
$\text{Sn}^{4+} + 2 e^-$	\rightarrow	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	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

ADVANCED PLACEMENT CHEMISTRY EQUATIONS AND CONSTANTS

ATOMIC STRUCTURE

$$\Delta E = h\nu$$

$$c = \lambda\nu$$

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

$$p = mv$$

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

E = energy

ν = frequency

λ = wavelength

p = momentum

v = velocity

n = principal quantum number

m = mass

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 Δn = moles product gas – moles reactant gas

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 = $6.022 \times 10^{23} \text{ molecules mol}^{-1}$

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

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

THERMOCHEMISTRY

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

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

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

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

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

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

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

$$q = mc\Delta T$$

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

Equilibrium Constants

K_a (weak acid)

K_b (weak base)

K_w (water)

K_p (gas pressure)

K_c (molar concentrations)

S° = standard entropy

H° = standard enthalpy

G° = standard free energy

E° = standard reduction potential

T = temperature

n = moles

m = mass

q = heat

c = specific heat capacity

C_p = molar heat capacity at constant pressure

1 faraday \mathcal{F} = 96,500 coulombs

GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

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

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

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

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

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

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

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

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

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

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

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

molarity, M = moles solute per liter solution

molality = moles solute per kilogram solvent

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

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

$$\pi = \frac{nRT}{V} i$$

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

π = osmotic pressure

i = van't Hoff factor

K_f = molal freezing-point depression constant

K_b = molal boiling-point elevation constant

Q = reaction quotient

I = current (amperes)

q = charge (coulombs)

t = time (seconds)

E° = standard reduction potential

K = equilibrium constant

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

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

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

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

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

$$= 760 \text{ torr}$$

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

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

OXIDATION-REDUCTION; ELECTROCHEMISTRY

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

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

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

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

GO ON TO THE NEXT PAGE.

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CHEMISTRY

Section II

(Total time—90 minutes)

Part A

Time—40 minutes

YOU MAY USE YOUR CALCULATOR FOR PART A.

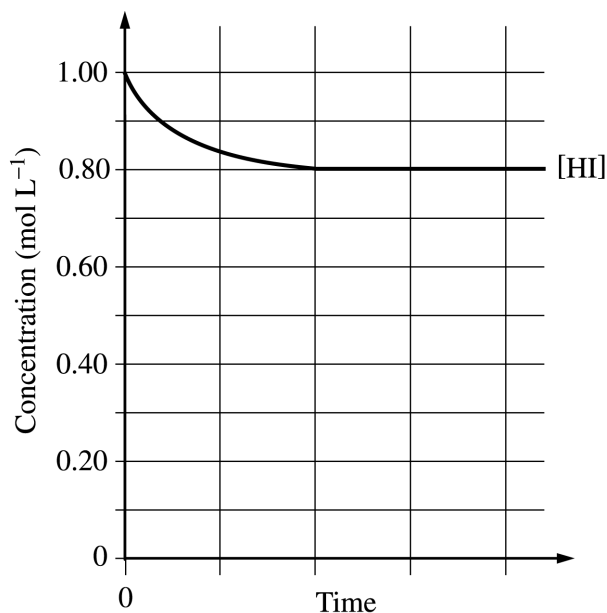
CLEARLY SHOW THE METHOD USED AND THE STEPS INVOLVED IN ARRIVING AT YOUR ANSWERS. It is to your advantage to do this, since you may obtain partial credit if you do and you will receive little or no credit if you do not. Attention should be paid to significant figures.

Be sure to write all your answers to the questions on the lined pages following each question in the booklet with the goldenrod cover. 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. After a 1.0 mole sample of $\text{HI}(g)$ is placed into an evacuated 1.0 L container at 700. K, the reaction represented above occurs. The concentration of $\text{HI}(g)$ as a function of time is shown below.



- (a) Write the expression for the equilibrium constant, K_c , for the reaction.
- (b) What is $[\text{HI}]$ at equilibrium?

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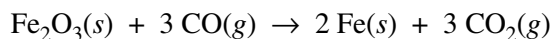
- (c) Determine the equilibrium concentrations of $\text{H}_2(g)$ and $\text{I}_2(g)$.
- (d) On the graph above, make a sketch that shows how the concentration of $\text{H}_2(g)$ changes as a function of time.
- (e) Calculate the value of the following equilibrium constants at 700. K.
- (i) K_c
 - (ii) K_p
- (f) At 1,000 K, the value of K_c for the reaction is 2.6×10^{-2} . In an experiment, 0.75 mole of $\text{HI}(g)$, 0.10 mole of $\text{H}_2(g)$, and 0.50 mole of $\text{I}_2(g)$ are placed in a 1.0 L container and allowed to reach equilibrium at 1,000 K. Determine whether the equilibrium concentration of $\text{HI}(g)$ will be greater than, equal to, or less than the initial concentration of $\text{HI}(g)$. Justify your answer.

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Answer EITHER Question 2 below OR Question 3 printed on page 9. 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.

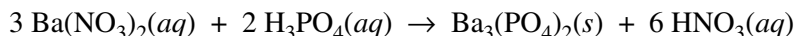
2. Answer the following questions that relate to chemical reactions.

- (a) Iron(III) oxide can be reduced with carbon monoxide according to the following equation.



A 16.2 L sample of $\text{CO}(g)$ at 1.50 atm and $200.^{\circ}\text{C}$ is combined with 15.39 g of $\text{Fe}_2\text{O}_3(s)$.

- (i) How many moles of $\text{CO}(g)$ are available for the reaction?
 - (ii) What is the limiting reactant for the reaction? Justify your answer with calculations.
 - (iii) How many moles of $\text{Fe}(s)$ are formed in the reaction?
- (b) In a reaction vessel, 0.600 mol of $\text{Ba}(\text{NO}_3)_2(s)$ and 0.300 mol of $\text{H}_3\text{PO}_4(aq)$ are combined with deionized water to a final volume of 2.00 L. The reaction represented below occurs.



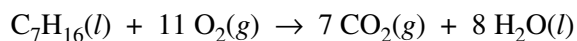
- (i) Calculate the mass of $\text{Ba}_3(\text{PO}_4)_2(s)$ formed.
- (ii) Calculate the pH of the resulting solution.
- (iii) What is the concentration, in mol L^{-1} , of the nitrate ion, $\text{NO}_3^-(aq)$, after the reaction reaches completion?

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3. In an experiment, a sample of an unknown, pure gaseous hydrocarbon was analyzed. Results showed that the sample contained 6.000 g of carbon and 1.344 g of hydrogen.

- (a) Determine the empirical formula of the hydrocarbon.
- (b) The density of the hydrocarbon at 25°C and 1.09 atm is 1.96 g L⁻¹.
- (i) Calculate the molar mass of the hydrocarbon.
- (ii) Determine the molecular formula of the hydrocarbon.

In another experiment, liquid heptane, C₇H₁₆(l), is completely combusted to produce CO₂(g) and H₂O(l), as represented by the following equation.



The heat of combustion, $\Delta H_{\text{comb}}^\circ$, for one mole of C₇H₁₆(l) is -4.85×10^3 kJ.

- (c) Using the information in the table below, calculate the value of ΔH_f° for C₇H₁₆(l) in kJ mol⁻¹.

Compound	ΔH_f° (kJ mol ⁻¹)
CO ₂ (g)	-393.5
H ₂ O(l)	-285.8

- (d) A 0.0108 mol sample of C₇H₁₆(l) is combusted in a bomb calorimeter.
- (i) Calculate the amount of heat released to the calorimeter.
- (ii) Given that the total heat capacity of the calorimeter is 9.273 kJ °C⁻¹, calculate the temperature change of the calorimeter.

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CHEMISTRY

Part B

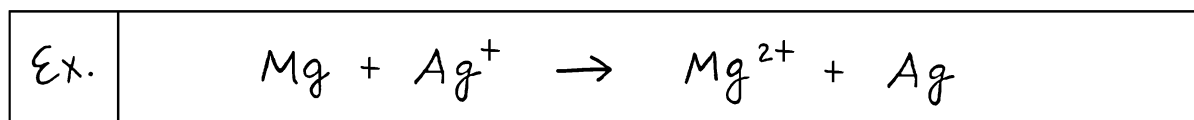
Time—50 minutes

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.



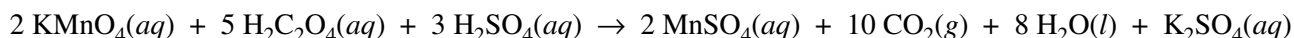
- (a) Hot hydrogen gas is passed over heated copper(II) oxide solid.
- (b) Solid sodium hydride is added to water.
- (c) Propanone is burned in air.
- (d) A solution of lead(II) nitrate is added to a solution of potassium sulfate.
- (e) Ammonia gas is mixed with hydrogen chloride gas.
- (f) Sulfur trioxide gas is bubbled into water.
- (g) Excess concentrated potassium hydroxide solution is added to a solution of nickel(II) chloride.
- (h) Solid sodium acetate is added to 1.0 *M* hydrobromic acid.

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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 12. Both of these questions will be graded. The Section II score weighting for these questions is 30 percent (15 percent each).

5. Oxalic acid, $\text{H}_2\text{C}_2\text{O}_4$, is a primary standard used to determine the concentration of potassium permanganate, KMnO_4 , in solution. The equation for the reaction is as follows.



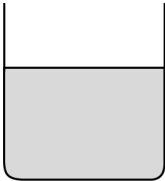
A student dissolves a sample of oxalic acid in a flask with 30 mL of water and 2.00 mL of 3.00 M H_2SO_4 . The KMnO_4 solution of unknown concentration is in a 25.0 mL buret. In the titration, the KMnO_4 solution is added to the solution containing oxalic acid.

- (a) What chemical species is being oxidized in the reaction?
- (b) What substance indicates the observable endpoint of the titration? Describe the observation that shows the endpoint has been reached.
- (c) What data must be collected in the titration in order to determine the molar concentration of the unknown KMnO_4 solution?
- (d) Without doing any calculations, explain how to determine the molarity of the unknown KMnO_4 solution.
- (e) How would the calculated concentration of the KMnO_4 solution be affected if 40 mL of water was added to the oxalic acid initially instead of 30 mL? Explain your reasoning.

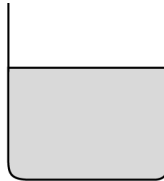
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6. Answer the following questions about electrochemistry.

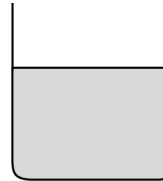
- (a) Several different electrochemical cells can be constructed using the materials shown below. Write the balanced net-ionic equation for the reaction that occurs in the cell that would have the greatest positive value of E_{cell}° .




1.0 M $\text{Al}(\text{NO}_3)_3$




1.0 M $\text{Cu}(\text{NO}_3)_2$




1.0 M $\text{Fe}(\text{NO}_3)_2$



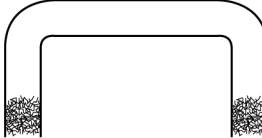
Al Metal Strip



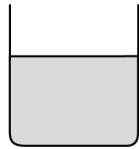
Cu Metal Strip



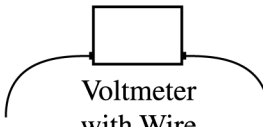
Fe Metal Strip



Materials for Salt Bridge

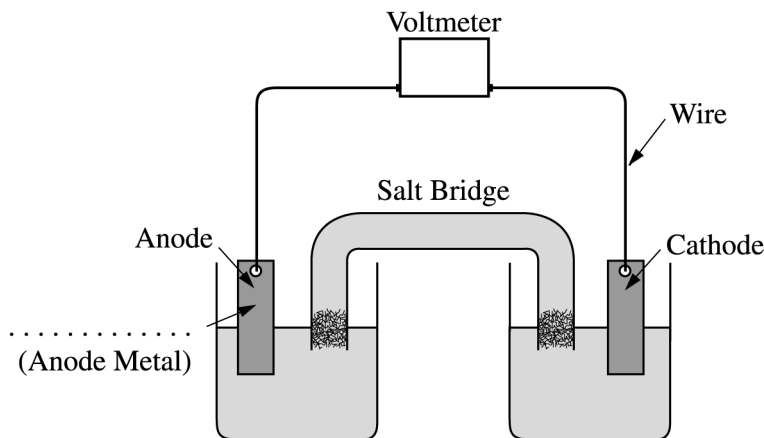


Solution to Fill Salt Bridge



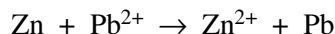
Voltmeter with Wire

- (b) Calculate the standard cell potential, E_{cell}° , for the reaction written in part (a).
- (c) A cell is constructed based on the reaction in part (a) above. Label the metal used for the anode on the cell shown in the figure below.



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- (d) Of the compounds NaOH , CuS , and NaNO_3 , which one is appropriate to use in a salt bridge? Briefly explain your answer, and for each of the other compounds, include a reason why it is not appropriate.
- (e) Another standard cell is based on the following reaction.



If the concentration of Zn^{2+} is decreased from 1.0 M to 0.25 M , what effect does this have on the cell potential? Justify your answer.

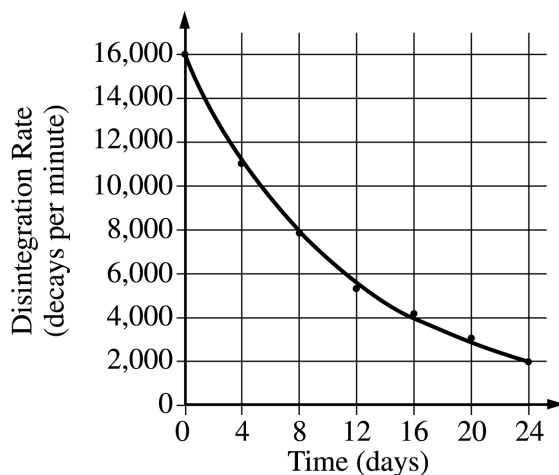
Answer EITHER Question 7 below OR Question 8 printed on page 14. Only one of these two questions will be graded. If you start both questions, be sure to cross out the question you do not want graded. The Section II score weighting for the question you choose is 15 percent.

7. Account for the following observations using principles of atomic structure and/or chemical bonding. In each part, your answer must include specific information about both substances.
- (a) The Ca^{2+} and Cl^- ions are isoelectronic, but their radii are not the same. Which ion has the larger radius? Explain.
- (b) Carbon and lead are in the same group of elements, but carbon is classified as a nonmetal and lead is classified as a metal.
- (c) Compounds containing Kr have been synthesized, but there are no known compounds that contain He .
- (d) The first ionization energy of Be is 900 kJ mol^{-1} , but the first ionization energy of B is 800 kJ mol^{-1} .

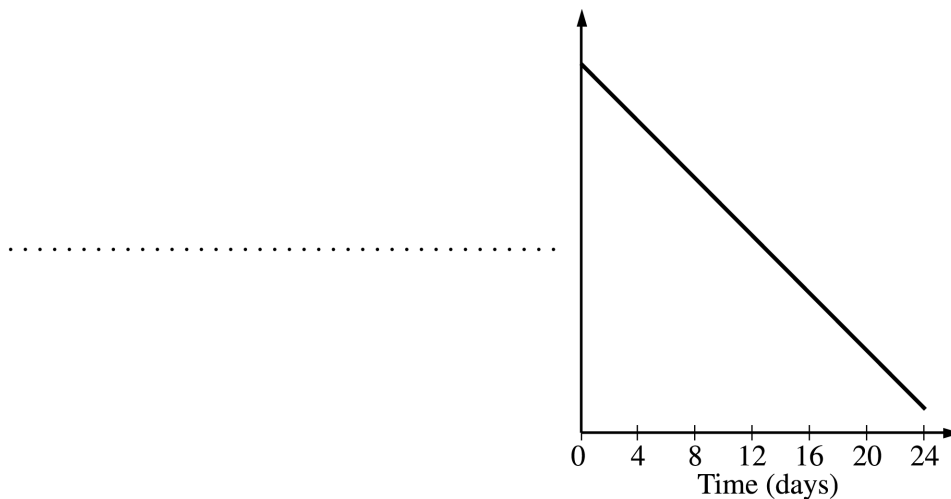
2003 AP[®] CHEMISTRY FREE-RESPONSE QUESTIONS (Form B)

8. The decay of the radioisotope I-131 was studied in a laboratory. I-131 is known to decay by beta (${}_{-1}^0e$) emission.
- (a) Write a balanced nuclear equation for the decay of I-131.
- (b) What is the source of the beta particle emitted from the nucleus?

The radioactivity of a sample of I-131 was measured. The data collected are plotted on the graph below.



- (c) Determine the half-life, $t_{1/2}$, of I-131 using the graph above.
- (d) The data can be used to show that the decay of I-131 is a first-order reaction, as indicated on the graph below.



- (i) Label the vertical axis of the graph above.
- (ii) What are the units of the rate constant, k , for the decay reaction?
- (iii) Explain how the half-life of I-131 can be calculated using the slope of the line plotted on the graph.
- (e) Compare the value of the half-life of I-131 at 25°C to its value at 50°C.

END OF EXAMINATION

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