CollegeBoard
Advanced Placement Program

AP® Chemistry
2007 Scoring Guidelines
Form B

Question 1

A sample of solid U_3O_8 is placed in a rigid 1.500 L flask. Chlorine gas, $Cl_2(g)$, is added, and the flask is heated to 862°C. The equation for the reaction that takes place and the equilibrium-constant expression for the reaction are given below.

$$U_3O_8(s) + 3\,Cl_2(g) \rightleftarrows 3\,UO_2Cl_2(g) + O_2(g) \qquad K_p = \frac{(p_{UO_2Cl_2})^3(p_{O_2})}{(p_{Cl_2})^3}$$

When the system is at equilibrium, the partial pressure of $Cl_2(g)$ is 1.007 atm and the partial pressure of $UO_2Cl_2(g)$ is 9.734×10^{-4} atm.

(a) Calculate the partial pressure of $O_2(g)$ at equilibrium at 862°C.

$U_3O_8(s) + 3\,Cl_2(g) \rightleftarrows 3\,UO_2Cl_2(g) + O_2(g)$ I: --- ; ? ; 0 ; 0 C E: 1.007 atm ; 9.734×10^{-4} atm ; ? 9.734×10^{-4} atm $UO_2Cl_2(g) \times \frac{(1 \text{ mol } O_2)}{(3 \text{ mol } UO_2Cl_2)} = 3.245 \times 10^{-4}$ atm $O_2(g)$	One point is earned for the correct answer.

(b) Calculate the value of the equilibrium constant, K_p, for the system at 862°C.

$K_p = \frac{(p_{UO_2Cl_2})^3(p_{O_2})}{(p_{Cl_2})^3} = \frac{(9.734\times10^{-4})^3(3.245\times10^{-4})}{(1.007)^3} = 2.931 \times 10^{-13}$	One point is earned for the correct substitution. One point is earned for the correct answer.

(c) Calculate the Gibbs free-energy change, $\Delta G°$, for the reaction at 862°C.

$\Delta G° = -RT \ln K_p$ $= (-8.31 \text{ J mol}^{-1} \text{ K}^{-1})((862+273) \text{ K})(\ln (2.931 \times 10^{-13}))$ $= 272{,}000 \text{ J mol}^{-1} = 272 \text{ kJ mol}^{-1}$	One point is earned for the correct setup. One point is earned for the correct answer with units.

Question 1 (continued)

(d) State whether the entropy change, $\Delta S°$, for the reaction at 862°C is positive, negative, or zero. Justify your answer.

$\Delta S°$ is positive because four moles of gaseous products are produced from three moles of gaseous reactants.	One point is earned for the correct explanation.

(e) State whether the enthalpy change, $\Delta H°$, for the reaction at 862°C is positive, negative, or zero. Justify your answer.

Both $\Delta G°$ and $\Delta S°$ are positive, as determined in parts (c) and (d). Thus, $\Delta H°$ must be positive because $\Delta H°$ is the sum of two positive terms in the equation $\Delta H° = \Delta G° + T\Delta S°$.	One point is earned for the correct sign. One point is earned for a correct explanation.

(f) After a certain period of time, 1.000 mol of $O_2(g)$ is added to the mixture in the flask. Does the mass of $U_3O_8(s)$ in the flask increase, decrease, or remain the same? Justify your answer.

The mass of $U_3O_8(s)$ will increase because the reaction is at equilibrium, and the addition of a product creates a "stress" on the product (right) side of the reaction. The reaction will then proceed from right to left to reestablish equilibrium so that some $O_2(g)$ is consumed (tending to relieve the stress) as more $U_3O_8(s)$ is produced.	One point is earned for a correct explanation.

Question 2

Answer the following problems about gases.

(a) The average atomic mass of naturally occurring neon is 20.18 amu. There are two common isotopes of naturally occurring neon as indicated in the table below.

Isotope	Mass (amu)
Ne-20	19.99
Ne-22	21.99

(i) Using the information above, calculate the percent abundance of each isotope.

Let x represent the natural abundance of Ne-20. $19.99x + 21.99(1-x) = 20.18$ $19.99x + 21.99 - 21.99x = 20.18$ $19.99x - 21.99x = 20.18 - 21.99$ $-2x = -1.81$ $x = 0.905$ ⇒ percent abundances are: Ne-20 = 90.5% Ne-22 = 9.5%	One point is earned for the correct answer.

(ii) Calculate the number of Ne-22 atoms in a 12.55 g sample of naturally occurring neon.

$12.55 \text{ g Ne} \times \frac{1 \text{ mol Ne}}{20.18 \text{ g Ne}} \times \frac{0.095 \text{ mol Ne-22}}{1 \text{ mol Ne}} \times \frac{6.022\times10^{23} \text{ Ne-22 atoms}}{1 \text{ mol Ne-22}}$ $= 3.6 \times 10^{22}$ Ne-22 atoms	One point is earned for the correct molar mass. One point is earned for the correct fraction of Ne-22 in Ne. One point is earned for the number of atoms.

Question 2 (continued)

(b) A major line in the emission spectrum of neon corresponds to a frequency of 4.34×10^{-14} s^{-1}. Calculate the wavelength, in nanometers, of light that corresponds to this line.

$c = \lambda\nu \quad \Rightarrow \quad \lambda = \frac{c}{\nu}$ $\lambda = \frac{3.0\times10^{8}\ \text{m s}^{-1}}{4.34\times10^{14}\ \text{s}^{-1}} \times \frac{1\ \text{nm}}{10^{-9}\ \text{m}} = 690\ \text{nm}$	One point is earned for the correct setup. One point is earned for the answer.

(c) In the upper atmosphere, ozone molecules decompose as they absorb ultraviolet (UV) radiation, as shown by the equation below. Ozone serves to block harmful ultraviolet radiation that comes from the Sun.

$$O_3(g) \xrightarrow{\text{UV}} O_2(g) + O(g)$$

A molecule of $O_3(g)$ absorbs a photon with a frequency of 1.00×10^{15} s^{-1}.

(i) How much energy, in joules, does the $O_3(g)$ molecule absorb per photon?

$E = h\nu$ $= 6.63 \times 10^{-34}\ \text{J s} \times 1.00 \times 10^{15}\ \text{s}^{-1}$ $= 6.63\times10^{-19}\ \text{J}$ per photon	One point is earned for the correct answer.

(ii) The minimum energy needed to break an oxygen-oxygen bond in ozone is 387 kJ mol^{-1}. Does a photon with a frequency of 1.00×10^{15} s^{-1} have enough energy to break this bond? Support your answer with a calculation.

$\frac{6.63\times10^{-19}\ \text{J}}{1\ \text{photon}} \times \frac{6.022\times10^{23}\ \text{photons}}{1\ \text{mol}} \times \frac{1\ \text{kJ}}{10^{3}\ \text{J}} = 399\ \text{kJ mol}^{-1}$ 399 kJ mol^{-1} > 387 kJ mol^{-1}, therefore the bond can be broken.	One point is earned for calculating the energy. One point is earned for the comparison of bond energies.

Question 3

$$2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(l)$$

In a hydrogen-oxygen fuel cell, energy is produced by the overall reaction represented above.

(a) When the fuel cell operates at 25°C and 1.00 atm for 78.0 minutes, 0.0746 mol of $O_2(g)$ is consumed. Calculate the volume of $H_2(g)$ consumed during the same time period. Express your answer in liters measured at 25°C and 1.00 atm.

$(0.0746 \text{ mol } O_2) \times \dfrac{2 \text{ mol } H_2}{1 \text{ mol } O_2} = 0.149 \text{ mol } H_2$ $V = \dfrac{n_{H_2}RT}{P} = \dfrac{(0.149 \text{ mol } H_2)(0.0821 \text{ L atm mol}^{-1}\ \text{K}^{-1})(298 \text{ K})}{1.00 \text{ atm}}$ $= 3.65 \text{ L } H_2$	One point is earned for calculation of moles of H_2. One point is earned for substitution into $PV = nRT$. One point is earned for the answer.

(b) Given that the fuel cell reaction takes place in an acidic medium,

(i) write the two half reactions that occur as the cell operates,

$O_2 + 4\ H^+ + 4\ e^- \rightarrow 2\ H_2O$ $H_2 \rightarrow 2\ H^+ + 2\ e^-$	One point is earned for each of the two half reactions.

(ii) identify the half reaction that takes place at the cathode, and

$O_2 + 4\ H^+ + 4\ e^- \rightarrow 2\ H_2O$	One point is earned for either the equation of the correct half reaction, or for indicating "the reduction half reaction" if the correct equation is given in (b)(i).

(iii) determine the value of the standard potential, $E°$, of the cell.

$E° = 1.23\text{V} + 0.00\text{ V} = 1.23\text{ V}$	One point is earned for the standard potential.

Question 3 (continued)

(c) Calculate the charge, in coulombs, that passes through the cell during the 78.0 minutes of operation as described in part (a).

$(0.0746 \text{ mol } O_2) \times \dfrac{4 \text{ mol } e^-}{1 \text{ mol } O_2} \times \dfrac{96{,}500 \text{ C}}{1 \text{ mol } e^-} = 2.88 \times 10^4 \text{ C}$	One point is earned for the stoichiometry. One point is earned for the answer.

AP® CHEMISTRY
2007 SCORING GUIDELINES (Form B)

Question 4

For each of the following three reactions, in part (i) write a balanced equation for the reaction and in part (ii) answer the question about the reaction. 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 graded.

(a) Solid ammonium carbonate decomposes as it is heated.

(i) Balanced equation: $(NH_4)_2CO_3 \rightarrow 2\,NH_3 + CO_2 + H_2O$	One point is earned for the correct reactant. Two points are earned for correct products. One point is earned for balancing mass and charge.

(ii) Predict the algebraic sign of $\Delta S°$ for the reaction. Explain your reasoning.

The algebraic sign of $\Delta S°$ for the reaction will be positive because one mole of solid (with relatively low entropy) is converted into four moles of gas (with much greater entropy).	One point is earned for the correct answer.

(b) Chlorine gas, an oxidizing agent, is bubbled into a solution of potassium bromide.

(i) Balanced equation: $Cl_2 + 2\,Br^- \rightarrow 2\,Cl^- + Br_2$	One point is earned for correct reactants. Two points are earned for correct products. One point is earned for balancing mass and charge.

(ii) What is the oxidation number of chlorine <u>before</u> the reaction occurs? What is the oxidation number of chlorine <u>after</u> the reaction occurs?

The oxidation number of chlorine is 0 before the reaction and −1 after the reaction.	One point is earned for the correct answer.

(c) A small piece of sodium is placed in a beaker of distilled water.

(i) Balanced equation: $2\,Na + 2\,H_2O \rightarrow H_2 + 2\,Na^+ + 2\,OH^-$	One point is earned for correct reactants. Two points are earned for correct products. One point is earned for balancing mass and charge.

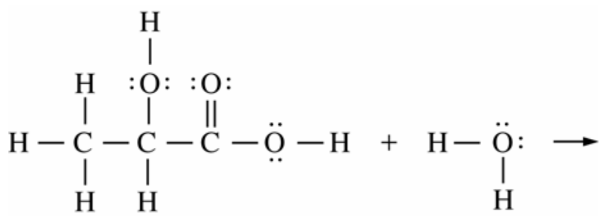
(ii) The reaction is exothermic, and sometimes small flames are observed as the sodium reacts with the water. Identify the product of the reaction that burns to produce the flames.

It is the H_2 gas that burns.	One point is earned for the correct answer.

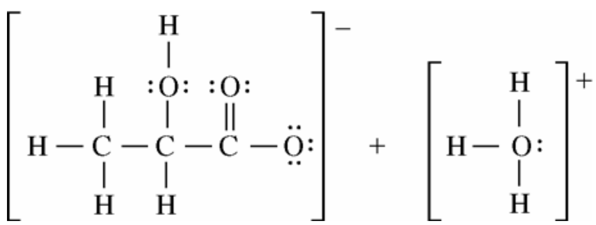
Question 5

Answer the following questions about laboratory solutions involving acids, bases, and buffer solutions.

(a) Lactic acid, $HC_3H_5O_3$, reacts with water to produce an acidic solution. Shown below are the complete Lewis structures of the reactants.



In the space provided above, complete the equation by drawing the complete Lewis structures of the reaction products.

	One point is earned for each correct structure.

(b) Choosing from the chemicals and equipment listed below, describe how to prepare 100.00 mL of a 1.00 *M* aqueous solution of NH_4Cl (molar mass 53.5 g mol^{-1}). Include specific amounts and equipment where appropriate.

$NH_4Cl(s)$	50 mL buret	100 mL graduated cylinder	100 mL pipet
Distilled water	100 mL beaker	100 mL volumetric flask	Balance

mass of NH_4Cl = (0.100 L)(1.00 mol L^{-1})(53.5 g mol^{-1}) = 5.35 g NH_4Cl 1. Measure out 5.35 g NH_4Cl using the balance. 2. Use the 100 mL graduated cylinder to transfer approximately 25 mL of distilled water to the 100 mL volumetric flask. 3. Transfer the 5.35 g NH_4Cl to the 100 mL volumetric flask. 4. Continue to add distilled water to the volumetric flask while swirling the flask to dissolve the NH_4Cl and remove all NH_4Cl particles adhered to the walls. 5. Carefully add distilled water to the 100 mL volumetric flask until the bottom of the meniscus of the solution reaches the etched mark on the flask.	One point is earned for the mass. One point is earned for using a volumetric flask. One point is earned for diluting to the mark.

Question 5 (continued)

(c) Two buffer solutions, each containing acetic acid and sodium acetate, are prepared. A student adds 0.10 mol of HCl to 1.0 L of each of these buffer solutions and to 1.0 L of distilled water. The table below shows the pH measurements made before and after the 0.10 mol of HCl is added.

	pH Before HCl Added	pH After HCl Added
Distilled Water	7.0	1.0
Buffer 1	4.7	2.7
Buffer 2	4.7	4.3

(i) Write the balanced net-ionic equation for the reaction that takes place when the HCl is added to buffer 1 or buffer 2.

$C_2H_3O_2^- + H_3O^+ \rightarrow HC_2H_3O_2 + H_2O$	One point is earned for the equation.

(ii) Explain why the pH of buffer 1 is different from the pH of buffer 2 after 0.10 mol of HCl is added.

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Before the HCl was added, each buffer had the same pH and thus had the same [H⁺]. Because K_a for acetic acid is a constant, the ratio of $[H^+]$ to K_a must also be constant; this means that the ratio of $[HC_2H_3O_2]$ to $[C_2H_3O_2^-]$ is the same for both buffers, as shown by the following equation, derived from the equilibrium-constant expression for the dissociation of acetic acid.

$$\frac{[HC_2H_3O_2]}{[C_2H_3O_2^-]} = \frac{[H^+]}{K_a}$$

After the addition of the H^+, the ratio in buffer 1 must have been greater than the corresponding ratio in buffer 2, as evidenced by their respective pH values. Thus a greater proportion of the $C_2H_3O_2^-$ in buffer 1 must have reacted with the added H^+ compared to the proportion that reacted in buffer 2. The difference between these proportions means that the original concentrations of $HC_2H_3O_2$ and $C_2H_3O_2^-$ had to be smaller in buffer 1 than in buffer 2.
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<td>One point is earned for a correct answer involving better buffering capacity or relative amount of base (acetate ion).</td>
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Question 5 (continued)

(iii) Explain why the pH of buffer 1 is the same as the pH of buffer 2 before 0.10 mol of HCl is added.

Both buffer solutions have the same acid to conjugate-base mole ratio in the formula below. $$[H^+] = K_a \frac{[HC_2H_3O_2]}{[C_2H_3O_2^-]}$$ Therefore, the buffers have the same $[H^+]$ and pH.	One point is earned for the correct answer involving ratio of acid to base in the buffer.

Question 6

	First Ionization Energy (kJ mol^{-1})	Second Ionization Energy (kJ mol^{-1})	Third Ionization Energy (kJ mol^{-1})
Element 1	1,251	2,300	3,820
Element 2	496	4,560	6,910
Element 3	738	1,450	7,730
Element 4	1,000	2,250	3,360

The table above shows the first three ionization energies for atoms of four elements from the third period of the periodic table. The elements are numbered randomly. Use the information in the table to answer the following questions.

(a) Which element is most metallic in character? Explain your reasoning.

Element 2. It has the lowest first-ionization energy. Metallic elements lose electron(s) when they become ions, and element 2 requires the least amount of energy to remove an electron.	One point is earned for the identification. One point is earned for the justification.

(b) Identify element 3. Explain your reasoning.

Magnesium. Element 3 has low first and second ionization energies relative to the third ionization energy, indicating that the element has two valence electrons, which is true for magnesium. (The third ionization of element 3 is dramatically higher, indicating the removal of an electron from a noble gas core.)	One point is earned for the identification. One point is earned for the justification.

(c) Write the <u>complete</u> electron configuration for an atom of element 3.

$1s^2\ 2s^2\ 2p^6\ 3s^2$	One point is earned for the correct electron configuration.

(d) What is the expected oxidation state for the most common ion of element 2?

1+	One point is earned for the correct oxidation state.

Question 6 (continued)

(e) What is the chemical symbol for element 2?

Na	One point is earned for the correct symbol.

(f) A neutral atom of which of the four elements has the smallest radius?

Element 1	One point is earned for the correct identification of the element.