



## **AP<sup>®</sup> Chemistry**

### **2011 Free-Response Questions**

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INFORMATION IN THE TABLE BELOW AND IN THE TABLES ON PAGES 3-5 MAY BE USEFUL IN ANSWERING THE QUESTIONS IN THIS SECTION OF THE EXAMINATION.

DO NOT DETACH FROM BOOK.

## PERIODIC TABLE OF THE ELEMENTS

1	2											3	4	5	6	7	8	9	10																	
<b>H</b>	<b>He</b>											<b>B</b>	<b>C</b>	<b>N</b>	<b>O</b>	<b>F</b>	<b>Ne</b>																			
1.008	4.00											10.81	12.01	14.01	16.00	19.00	20.18																			
3												13	14	15	16	17	18																			
<b>Li</b>	<b>Be</b>											<b>Al</b>	<b>Si</b>	<b>P</b>	<b>S</b>	<b>Cl</b>	<b>Ar</b>																			
6.94	9.01											26.98	28.09	30.97	32.06	35.45	39.95																			
11	12											26.98	28.09	30.97	32.06	35.45	39.95																			
<b>Na</b>	<b>Mg</b>											<b>K</b>	<b>Ca</b>	<b>Sc</b>	<b>Ti</b>	<b>V</b>	<b>Cr</b>	<b>Mn</b>	<b>Fe</b>	<b>Co</b>	<b>Ni</b>	<b>Cu</b>	<b>Zn</b>	<b>Ga</b>	<b>Ge</b>	<b>As</b>	<b>Se</b>	<b>Br</b>	<b>Kr</b>							
22.99	24.30											39.10	40.08	44.96	47.90	50.94	52.00	54.94	55.85	58.93	58.69	63.55	65.39	69.72	72.59	74.92	78.96	79.90	83.80							
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54																			
<b>Rb</b>	<b>Sr</b>	<b>Y</b>	<b>Zr</b>	<b>Nb</b>	<b>Mo</b>	<b>Tc</b>	<b>Ru</b>	<b>Rh</b>	<b>Pd</b>	<b>Ag</b>	<b>Cd</b>	<b>In</b>	<b>Sn</b>	<b>Sb</b>	<b>Te</b>	<b>I</b>	<b>Xe</b>																			
85.47	87.62	88.91	91.22	92.91	95.94	(98)	101.1	102.91	106.42	107.87	112.41	114.82	118.71	121.75	127.60	126.91	131.29																			
55	56	57	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86																			
<b>Cs</b>	<b>Ba</b>	<b>*La</b>	<b>Hf</b>	<b>Ta</b>	<b>W</b>	<b>Re</b>	<b>Os</b>	<b>Ir</b>	<b>Pt</b>	<b>Au</b>	<b>Hg</b>	<b>Tl</b>	<b>Pb</b>	<b>Bi</b>	<b>Po</b>	<b>At</b>	<b>Rn</b>																			
132.91	137.33	138.91	178.49	180.95	183.85	186.21	190.2	192.2	195.08	196.97	200.59	204.38	207.2	208.98	(209)	(210)	(222)																			
87	88	89	104	105	106	107	108	109	110	111																										
<b>Fr</b>	<b>Ra</b>	<b>†Ac</b>	<b>Rf</b>	<b>Db</b>	<b>Sg</b>	<b>Bh</b>	<b>Hs</b>	<b>Mt</b>	<b>Ds</b>	<b>Rg</b>																										
(223)	226.02	227.03	(261)	(262)	(266)	(264)	(277)	(268)	(271)	(272)																										
																			*Lanthanide Series																	
																			†Actinide Series																	
																			58	59	60	61	62	63	64	65	66	67	68	69	70	71				
																			<b>Ce</b>	<b>Pr</b>	<b>Nd</b>	<b>Pm</b>	<b>Sm</b>	<b>Eu</b>	<b>Gd</b>	<b>Tb</b>	<b>Dy</b>	<b>Ho</b>	<b>Er</b>	<b>Tm</b>	<b>Yb</b>	<b>Lu</b>				
																			140.12	140.91	144.24	(145)	150.4	151.97	157.25	158.93	162.50	164.93	167.26	168.93	173.04	174.97				
																			90	91	92	93	94	95	96	97	98	99	100	101	102	103				
																			<b>Th</b>	<b>Pa</b>	<b>U</b>	<b>Np</b>	<b>Pu</b>	<b>Am</b>	<b>Cm</b>	<b>Bk</b>	<b>Cf</b>	<b>Es</b>	<b>Fm</b>	<b>Md</b>	<b>No</b>	<b>Lr</b>				
																			232.04	231.04	238.03	(237)	(244)	(243)	(247)	(247)	(251)	(252)	(257)	(258)	(259)	(262)				

## 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

## ADVANCED PLACEMENT CHEMISTRY EQUATIONS AND CONSTANTS

### ATOMIC STRUCTURE

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

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

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

### 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

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

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

$$= 62.4 \text{ L torr mol}^{-1} \text{ K}^{-1}$$

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

## 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

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

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

$$\pi = iMRT$$

$$A = abc$$

$P$  = 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

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

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

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

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

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

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

$$= 62.4 \text{ L torr mol}^{-1} \text{ K}^{-1}$$

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

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

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

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

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

$$= 760 \text{ torr}$$

STP =  $0.00^\circ\text{C}$  and  $1.0 \text{ atm}$

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

2011 AP<sup>®</sup> CHEMISTRY FREE-RESPONSE QUESTIONS

CHEMISTRY

Section II

(Total time—95 minutes)

Part A

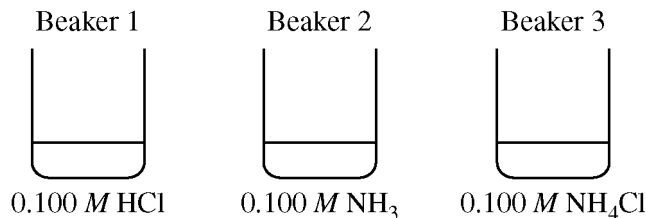
Time—55 minutes

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 Questions 1, 2, and 3. The Section II score weighting for each question is 20 percent.



1. Each of three beakers contains 25.0 mL of a 0.100 M solution of HCl, NH<sub>3</sub>, or NH<sub>4</sub>Cl, as shown above. Each solution is at 25°C.
- (a) Determine the pH of the solution in beaker 1. Justify your answer.
- (b) In beaker 2, the reaction  $\text{NH}_3(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{NH}_4^+(aq) + \text{OH}^-(aq)$  occurs. The value of  $K_b$  for  $\text{NH}_3(aq)$  is  $1.8 \times 10^{-5}$  at 25°C.
- (i) Write the  $K_b$  expression for the reaction of  $\text{NH}_3(aq)$  with  $\text{H}_2\text{O}(l)$ .
- (ii) Calculate the  $[\text{OH}^-]$  in the solution in beaker 2.
- (c) In beaker 3, the reaction  $\text{NH}_4^+(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{NH}_3(aq) + \text{H}_3\text{O}^+(aq)$  occurs.
- (i) Calculate the value of  $K_a$  for  $\text{NH}_4^+(aq)$  at 25°C.
- (ii) The contents of beaker 2 are poured into beaker 3 and the resulting solution is stirred. Assume that volumes are additive. Calculate the pH of the resulting solution.
- (d) The contents of beaker 1 are poured into the solution made in part (c)(ii). The resulting solution is stirred. Assume that volumes are additive.
- (i) Is the resulting solution an effective buffer? Justify your answer.
- (ii) Calculate the final  $[\text{NH}_4^+]$  in the resulting solution at 25°C.

## 2011 AP<sup>®</sup> CHEMISTRY FREE-RESPONSE QUESTIONS

2. A student is assigned the task of determining the mass percent of silver in an alloy of copper and silver by dissolving a sample of the alloy in excess nitric acid and then precipitating the silver as AgCl.

First the student prepares 50. mL of 6 M HNO<sub>3</sub>.

- (a) The student is provided with a stock solution of 16 M HNO<sub>3</sub>, two 100 mL graduated cylinders that can be read to ±1 mL, a 100 mL beaker that can be read to ±10 mL, safety goggles, rubber gloves, a glass stirring rod, a dropper, and distilled H<sub>2</sub>O.
- (i) Calculate the volume, in mL, of 16 M HNO<sub>3</sub> that the student should use for preparing 50. mL of 6 M HNO<sub>3</sub>.
  - (ii) Briefly list the steps of an appropriate and safe procedure for preparing the 50. mL of 6 M HNO<sub>3</sub>. Only materials selected from those provided to the student (listed above) may be used.
  - (iii) Explain why it is not necessary to use a volumetric flask (calibrated to 50.00 mL ±0.05 mL) to perform the dilution.
  - (iv) During the preparation of the solution, the student accidentally spills about 1 mL of 16 M HNO<sub>3</sub> on the bench top. The student finds three bottles containing liquids sitting near the spill: a bottle of distilled water, a bottle of 5 percent NaHCO<sub>3</sub>(aq), and a bottle of saturated NaCl(aq). Which of the liquids is best to use in cleaning up the spill? Justify your choice.

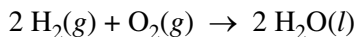
Then the student pours 25 mL of the 6 M HNO<sub>3</sub> into a beaker and adds a 0.6489 g sample of the alloy. After the sample completely reacts with the acid, some saturated NaCl(aq) is added to the beaker, resulting in the formation of an AgCl precipitate. Additional NaCl(aq) is added until no more precipitate is observed to form. The precipitate is filtered, washed, dried, and weighed to constant mass in a filter crucible. The data are shown in the table below.

Mass of sample of copper-silver alloy	0.6489 g
Mass of dry filter crucible	28.7210 g
Mass of filter crucible and precipitate (first weighing)	29.3587 g
Mass of filter crucible and precipitate (second weighing)	29.2599 g
Mass of filter crucible and precipitate (third weighing)	29.2598 g

- (b) Calculate the number of moles of AgCl precipitate collected.
- (c) Calculate the mass percent of silver in the alloy of copper and silver.

**2011 AP<sup>®</sup> CHEMISTRY FREE-RESPONSE QUESTIONS**

3. Hydrogen gas burns in air according to the equation below.



- (a) Calculate the standard enthalpy change,  $\Delta H_{298}^\circ$ , for the reaction represented by the equation above. (The molar enthalpy of formation,  $\Delta H_f^\circ$ , for  $\text{H}_2\text{O}(l)$  is  $-285.8 \text{ kJ mol}^{-1}$  at 298 K.)
- (b) Calculate the amount of heat, in kJ, that is released when 10.0 g of  $\text{H}_2(g)$  is burned in air.
- (c) Given that the molar enthalpy of vaporization,  $\Delta H_{vap}^\circ$ , for  $\text{H}_2\text{O}(l)$  is  $44.0 \text{ kJ mol}^{-1}$  at 298 K, what is the standard enthalpy change,  $\Delta H_{298}^\circ$ , for the reaction  $2 \text{H}_2(g) + \text{O}_2(g) \rightarrow 2 \text{H}_2\text{O}(g)$  ?

A fuel cell is an electrochemical cell that converts the chemical energy stored in a fuel into electrical energy. A cell that uses  $\text{H}_2$  as the fuel can be constructed based on the following half-reactions.

Half-reaction	$E^\circ$ (298 K)
$2 \text{H}_2\text{O}(l) + \text{O}_2(g) + 4 e^- \rightarrow 4 \text{OH}^-(aq)$	0.40 V
$2 \text{H}_2\text{O}(l) + 2 e^- \rightarrow \text{H}_2(g) + 2 \text{OH}^-(aq)$	-0.83 V

- (d) Write the equation for the overall cell reaction.
- (e) Calculate the standard potential for the cell at 298 K.
- (f) Assume that 0.93 mol of  $\text{H}_2(g)$  is consumed as the cell operates for 600. seconds.
- Calculate the number of moles of electrons that pass through the cell.
  - Calculate the average current, in amperes, that passes through the cell.
- (g) Some fuel cells use butane gas,  $\text{C}_4\text{H}_{10}$ , rather than hydrogen gas. The overall reaction that occurs in a butane fuel cell is  $2 \text{C}_4\text{H}_{10}(g) + 13 \text{O}_2(g) \rightarrow 8 \text{CO}_2(g) + 10 \text{H}_2\text{O}(l)$ . What is one environmental advantage of using fuel cells that are based on hydrogen rather than on hydrocarbons such as butane?

**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.**



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CHEMISTRY

Part B

Time—40 minutes

NO CALCULATORS MAY BE USED FOR PART B.

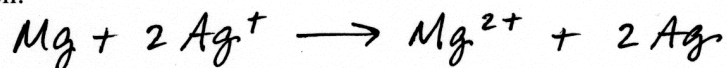
Answer Question 4 below. The Section II score weighting for this question is 10 percent.

4. For each of the following three reactions, write a balanced equation for the reaction in part (i) and answer the question about the reaction in part (ii). In part (i), coefficients should be in terms of lowest whole numbers. Assume that solutions are aqueous unless otherwise indicated. Represent substances in solutions as ions if the substances are extensively ionized. Omit formulas for any ions or molecules that are unchanged by the reaction. You may use the empty space at the bottom of the next page for scratch work, but only equations that are written in the answer boxes provided will be scored.

EXAMPLE:

A strip of magnesium metal is added to a solution of silver(I) nitrate.

(i) Balanced equation:



(ii) Which substance is oxidized in the reaction?

Mg is oxidized.

- (a) Solid magnesium hydroxide is added to a solution of hydrobromic acid.

(i) Balanced equation:

(ii) What volume, in mL, of 2.00 M hydrobromic acid is required to react completely with 0.10 mol of solid magnesium hydroxide?

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(b) Excess hydrochloric acid is added to a solution of cobalt(II) nitrate to produce a coordination complex.

(i) Balanced equation:

(ii) Which species in the reaction acts as a Lewis base?

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(c) A copper wire is dipped into a solution of silver(I) nitrate.

(i) Balanced equation:

(ii) Describe what is observed as the reaction proceeds.

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**YOU MAY USE THE SPACE BELOW FOR SCRATCH WORK, BUT ONLY EQUATIONS THAT ARE WRITTEN IN THE ANSWER BOXES PROVIDED WILL BE SCORED.**

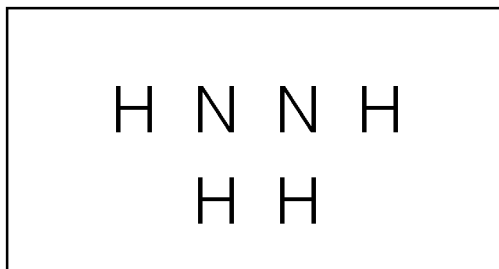
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Answer Question 5 and Question 6. The Section II score weighting for these questions is 15 percent each.

Your responses to these questions will be scored 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.

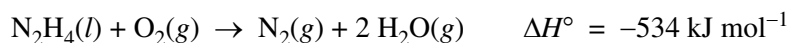
5. Hydrazine is an inorganic compound with the formula  $N_2H_4$ .

- (a) In the box below, complete the Lewis electron-dot diagram for the  $N_2H_4$  molecule by drawing in all the electron pairs.



- (b) On the basis of the diagram you completed in part (a), do all six atoms in the  $N_2H_4$  molecule lie in the same plane? Explain.
- (c) The normal boiling point of  $N_2H_4$  is  $114^\circ C$ , whereas the normal boiling point of  $C_2H_6$  is  $-89^\circ C$ . Explain, in terms of the intermolecular forces present in each liquid, why the boiling point of  $N_2H_4$  is so much higher than that of  $C_2H_6$ .
- (d) Write a balanced chemical equation for the reaction between  $N_2H_4$  and  $H_2O$  that explains why a solution of hydrazine in water has a pH greater than 7.

$N_2H_4$  reacts in air according to the equation below.



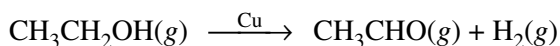
- (e) Is the reaction an oxidation-reduction, acid-base, or decomposition reaction? Justify your answer.
- (f) Predict the sign of the entropy change,  $\Delta S$ , for the reaction. Justify your prediction.
- (g) Indicate whether the statement written in the box below is true or false. Justify your answer.

The large negative  $\Delta H^\circ$  for the combustion of hydrazine results from the large release of energy that occurs when the strong bonds of the reactants are broken.

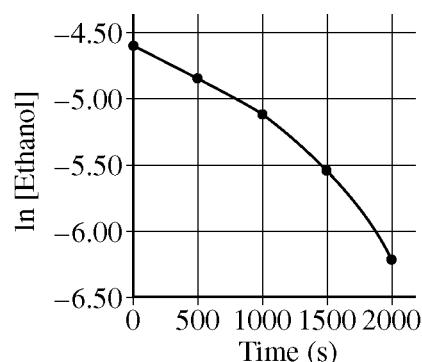
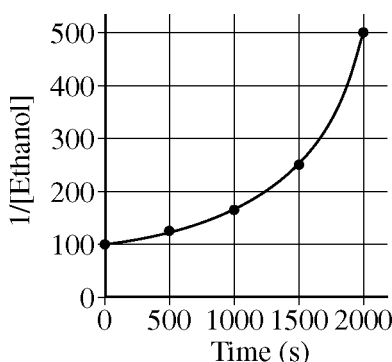
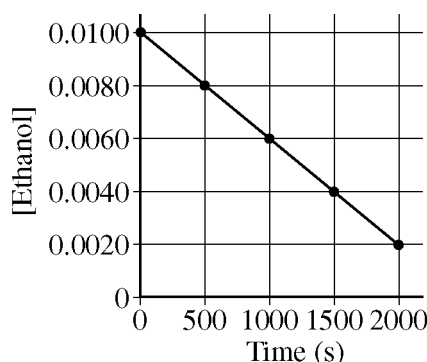
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6. In an experiment, all the air in a rigid 2.0 L flask is pumped out. Then some liquid ethanol is injected into the sealed flask, which is held at 35°C. The amount of liquid ethanol initially decreases, but after five minutes the amount of liquid ethanol in the flask remains constant. Ethanol has a boiling point of 78.5°C and an equilibrium vapor pressure of 100 torr at 35°C.
- (a) When the amount of liquid ethanol in the flask is constant, is the pressure in the flask greater than, less than, or equal to 100 torr? Justify your answer.
- (b) The flask is then heated to 45°C, and the pressure in the flask increases. In terms of kinetic molecular theory, provide TWO reasons that the pressure in the flask is greater at 45°C than at 35°C.

In a second experiment, which is performed at a much higher temperature, a sample of ethanol gas and a copper catalyst are placed in a rigid, empty 1.0 L flask. The temperature of the flask is held constant, and the initial concentration of the ethanol gas is 0.0100 M. The ethanol begins to decompose according to the chemical reaction represented below.



The concentration of ethanol gas over time is used to create the three graphs below.



- (c) Given that the reaction order is zero, one, or two, use the information in the graphs to respond to the following.
- (i) Determine the order of the reaction with respect to ethanol. Justify your answer.
- (ii) Write the rate law for the reaction.
- (iii) Determine the rate constant for the reaction, including units.
- (d) The pressure in the flask at the beginning of the experiment is 0.40 atm. If the ethanol completely decomposes, what is the final pressure in the flask?

STOP

END OF EXAM