Version A

Name: ________________________

Period: ____________

AP* Chemistry: 2002 Released Multiple Choice Exam

NO CALCULATORS MAY BE USED

Note: For all questions, assume that the temperature is 298 K, the pressure is 1.00 atmosphere, and solutions are aqueous unless otherwise specified.

Throughout the test the following symbols have the definitions specified unless otherwise noted.

T	= temperature	M	= molar
P	= pressure	m	= molal
V	= volume	L, mL	= liter(s), milliliter(s)
S	= entropy	g	= gram(s)
H	= enthalpy	nm	= nanometer(s)
G	= free energy	atm	= atmosphere(s)
R	= molar gas constant	J, kJ	= joule(s), kilojoule(s)
n	= number of moles	V	= volt(s)
mol	= mole(s)		

Directions: Each set of lettered choices below refers to the numbered questions or statements immediately following it. Select the one lettered choice that best answers each question or best fits each statement and then fill in the corresponding oval on the answer sheet. A choice may be used once, more than once, or not at all in each set. ***Before turning in your answer sheet, count the number of questions that you have skipped and place that number next to your name ON YOUR ANSWER SHEET and circle it.***

Questions 1-2

Consider atoms of the following elements. Assume that the atoms are in the ground state.

(A) S
(B) Ca
(C) Ga
(D) Sb
(E) Br

1. The atom that contains exactly two unpaired electrons

2. The atom that contains only one electron in the highest occupied energy sublevel

Questions 3-5 refer to the following molecules.

(A) CO_2
(B) H_2O
(C) CH_4
(D) C_2H_4
(E) PH_3

3. The molecule with only one double bond

4. The molecule with the largest dipole moment

5. The molecule that has trigonal pyramidal geometry

Questions 6-7 refer to the following solid compounds.

(A) $PbSO_4$
(B) CuO
(C) $KMnO_4$
(D) KC1
(E) $FeCl_3$

6. Is purple in aqueous solution

7. Is white and very soluble in water

Questions 8-10 refer to the following gases at 0ºC and 1 atm.

(A) Ne
(B) Xe
(C) O_2
(D) CO
(E) NO

8. Has an average atomic or molecular speed closest to that of N_2 molecules at 0ºC and 1 atm

9. Has the greatest density

10. Has the greatest rate of effusion through a pinhole

Questions 11-14 refer to the reactions represented below.

(A) $H_2SeO_4(aq) + 2\ Cl^-(aq) + 2\ H^+(aq) \rightarrow H_2SeO_3(aq) + Cl_2(g) + H_2O(l)$

(B) $S_8(s) + 8\ O_2(g) \rightarrow 8\ SO_2(g)$

(C) $3\ Br_2(aq) + 6\ OH^-(aq) \rightarrow 5\ Br^-\ (aq) + BrO_3^-\ (aq)\ 3\ H_2O(l)$

(D) $Ca^{2+}(aq) + SO_4^{2-}(aq) \rightarrow CaSO_4(s)$

(E) $PtCl_4(s) + 2\ Cl^-\ (aq) \rightarrow PtCl_6^{2-}\ (aq)$

11. A precipitation reaction

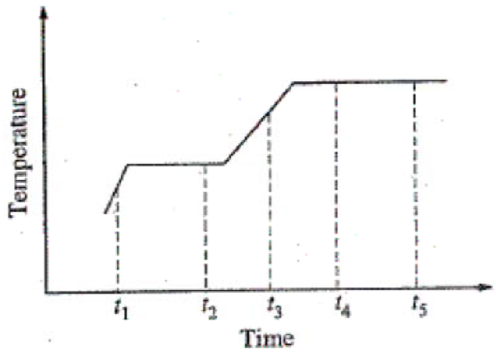
12. A reaction that produces a coordination complex

13. A reaction in which the same reactant undergoes both oxidation and reduction

14. A combustion reaction

Directions: Each of the questions or incomplete statements below is followed by five suggested answers or completions. Select the one that is best in each case and then fill in the corresponding oval on the answer sheet.

Questions 15-16 relate to the graph below. The graph shows the temperature of a pure substance as it is heated at a constant rate in an open vessel at 1.0 atm pressure. The substance changes from the solid to the liquid to gas phase.



15. The substance is at its normal freezing point at time

A) t_1
B) t_2
C) t_3
D) t_4
E) t_5

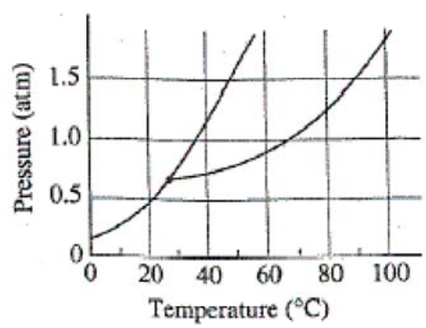
16. Which of the following best describes what happens to the substance between t_4 and t_5?

A) The molecules are leaving the liquid phase.
B) The solid and liquid phases coexist in equilibrium.
C) The vapor pressure of the substance is decreasing.
D) The average intermolecular distance is decreasing.
E) The temperature of the substance is increasing.

17. In which of the following groups are the three species isoelectronic; i.e., have the same number of electrons?

A) S^{2-}, K^{+}, Ca^{2+}
B) Sc, Ti, V^{2+}
C) O^{2-}, S^{2-}, Cl^{-}
D) Mg^{2+}, Ca^{2+}, Sr^{2+}
E) Cs, Ba^{2+}, La^{3+}

18.



The phase diagram for the pure substance X is shown above. The temperature of a sample of pure solid X is slowly raised from 10ºC to 100ºC at a constant pressure of 0.5 atm. What is the expected behavior of the substance?

A) It first melts to a liquid and then boils at about 70ºC.
B) It first melts to a liquid and then boils at about 30ºC.
C) It melts to a liquid at a temperature of about 20ºC and remains a liquid until the temperature is greater than 100ºC.
D) It sublimes to vapor at an equilibrium temperature of about 20ºC.
E) It remains a solid until the temperature is greater than 100ºC.

19. In which of the following species does sulfur have the same oxidation number as it does in H_2SO_4?

A) H_2SO_3
B) $S_2O_3^{2-}$
C) S^{2-}
D) S_8
E) SO_2Cl_2

20. A flask contains 0.25 mole of $SO_2(g)$, 0.50 mole of $CH_4(g)$, and 0.50 mole of $O_2(g)$. The total pressure of the gases in the flask is 800 mm Hg. What is the partial pressure of the $SO_2(g)$ in the flask?

A) 800 mm Hg
B) 600 mm Hg
C) 250 mm Hg
D) 200 mm Hg
E) 160 mm Hg

21. In the laboratory, $H_2(g)$ can be produced by adding which of the following to 1 *M* HC1(*aq*)?

I. 1 *M* $NH_3(aq)$
II. Zn(*s*)
III. $NaHCO_3(s)$

A) I only
B) II only
C) III only
D) I and II only
E) I, II, and III

22.

$$2\ NH_3 \rightleftarrows NH_4^+ + NH_2^-$$

In liquid ammonia, the reaction represented above occurs. In the reaction NH_4^+ acts as

A) a catalyst
B) both an acid and a base
C) the conjugate acid of NH_3
D) the reducing agent
E) the oxidizing agent

23.

$$^{235}_{92}\mathrm{U} + ^{1}_{0}n \longrightarrow ^{141}_{55}\mathrm{Cs} + 3\,^{1}_{0}n + X$$

Neutron bombardment of uranium can induce the reaction represented above. Nuclide *X* is which of the following?

A) $^{92}_{35}\mathrm{Br}$
B) $^{94}_{35}\mathrm{Br}$
C) $^{91}_{37}\mathrm{Rb}$
D) $^{92}_{37}\mathrm{Rb}$
E) $^{94}_{37}\mathrm{Rb}$

24. A compound contains 1.10 mol of K, 0.55 mol of Te, and 1.65 mol of O. What is the simplest formula of this compound?

A) KTeO
B) KTe_2O
C) K_2TeO_3
D) K_2TeO_6
E) K_4TeO_6

25.

$$3\ C_2H_2(g) \rightarrow C_6H_6(g)$$

What is the standard enthalpy change, ΔH°, for the reaction represented above? (ΔH°_f of $C_2H_2(g)$ is 230 kJ mol^{-1}; ΔH°_f of $C_6H_6(g)$ is 83 kJ mol^{-1}.)

A) –607 kJ
B) –147 kJ
C) –19 kJ
D) +19 kJ
E) +773 kJ

26. Approximately what mass of $CuSO_4 \cdot 5\ H_2O$ (250 g mol^{-1}) is required to prepare 250 mL of 0.10 *M* copper(II) sulfate solution?

A) 4.0 g
B) 6.2 g
C) 34 g
D) 85 g
E) 140 g

27.

$$2NO(g) + O_2 \rightarrow 2\ NO_2(g)$$

A possible mechanism for the overall reaction represented above is the following.

(1) $NO(g) + NO(g) \rightarrow N_2O_2(g)$ *slow*

(2) $N_2O_2(g) + O_2(g) \rightarrow 2NO_2(g)$ *fast*

Which of the following rate expressions agrees best with this possible mechanism?

A) Rate = $k[NO]^2$
B) Rate = $k\dfrac{[NO]}{[O_2]}$
C) Rate = $k\dfrac{[NO]^2}{[O_2]}$
D) Rate = $k[NO]^2[O_2]$
E) Rate = $k[N_2O_2][O_2]$

28. Of the following compounds, which is the most ionic?

A) $SiCl_4$
B) BrCl
C) PCl_3
D) Cl_2O
E) $CaCl_2$

29. The best explanation for the fact that diamond is extremely hard is that diamond crystals

A) are made up of atoms that are intrinsically hard because of their electronic structures
B) consist of positive and negative ions that are strongly attracted to each
C) are giant molecules in which each atom forms strong covalent bonds with all of its neighboring atoms
D) are formed under extreme conditions of temperature and pressure
E) contains orbitals or bands of delocalized electrons that belong not to single atoms but to each crystal as a whole

30. The 25ºC, aqueous solutions with a pH of 8 have a hydroxide ion concentration, $[OH^-]$, of

A) 1×10^{-14} *M*
B) 1×10^{-8} *M*
C) 1×10^{-6} *M*
D) 1 *M*
E) 8 *M*

31.

$$CS_2(l) + 3\,O_2(g) \rightarrow CO_2(g) + 2\,SO_2(g)$$

What volume of $O_2(g)$ is required to react with excess $CS_2(l)$ to produce 4.0 L of $CO_2(g)$? (Assume all gases are measured at 0ºC and 1 atm.)

A) 12 L

B) 22.4 L

C) $\frac{1}{3} \times 22.4$ L

D) 2×22.4 L

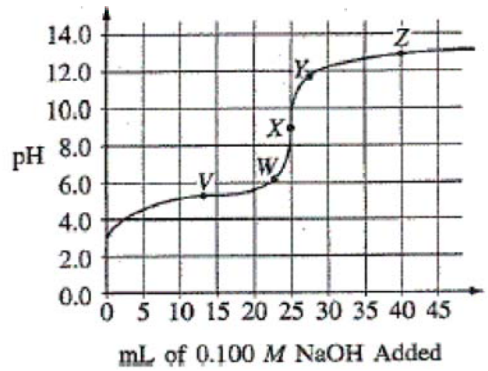
E) 3×22.4 L

32. Which of the following oxides is a gas at 25ºC and 1 atm ?

A) Rb_2O
B) N_2O
C) Na_2O_2
D) SiO_2
E) La_2O_3

Questions 33-34

The graph below shows the titration curve that results when 100. mL of 0.0250 *M* acetic acid is titrated with 0.100 *M* NaOH.



33. Which of the following indicators is the best choice for this titration?

	Indicator	pH Range of Color Change
A)	Methyl orange	3.2 - 4.4
B)	Methyl red	4.8 - 6.0
C)	Bromothymol blue	6.1 - 7.6
D)	Phenolphthalein	8.2 - 10.0
E)	Alizarin	11.0 - 12.4

34. What part of the curve corresponds to the optimum buffer action for the acetic acid/acetate ion pair?

A) Point V
B) Point X
C) Point Z
D) Along all of section WY
E) Along all of section YZ

35. A solution is made by dissolving a nonvolatile solute in a pure solvent. Compared to the pure solvent, the solution

A) has a higher normal boiling point
B) has a higher vapor pressure
C) has the same vapor pressure
D) has a higher freezing point
E) is more nearly ideal

36. A sample of a solution of an unknown was treated with dilute hydrochloric acid. The white precipitate formed was filtered and washed with hot water. A few drops of potassium iodide solution were added to the hot water filtrate and a bright yellow precipitate was produced. The white precipitate remaining on the filter paper was readily soluble in ammonia solution. What two ions could have been present in the unknown?

A) $Ag^{+}(aq)$ and $Hg_2^{2+}(aq)$
B) $Ag^{+}(aq)$ and $Pb^{2+}(aq)$
C) $Ba^{2+}(aq)$ and $Ag^{+}(aq)$
D) $Ba^{2+}(aq)$ and $Hg_2^{2+}(aq)$
E) $Ba^{2+}(aq)$ and $Pb^{2+}(aq)$

37.

$$HCO_3^-(aq) + OH^-(aq) \rightleftarrows H_2O(l) + CO_3^{2-}(aq) \qquad \Delta H = -41.4 \text{ kJ}$$

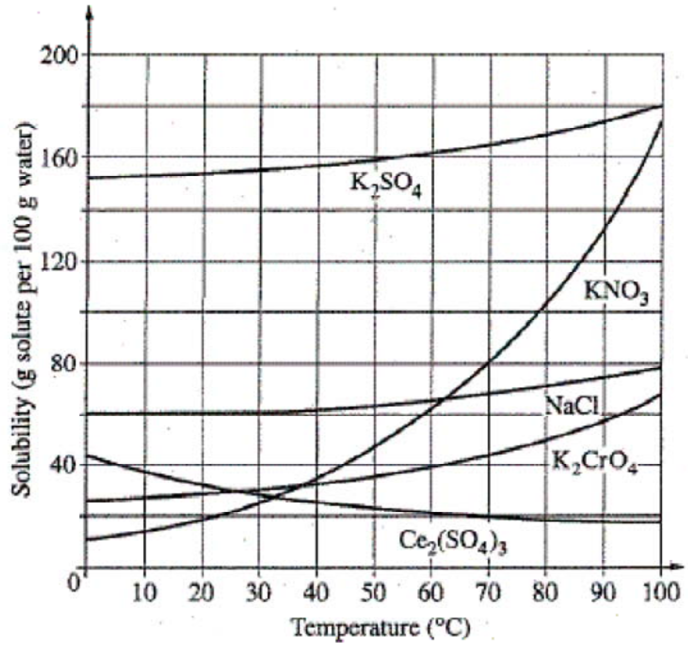
When the reaction represented by the equation above is at equilibrium at 1 atm and 25ºC, the ratio $\frac{[CO_3^{2-}]}{[HCO_3^-]}$ can be increased by doing which of the following?

A) Decreasing the temperature
B) Adding acid
C) Adding a catalyst
D) Diluting the solution with distilled water
E) Bubbling neon gas through the solution

38. A 0.10 *M* aqueous solution of sodium sulfate, Na_2SO_4, is a better conductor of electricity than a 0.10 *M* aqueous solution of sodium chloride, NaCl. Which of the following best explains this observation?

A) Na_2SO_4 is more soluble in water than NaCl is.
B) Na_2SO_4 has a higher molar mass than NaCl has.
C) To prepare a given volume of 0.10 *M* solution, the mass of Na_2SO_4 needed.
D) More moles of ions are present in a given volume of 0.10 *M* Na_2SO_4 than in the same volume of 0.10 *M* NaCl.
E) The degree of dissociation of Na_2SO_4 in solution is significantly greater than that of NaCl.

39.



On the basis of the solubility curves shown above, the greatest percentage of which compound can be recovered by cooling a saturated solution of that compound from 90ºC to 30ºC?

A) NaCl
B) KNO_3
C) K_2CrO_4
D) K_2SO_4
E) $Ce_2(SO_4)_3$

40. An excess of Mg(*s*) is added to 100. mL of 0.400 *M* HCl. At 0ºC and 1 atm pressure, what volume of H_2 gas can be obtained?

A) 22.4 mL
B) 44.8 mL
C) 224 mL
D) 448 mL
E) 896 mL

41. When solid NH_4SCN is mixed with solid $Ba(OH)_2$ in a closed container, the temperature drops and a gas is produced. Which of the following indicates the correct signs for ΔG, ΔH, and ΔS for the process?

	ΔG	ΔH	ΔS
A)	–	–	–
B)	–	+	–
C)	–	+	+
D)	+	–	+
E)	+	–	–

42.

$$H_2(g) + Br_2(g) \rightleftarrows 2HBr(g)$$

At a certain temperature, the value of the equilibrium constant, K, for the reaction represented above is 2.0×10^5. What is the value of K for the reverse reaction at the same temperature?

A) -2.0×10^{-5}
B) 5.0×10^{-6}
C) 2.0×10^{-5}
D) 5.0×10^{-5}
E) 5.0×10^{-4}

43. The atomic mass of copper is 63.55. Given that there are two naturally occurring isotopes of copper, ^{63}Cu and ^{65}Cu, the natural abundance of the ^{65}Cu isotope must be approximately

A) 90%
B) 70%
C) 50%
D) 25%
E) 10%

44. Which of the following properties generally decreases across the periodic table from sodium to chlorine?

A) First ionization energy
B) Atomic mass
C) Electronegativity
D) Maximum value of oxidation number
E) Atomic radius

45. What is the mole fraction of ethanol, C_2H_5OH, in an aqueous solution that is 46 percent ethanol by mass? (The molar mass of C_2H_5OH is 46 g; the molar mass of H_2O is 18 g.)

A) 0.25
B) 0.46
C) 0.54
D) 0.67
E) 0.75

46. The effective nuclear charge experienced by the outermost electron of Na is different than the effective nuclear charge experienced by the outermost electron of Ne. This difference best accounts for which of the following?

A) Na has a greater density at standard conditions than Ne.
B) Na has a lower first ionization energy than Ne.
C) Na has a higher melting point than Ne.
D) Na has a higher neutron-to-proton ratio than Ne.
E) Na has fewer naturally occurring isotopes than Ne.

47. Which of the following is a correct statement about reaction order?

A) Reaction order can only be a whole number.
B) Reaction order can be determined only from the coefficients of the balanced equation for the reaction.
C) Reaction order can be determined only by experiment.
D) Reaction order increases with increasing temperature.
E) A second-order reaction must involve at least two different compounds as reactants.

48. Sodium chloride is LEAST soluble in which of the following liquids?

A) H_2O
B) CCl_4
C) HF
D) CH_3OH
E) CH_3COOH

49.

$$\ldots Cr_2O_7^{2-}(aq) + \ldots H_2S(g) + \ldots H^+(aq) \longrightarrow \ldots Cr^{3+}(aq) + \ldots S(s) + \ldots H_2O(l)$$

When the equation above is correctly balanced and all coefficients are reduced to lowest whole-number terms, the coefficient for $H^+(aq)$ is

A) 2
B) 4
C) 6
D) 8
E) 14

50. Which of the following represents acceptable laboratory practice?

A) Placing a hot object on a balance pan
B) Using distilled water for the final rinse of a buret before filling it with standardized solution
C) Adding a weighed quantity of solid acid to a titration flask wet with distilled water
D) Using 10 mL of standard strength phenolphthalein indicator solution for titration of 25 mL of acid solution
E) Diluting a solution in a volumetric flask to its final concentration with hot water

51.

$$3\,Cu(s) + 8H^+(aq) + 2\,NO_3^-(aq) \rightarrow 3Cu^{2+}(aq) + 2\,NO(g) + 4H_2O(l)$$

True statements about the reaction represented above include which of the following?

I. $Cu(s)$ acts as an oxidizing agent.
II. The oxidation state of nitrogen changes from +5 to +2.
III. Hydrogen ions are oxidized to form $H_2O(l)$.

A) I only
B) II only
C) III only
D) I and II only
E) II and III only

52. Propane gas, C_3H_8, burns in excess oxygen gas. When the equation for this reaction is correctly balanced and all coefficients are reduced to their lowest whole-number terms, the coefficient for O_2 is

A) 4
B) 5
C) 7
D) 10
E) 22

53. According to the VSEPR model, the progressive decrease in the bond angles in the series of molecules CH_4, NH_3, and H_2O is best accounted for by the

A) increasing strength of the bonds
B) decreasing size of the central atom
C) increasing Electronegativity of the central atom
D) increasing number of unshared pairs of electrons
E) decreasing repulsion between hydrogen atoms

54. Which of the following must be true for a reaction for which the activation energy is the same for both the forward and the reverse reactions?

A) A catalyst is present.
B) The reaction order can be obtained directly from the balanced equation.
C) The reaction order is zero.
D) ΔH for the reaction is zero.
E) ΔS for the reaction is zero.

55.

Time (days)	0	1	2	3	4	5	6	7	. . .	10	. . .	20
% Reactant remaining	100	79	63	50	40	31	25	20		10		1

A reaction was observed for 20 days and the percentage of the reactant remaining after each day was recorded in the table above. Which of the following best describes the order and the half-life of the reaction?

	Reaction Order	Half-life (days)
A)	First	3
B)	First	10
C)	Second	3
D)	Second	6
E)	Second	10

56. The boiling points of the elements helium, neon, argon, krypton, and xenon increase in that order. Which of the following statements accounts for this increase?

A) The London (dispersion) forces increase.
B) The hydrogen bonding increases.
C) The dipole-dipole forces increase.
D) The chemical reactivity increases.
E) The number of nearest neighbors increases.

57.

$$\text{Rate} = k[\text{M}][\text{N}]^2$$

The rate of a certain chemical reaction between substances M and N obeys the rate law above. The reaction is first studied with [M] and [N] each 1×10^{-3} molar. If a new experiment is conducted with [M] and [N] each 2×10^{-3} molar, the reaction rate will increase by a factor of

A) 2
B) 4
C) 6
D) 8
E) 16

58.

$$2\ N_2H_4(g) + N_2O_4(g) \rightarrow 3\ N_2(g) + 4\ H_2O(g)$$

When 8.0 g of N_2H_4 (32 g mol^{-1}) and 92 g of N_2O_4 (92 g mol^{-1}) are mixed together and react according to the equation above, what is the maximum mass of H_2O that can be produced?

A) 9.0 g
B) 18 g
C) 36 g
D) 72 g
E) 144 g

59. All of the halogens in their elemental form at 25ºC and 1 atm are

A) conductors of electricity
B) diatomic molecules
C) odorless
D) colorless
E) gases

60.

$$2\ H_2O(l) + 4\ MnO_4^-(aq) + 3\ ClO_2^-(aq) \rightarrow 4\ MnO_2(s) + 3\ ClO_4^-(aq) + 4\ OH^-(aq)$$

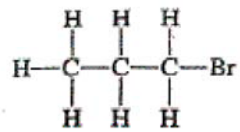
According to the balanced equation above, how many moles of $ClO^{2-}(aq)$ are needed to react completely with 20. mL of 0.20 M $KMnO_4$ solution?

A) 0.0030 mol
B) 0.0053 mol
C) 0.0075 mol
D) 0.013 mol
E) 0.030 mol

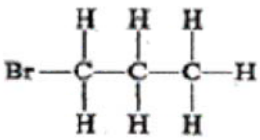
61. How can 100. mL of sodium hydroxide solution with a pH of 13.00 be converted to a sodium hydroxide solution with a pH of 12.00?

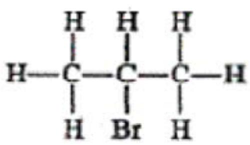
A) By diluting the solution with distilled water to a total volume of 108 mL
B) By diluting the solution with distilled water to a total volume of 200 mL
C) By diluting the solution with distilled water to a total volume of 1.00 L
D) By adding 100. mL of 0.10 M HCl
E) By adding 100. mL of 0.10 M NaOH

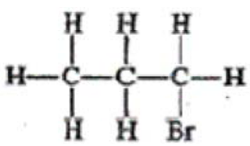
62.

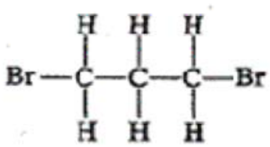


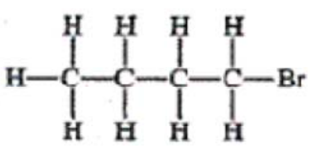
Which of the following structural formulas represents an isomer of the compound that has the structural formula represented above?

A) 

B) 

C) 

D) 

E) 

63. Mixtures that would be considered buffers include which of the following?

I. 0.10 M HCl + 0.10 *M* NaCl
II. 0.10 M HF + 0.10 *M* NaF
III. 0.10 M HBr + 0.10 *M* NaBr

A) I only
B) II only
C) III only
D) I and II
E) II and III

64. Ascorbic acid, $H_2C_6H_6O_6(s)$, is a diprotic acid with $K_1 = 7.9 \times 10^{-5}$ and $K_2 = 1.6 \times 10^{-12}$. In a 0.005 *M* aqueous solution of ascorbic acid, which of the following species is present in the <u>lowest</u> concentration?

A) $H_2O(l)$
B) $H_3O^+(aq)$
C) $H_2C_6H_6O_6(aq)$
D) $HC_6H_6O_6^-\ (aq)$
E) $C_6H_6O_6^{2-}\ (aq)$

65. Which of the following substances is LEAST soluble in water?

A) $(NH_4)_2SO_4$
B) $KMnO_4$
C) $BaCO_3$
D) $Zn(NO_3)_2$
E) Na_3PO_4

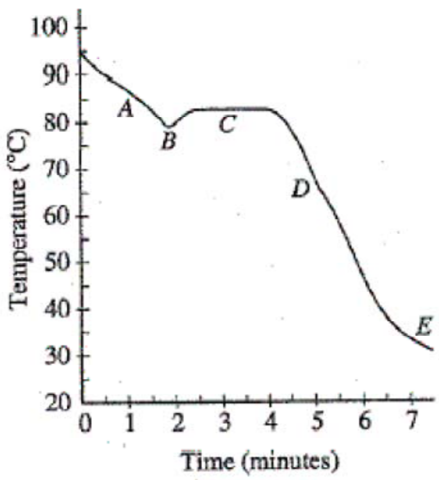
66. A 2-L container will hold about 4 g of which of the following gases of 0ºC and 1 atm?

A) SO_2
B) N_2
C) CO_2
D) C_4H_8
E) NH_3

67. Which of the following describes the changes in forces of attraction that occur as H_2O changes phase from a liquid to a vapor?

A) H–O bonds break as H–H and O–O bonds form.
B) Hydrogen bonds between H_2O molecules are broken.
C) Covalent bonds between H_2O molecules are broken.
D) Ionic bonds between H^+ ions and OH^- ions are broken.
E) Covalent bonds between H^+ ions and H_2O molecules become more effective.

68.



Liquid naphthalene at 95ºC was cooled to 30ºC, as represented in the cooling curve above. From which section of the curve can the melting point of naphthalene be determined?

A) A
B) B
C) C
D) D
E) E

69. If 200. mL of 0.60 *M* $MgCl_2(aq)$ is added to 400. mL of distilled water, what is the concentration of $Mg^{2+}(aq)$ in the resulting solution? (Assume volumes are additive).

A) 0.20 *M*
B) 0.30 *M*
C) 0.40 *M*
D) 0.60 *M*
E) 1.2 *M*

70. Of the following pure substances, which has the highest melting point?

A) S_8
B) I_2
C) SiO_2
D) SO_2
E) C_6H_6

71. In the electroplating of nickel, 0.200 faraday of electrical charge is passed through a solution of $NiSO_4$. What mass of nickel is deposited?

A) 2.94g
B) 5.87 g
C) 11.7 g
D) 58.7 g
E) 294 g

72. A colorless solution is divided into three samples. The following tests were performed on samples of the solution.

Sample	Test	Observation
1	Add $H^+(aq)$	No change
2	Add $NH_3(aq)$	No change
3	Add $SO_4^{2-}(aq)$	No change

Which of the following ions could be present in the solution at a concentration of 0.10 M ?

A) $Ni^{2+}(aq)$
B) $Al^{3+}(aq)$
C) $Ba^{2+}(aq)$
D) $Na^+(aq)$
E) $CO_3^{2-}(aq)$

73.

$$X(s) \rightleftarrows X(l)$$

Which of the following is true for any substance undergoing the process represented above at its normal melting point?

A) $\Delta S < 0$

B) $\Delta H = 0$

C) $\Delta H = T\Delta G$

D) $T\Delta S = 0$

E) $\Delta H = T\Delta S$

74. A pure, white crystalline solid dissolves in water to yield a basic solution that liberates a gas when excess acid is added to it. On the basis of this information, the solid could be

A) KNO_3
B) K_2CO_3
C) KOH
D) $KHSO_4$
E) KCl

75. In a saturated solution of $Zn(OH)_2$ at 25ºC, the value of $[OH^–]$ is 2.0×10^{-6} M. What is the value of the solubility product constant, K_{sp}, for $Zn(OH)_2$ at 25ºC ?

A) 4.0×10^{-18}
B) 8.0×10^{-18}
C) 1.6×10^{-17}
D) 4.0×10^{-12}
E) 2.0×10^{-6}

AP® Chemistry
2002 Free-Response Questions

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 **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
†Actinide Series	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)

STANDARD REDUCTION POTENTIALS IN AQUEOUS SOLUTION AT 25°C

Half-reaction			$E°$(V)
$F_2(g) + 2e^-$	$\rightarrow$	$2F^-$	2.87
$Co^{3+} + e^-$	$\rightarrow$	Co^{2+}	1.82
$Au^{3+} + 3e^-$	$\rightarrow$	$Au(s)$	1.50
$Cl_2(g) + 2e^-$	$\rightarrow$	$2Cl^-$	1.36
$O_2(g) + 4H^+ + 4e^-$	$\rightarrow$	$2H_2O(l)$	1.23
$Br_2(l) + 2e^-$	$\rightarrow$	$2Br^-$	1.07
$2Hg^{2+} + 2e^-$	$\rightarrow$	Hg_2^{2+}	0.92
$Hg^{2+} + 2e^-$	$\rightarrow$	$Hg(l)$	0.85
$Ag^+ + e^-$	$\rightarrow$	$Ag(s)$	0.80
$Hg_2^{2+} + 2e^-$	$\rightarrow$	$2Hg(l)$	0.79
$Fe^{3+} + e^-$	$\rightarrow$	Fe^{2+}	0.77
$I_2(s) + 2e^-$	$\rightarrow$	$2I^-$	0.53
$Cu^+ + e^-$	$\rightarrow$	$Cu(s)$	0.52
$Cu^{2+} + 2e^-$	$\rightarrow$	$Cu(s)$	0.34
$Cu^{2+} + e^-$	$\rightarrow$	Cu^+	0.15
$Sn^{4+} + 2e^-$	$\rightarrow$	Sn^{2+}	0.15
$S(s) + 2H^+ + 2e^-$	$\rightarrow$	$H_2S(g)$	0.14
$2H^+ + 2e^-$	$\rightarrow$	$H_2(g)$	0.00
$Pb^{2+} + 2e^-$	$\rightarrow$	$Pb(s)$	–0.13
$Sn^{2+} + 2e^-$	$\rightarrow$	$Sn(s)$	–0.14
$Ni^{2+} + 2e^-$	$\rightarrow$	$Ni(s)$	–0.25
$Co^{2+} + 2e^-$	$\rightarrow$	$Co(s)$	–0.28
$Tl^+ + e^-$	$\rightarrow$	$Tl(s)$	–0.34
$Cd^{2+} + 2e^-$	$\rightarrow$	$Cd(s)$	–0.40
$Cr^{3+} + e^-$	$\rightarrow$	Cr^{2+}	–0.41
$Fe^{2+} + 2e^-$	$\rightarrow$	$Fe(s)$	–0.44
$Cr^{3+} + 3e^-$	$\rightarrow$	$Cr(s)$	–0.74
$Zn^{2+} + 2e^-$	$\rightarrow$	$Zn(s)$	–0.76
$Mn^{2+} + 2e^-$	$\rightarrow$	$Mn(s)$	–1.18
$Al^{3+} + 3e^-$	$\rightarrow$	$Al(s)$	–1.66
$Be^{2+} + 2e^-$	$\rightarrow$	$Be(s)$	–1.70
$Mg^{2+} + 2e^-$	$\rightarrow$	$Mg(s)$	–2.37
$Na^+ + e^-$	$\rightarrow$	$Na(s)$	–2.71
$Ca^{2+} + 2e^-$	$\rightarrow$	$Ca(s)$	–2.87
$Sr^{2+} + 2e^-$	$\rightarrow$	$Sr(s)$	–2.89
$Ba^{2+} + 2e^-$	$\rightarrow$	$Ba(s)$	–2.90
$Rb^+ + e^-$	$\rightarrow$	$Rb(s)$	–2.92
$K^+ + e^-$	$\rightarrow$	$K(s)$	–2.92
$Cs^+ + e^-$	$\rightarrow$	$Cs(s)$	–2.92
$Li^+ + e^-$	$\rightarrow$	$Li(s)$	–3.05

GO ON TO THE NEXT PAGE.

ADVANCED PLACEMENT CHEMISTRY EQUATIONS AND CONSTANTS

ATOMIC STRUCTURE

$$\Delta E = h\nu$$
$$c = \lambda \nu$$
$$\lambda = \frac{h}{m\upsilon}$$
$$p = m\upsilon$$
$$E_n = \frac{-2.178 \times 10^{-18}}{n^2} \text{ joule}$$

E = energy
ν = frequency
λ = wavelength
p = momentum
υ = velocity
n = principal quantum number
m = mass

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

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

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

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

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

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

EQUILIBRIUM

$$K_a = \frac{[\mathrm{H^+}][\mathrm{A^-}]}{[\mathrm{HA}]}$$
$$K_b = \frac{[\mathrm{OH^-}][\mathrm{HB^+}]}{[\mathrm{B}]}$$
$$K_w = [\mathrm{OH^-}][\mathrm{H^+}] = 1.0 \times 10^{-14} \quad @ \; 25^\circ\mathrm{C}$$
$$= K_a \times K_b$$
$$\mathrm{pH} = -\log[\mathrm{H^+}], \; \mathrm{pOH} = -\log[\mathrm{OH^-}]$$
$$14 = \mathrm{pH} + \mathrm{pOH}$$
$$\mathrm{pH} = \mathrm{p}K_a + \log\frac{[\mathrm{A^-}]}{[\mathrm{HA}]}$$
$$\mathrm{pOH} = \mathrm{p}K_b + \log\frac{[\mathrm{HB^+}]}{[\mathrm{B}]}$$
$$\mathrm{p}K_a = -\log K_a, \; \mathrm{p}K_b = -\log K_b$$
$$K_p = K_c(RT)^{\Delta n},$$
where Δn = moles product gas $-$ moles reactant gas

Equilibrium Constants

K_a (weak acid)
K_b (weak base)
K_w (water)
K_p (gas pressure)
K_c (molar concentrations)

THERMOCHEMISTRY

$$\Delta S^\circ = \sum S^\circ \text{ products} - \sum S^\circ \text{ reactants}$$
$$\Delta H^\circ = \sum \Delta H_f^\circ \text{ products} - \sum \Delta H_f^\circ \text{ reactants}$$
$$\Delta G^\circ = \sum \Delta G_f^\circ \text{ products} - \sum \Delta G_f^\circ \text{ reactants}$$
$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$
$$= -RT \ln K = -2.303\, RT \log K$$
$$= -n\mathcal{F}E^\circ$$
$$\Delta G = \Delta G^\circ + RT \ln Q = \Delta G^\circ + 2.303\, RT \log Q$$
$$q = mc\Delta T$$
$$C_p = \frac{\Delta H}{\Delta T}$$

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

GO ON TO THE NEXT PAGE.

GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

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

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

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

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

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

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

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

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

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

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

$$\frac{r_1}{r_2} = \sqrt{\frac{\boldsymbol{M}_2}{\boldsymbol{M}_1}}$$

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
υ = velocity

u_{rms} = root-mean-square speed
KE = kinetic energy
r = rate of effusion
$\boldsymbol{M}$ = 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

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

Boltzmann's constant, k = 1.38×10^{-23} J K^{-1}

K_f for H_2O = 1.86 K kg mol^{-1}

K_b for H_2O = 0.512 K kg mol^{-1}

1 atm = 760 mm Hg
= 760 torr

STP = 0.000°C and 1.000 atm

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

OXIDATION-REDUCTION; ELECTROCHEMISTRY

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

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

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

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

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.

$$HOBr(aq) \rightleftarrows H^+(aq) + OBr^-(aq) \qquad K_a = 2.3 \times 10^{-9}$$

1. Hypobromous acid, $HOBr$, is a weak acid that dissociates in water, as represented by the equation above.

   (a) Calculate the value of $[H^+]$ in an $HOBr$ solution that has a pH of 4.95.

   (b) Write the equilibrium constant expression for the ionization of $HOBr$ in water, then calculate the concentration of $HOBr(aq)$ in an $HOBr$ solution that has $[H^+]$ equal to 1.8×10^{-5} M.

   (c) A solution of $Ba(OH)_2$ is titrated into a solution of $HOBr$.

      (i) Calculate the volume of 0.115 M $Ba(OH)_2(aq)$ needed to reach the equivalence point when titrated into a 65.0 mL sample of 0.146 M $HOBr(aq)$.

      (ii) Indicate whether the pH at the equivalence point is less than 7, equal to 7, or greater than 7. Explain.

   (d) Calculate the number of moles of $NaOBr(s)$ that would have to be added to 125 mL of 0.160 M $HOBr$ to produce a buffer solution with $[H^+] = 5.00 \times 10^{-9}$ M. Assume that volume change is negligible.

   (e) $HOBr$ is a weaker acid than $HBrO_3$. Account for this fact in terms of molecular structure.

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. Answer parts (a) through (e) below, which relate to reactions involving silver ion, Ag^+.

The reaction between silver ion and solid zinc is represented by the following equation.

$$2\ Ag^+(aq)\ +\ Zn(s)\ \rightarrow\ Zn^{2+}(aq)\ +\ 2\ Ag(s)$$

(a) A 1.50 g sample of Zn is combined with 250. mL of 0.110 M $AgNO_3$ at 25°C.

(i) Identify the limiting reactant. Show calculations to support your answer.

(ii) On the basis of the limiting reactant that you identified in part (i), determine the value of $[Zn^{2+}]$ after the reaction is complete. Assume that volume change is negligible.

(b) Determine the value of the standard potential, $E°$, for a galvanic cell based on the reaction between $AgNO_3(aq)$ and solid Zn at 25°C.

Another galvanic cell is based on the reaction between $Ag^+(aq)$ and $Cu(s)$, represented by the equation below. At 25°C, the standard potential, $E°$, for the cell is 0.46 V.

$$2\ Ag^+(aq)\ +\ Cu(s)\ \rightarrow\ Cu^{2+}(aq)\ +\ 2\ Ag(s)$$

(c) Determine the value of the standard free-energy change, $\Delta G°$, for the reaction between $Ag^+(aq)$ and $Cu(s)$ at 25°C.

(d) The cell is constructed so that $[Cu^{2+}]$ is 0.045 M and $[Ag^+]$ is 0.010 M. Calculate the value of the potential, E, for the cell.

(e) Under the conditions specified in part (d), is the reaction in the cell spontaneous? Justify your answer.

GO ON TO THE NEXT PAGE.

3. Consider the hydrocarbon pentane, C_5H_{12} (molar mass 72.15 g).

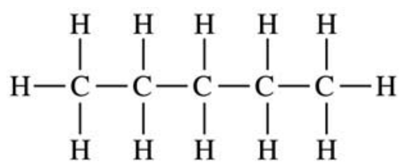
   (a) Write the balanced equation for the combustion of pentane to yield carbon dioxide and water.

   (b) What volume of dry carbon dioxide, measured at 25°C and 785 mm Hg, will result from the complete combustion of 2.50 g of pentane?

   (c) The complete combustion of 5.00 g of pentane releases 243 kJ of heat. On the basis of this information, calculate the value of ΔH for the complete combustion of one mole of pentane.

   (d) Under identical conditions, a sample of an unknown gas effuses into a vacuum at twice the rate that a sample of pentane gas effuses. Calculate the molar mass of the unknown gas.

   (e) The structural formula of one isomer of pentane is shown below. Draw the structural formulas for the other two isomers of pentane. Be sure to include all atoms of hydrogen and carbon in your structures.



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.

Ex.	$Mg + Ag^{+} \rightarrow Mg^{2+} + Ag$

   (a) A solution of sodium iodide is added to a solution of lead(II) acetate.

   (b) Pure solid phosphorus (white form) is burned in air.

   (c) Solid cesium oxide is added to water.

   (d) Excess concentrated hydrochloric acid is added to a 1.0 *M* solution of cobalt(II) chloride.

   (e) Solid sodium hydrogen carbonate (sodium bicarbonate) is strongly heated.

   (f) An excess of hydrochloric acid is added to solid zinc sulfide.

   (g) Acidified solutions of potassium permanganate and iron(II) nitrate are mixed together.

   (h) A solution of potassium hydroxide is added to solid ammonium chloride.

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).

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$$

5. A student is asked to determine the molar enthalpy of neutralization, ΔH_{neut}, for the reaction represented above. The student combines equal volumes of 1.0 M HCl and 1.0 M NaOH in an open polystyrene cup calorimeter. The heat released by the reaction is determined by using the equation $q = mc\Delta T$.

   Assume the following.

   - Both solutions are at the same temperature before they are combined.
   - The densities of all the solutions are the same as that of water.
   - Any heat lost to the calorimeter or to the air is negligible.
   - The specific heat capacity of the combined solutions is the same as that of water.

   (a) Give appropriate units for each of the terms in the equation $q = mc\Delta T$.

   (b) List the measurements that must be made in order to obtain the value of q.

   (c) Explain how to calculate each of the following.

   (i) The number of moles of water formed during the experiment

   (ii) The value of the molar enthalpy of neutralization, ΔH_{neut}, for the reaction between HCl(aq) and NaOH(aq)

   (d) The student repeats the experiment with the same equal volumes as before, but this time uses 2.0 M HCl and 2.0 M NaOH.

   (i) Indicate whether the value of q increases, decreases, or stays the same when compared to the first experiment. Justify your prediction.

   (ii) Indicate whether the value of the molar enthalpy of neutralization, ΔH_{neut}, increases, decreases, or stays the same when compared to the first experiment. Justify your prediction.

   (e) Suppose that a significant amount of heat were lost to the air during the experiment. What effect would this have on the calculated value of the molar enthalpy of neutralization, ΔH_{neut}? Justify your answer.

6. Use the principles of atomic structure and/or chemical bonding to explain each of the following. In each part, your answer must include references to both substances.

   (a) The atomic radius of Li is larger than that of Be.

   (b) The second ionization energy of K is greater than the second ionization energy of Ca .

   (c) The carbon-to-carbon bond energy in C_2H_4 is greater than it is in C_2H_6 .

   (d) The boiling point of Cl_2 is lower than the boiling point of Br_2 .

Answer EITHER Question 7 below OR Question 8 printed on page 12. 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. An environmental concern is the depletion of O_3 in Earth's upper atmosphere, where O_3 is normally in equilibrium with O_2 and O . A proposed mechanism for the depletion of O_3 in the upper atmosphere is shown below.

$$\begin{array}{ll} \text{Step I} & O_3 + Cl \rightarrow O_2 + ClO \\ \text{Step II} & ClO + O \rightarrow Cl + O_2 \end{array}$$

   (a) Write a balanced equation for the overall reaction represented by Step I and Step II above.

   (b) Clearly identify the catalyst in the mechanism above. Justify your answer.

   (c) Clearly identify the intermediate in the mechanism above. Justify your answer.

   (d) If the rate law for the overall reaction is found to be $rate = k[O_3][Cl]$, determine the following.

      (i) The overall order of the reaction

      (ii) Appropriate units for the rate constant, k

      (iii) The rate-determining step of the reaction, along with justification for your answer

GO ON TO THE NEXT PAGE.

$$C(s) + CO_2(g) \rightleftarrows 2\,CO(g)$$

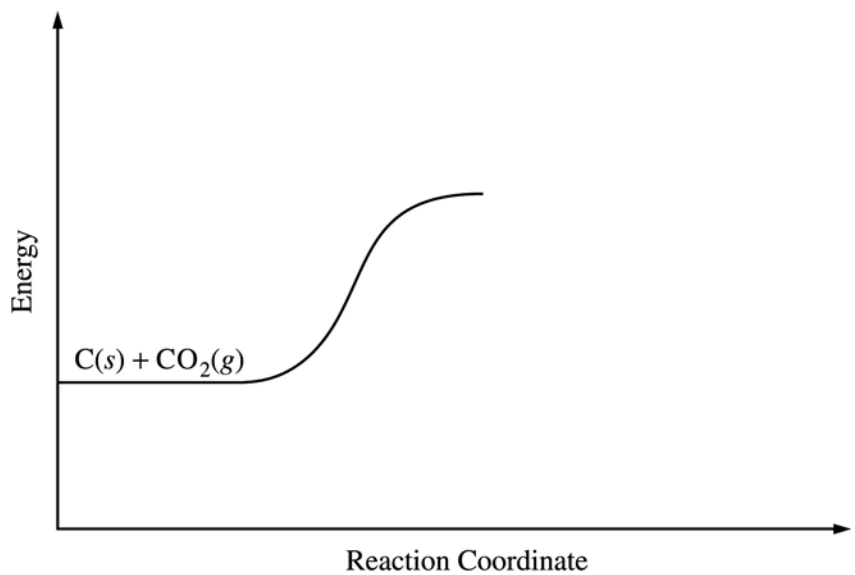
8. Carbon (graphite), carbon dioxide, and carbon monoxide form an equilibrium mixture, as represented by the equation above.

   (a) Predict the sign for the change in entropy, ΔS, for the reaction. Justify your prediction.

   (b) In the table below are data that show the percent of CO in the equilibrium mixture at two different temperatures. Predict the sign for the change in enthalpy, ΔH, for the reaction. Justify your prediction.

Temperature	**% CO**
700°C	60
850°C	94

   (c) Appropriately complete the potential energy diagram for the reaction by finishing the curve on the graph below. Also, clearly indicate ΔH for the reaction on the graph.



   (d) If the initial amount of $C(s)$ were doubled, what would be the effect on the percent of CO in the equilibrium mixture? Justify your answer.

END OF EXAMINATION

AP* Chemistry: 2002 Released Multiple Choice Exam
Answer Section

OTHER

1. ANS:
   A

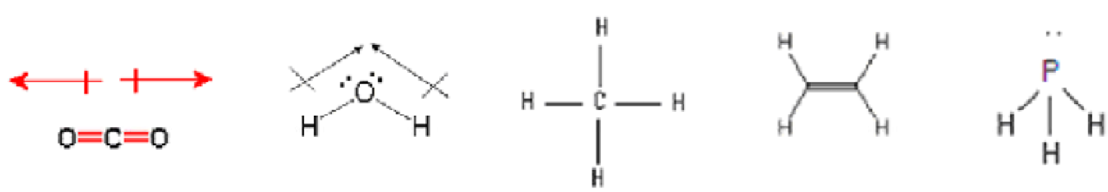
   You're looking for an electron configuration with s^2, p^2, d^2, etc. Calcium is $4s^2$.

   DIF: Medium TOP: Atomic Structure MSC: 2002 #1
   NOT: 63% answered correctly
2. ANS:
   C

   You're looking for a high value of *n* and a high energy sublevel remembering that *s* is lowest in energy, followed by *p*, then *d*, then *f*.

   Sb has the highest *n*, since $n = 5$, but 3 unpaired electrons. Ca, Ga, and Br all have $n = 4$, but only Ga has one unpaired electron in $4p^1$.

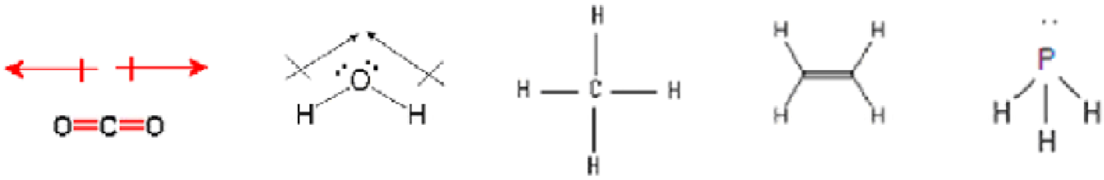
   DIF: Easy TOP: Atomic Structure MSC: 2002 #2
   NOT: 70% answered correctly
3. ANS:
   D

   Carbon dioxide has 2 double bonds, is linear and is nonpolar since its dipole moments cancel.
   Water has all single bonds, is "bent" and is polar since its dipole moments do not cancel. Water also has the largest dipole moment since 2 unshared electrons are present.
   Methane has all single bonds, is tetrahedral and is nonpolar since all of its dipole moments cancel.
   Ethene has one double bond and is nonpolar since its dipole moments cancel out.
   Phosphorous trihidride has all single bonds, is trigonal pyramidial and polar since its dipole moments do not cancel out.

   DIF: Easy TOP: Bonding & Molecular Structure MSC: 2002 #3
   NOT: 74% answered correctly

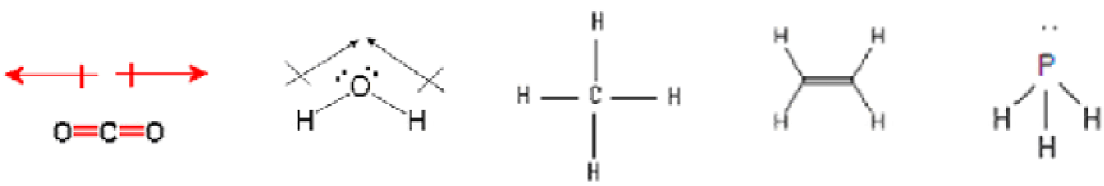
4. ANS:
B



Carbon dioxide has 2 double bonds, is linear and is nonpolar since its dipole moments cancel.
Water has all single bonds, is “bent” and is polar since its dipole moments do not cancel. Water also has the largest dipole moment since 2 unshared electrons are present.
Methane has all single bonds, is tetrahedral and is nonpolar since all of its dipole moments cancel.
Ethene has one double bond and is nonpolar since its dipole moments cancel out.
Phosphorous trihidride has all single bonds, is trigonal pyramidial and polar since its dipole moments do not cancel out.

DIF: Medium TOP: Bonding & Molecular Structure MSC: 2002 #4
NOT: 54% answered correctly

5. ANS:
E



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Phosphorous trihidride has all single bonds, is trigonal pyramidial and polar since its dipole moments do not cancel out.

DIF: Easy TOP: Bonding & Molecular Structure MSC: 2002 #5
NOT: 75% answered correctly

6. ANS:
C

You are at a distinct disadvantage with this question if you have neither done a lab with the permanganate ion nor seen a demo. It is purple in solution. The Cu^{2+} ion is blue in solution and the Fe^{3+} ion is yellow to brown, depending upon concentration. Remember, only transition metals having *unpaired d*-electrons make ions that exhibit color in solution. Follow this link: http://en.wikipedia.org/wiki/Colors_of_chemicals

DIF: Medium TOP: Lab MSC: 2002 #6 NOT: 55% answered correctly

7. ANS:
   D

   In solid form $KMnO_4$ purple and $FeCl_3$ is yellow to amber. All the others are white, but lead compounds are not very soluble nor are oxides. KCl is the most soluble.

   DIF: Medium TOP: Lab MSC: 2002 #7 NOT: 61% answered correctly
8. ANS:
   D

   So, you're looking for a gas with a molar mass close to that of a nitrogen molecule (28ish). CO has a molar mass of 12 + 16 = 28 g/mol.

   DIF: Medium TOP: Gas Laws MSC: 2002 #8 NOT: 41% answered correctly
9. ANS:
   B

   The conditions stated are STP, so density of a gas is simply computed as $\frac{MM}{22.4}$, so really you're just looking for the highest molar mass since it will have the largest density. Xe has a molar mass of 131 g/mol.

   DIF: Easy TOP: Gas Laws MSC: 2002 #9 NOT: 71% answered correctly
10. ANS:
    A

    Light gas molecules move faster than heavy ones. Neon has the smallest molar mass of the choices listed.

    DIF: Medium TOP: Gas Laws MSC: 2002 #10 NOT: 59% answered correctly
11. ANS:
    D

    Most sulfate salts are soluble. Important exceptions to this rule include $BaSO_4$, $PbSO_4$, Ag_2SO_4 and $SrSO_4$.

    DIF: Easy TOP: Chemical Reactions MSC: 2002 #11
    NOT: 82% answered correctly
12. ANS:
    E

    A coordination complex contains a metal ion with a ligand. It is not unusual for there to be twice the number of ligands present as the metal's oxidation number. The combination can be charged or neutral and can be an ion or a compound.

    DIF: Hard TOP: Chemical Reactions MSC: 2002 #12
    NOT: 30% answered correctly

13. ANS:
C

This is called a disproportionation reaction. Halogens do this well since they can have both positive and negative oxidation states. Reduction is well...a reduction in oxidation number (gain of electrons) and oxidation is an increase in oxidation number (loss of electrons).

Br's Ox # 0 –1 +5

$$3\ Br_2(aq) + 6\ OH^-(aq) \rightarrow 5\ Br^-\ (aq) + BrO_3^-\ (aq)\ 3\ H_2O(l)$$

DIF: Easy TOP: Chemical Reactions MSC: 2002 #13
NOT: 67% answered correctly

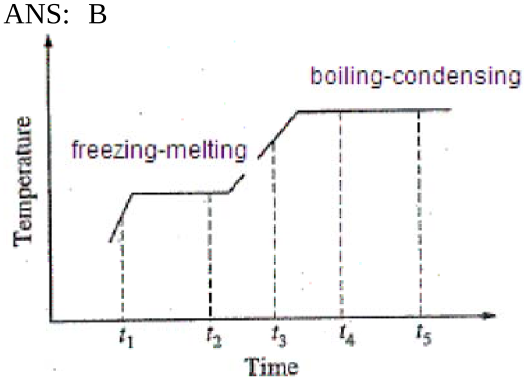
14. ANS:
B

I bet you were looking for a carbon compound being burned. Remember, any nonmetal or nonmetal-nonmetal covalent compound undergoing combustion will make the oxides of the nonmetals involved.

DIF: Easy TOP: Chemical Reactions MSC: 2002 #14
NOT: 74% answered correctly

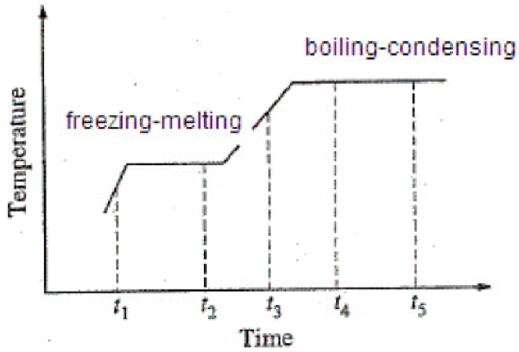
MULTIPLE CHOICE

15. ANS: B



DIF: Medium TOP: States of Matter MSC: 2002 #15
NOT: 56% answered correctly

16. ANS: A



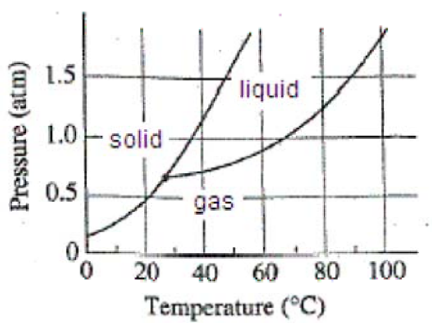
It is an equilibrium process between t_4 and t_5, but its the liquid and gas phases that are in equilibrium. Boiling begins once the vapor pressure of the system reaches atmospheric pressure, the molecules are spreading farther apart as any IMFs are being overcome and the temperature remains constant during any phase change.

DIF: Medium TOP: States of Matter MSC: 2002 #16
NOT: 58% answered correctly

17. ANS: A
All of these ions have the noble gas configuration of argon, $1s^2\ 2s^2$, $2p^6$, $3s^2$, $3p^6$.

DIF: Easy TOP: Atomic Structure MSC: 2002 #17
NOT: 70% answered correctly

18. ANS: D
Place your pencil at 0.5 atm pressure and draw a straight horizontal line between 10 and 100°C. You can see that the transition is from solid to gas which is sublimation. The opposite of which is deposition--not a word used often in your text!



DIF: Easy MSC: 2002 #18 NOT: 69% answered correctly

19. ANS: E
First calculate the oxidation number of sulfur in sulfuric acid. H is always + 1 and O is always –2 (unless in a peroxide). So far, that is 2(+1) + 4(–2) = –6. Since this is a neutral compound, and only one S is present, we are looking for a compound where the oxidation number of sulfur in it is +6.

H_2SO_3 oxidation number of S = +4
$S_2O_3^{2-}$ oxidation number of S = +2
S^{2-} oxidation number of S = –2
S_8 oxidation number of S = 0 (this is an allotrope of the element sulfur)
SO_2Cl_2 oxidation number of S = +6

DIF: Easy TOP: Chemical Reactions MSC: 2002 #19
NOT: 72% answered correctly

20. ANS: E
Expect easy math! Since the quantity of moles given are related by a factor of 0.25...simplify! Think: 1 part SO_2 + 2 parts CH_4 +2 parts O_2 = 5 total parts. Divide the total pressure of 800 mm Hg by 5 (Avogadro's Law--equal moles of gases exert equal pressures at constant *T* and *P*.) Each part is equal to 160 mm Hg and SO_2 is only one "part" of the mixture, so its pressure is 160 mm Hg.

DIF: Easy TOP: Gas Laws MSC: 2002 #20 NOT: 67% answered correctly

21. ANS: B
If you haven't done the labs, at least try to write reasonable chemical equations for each process:

I. $NH_3(aq) + HCl\,(aq) \rightleftarrows NH_4Cl\,(aq)$ Rather than mixing aqueous solutions of these two, it is far more exciting to put a plug of cotton soaked in each reactant into a large glass tube and let diffusion of their vapors take over. You get a delightful "smoke ring" of solid ammonium chloride formed near the HCl end of the tube (think about why--which gas moves fastest?).

II. $Zn(s) + HCl\,(aq) \rightarrow H_2\,(g) + ZnCl_2\,(aq)$ the bubbles that form are hydrogen. This is the reaction you most likely used to determine the molar volume of a gas. Zn may have been replaced with Mg.

III. $NaHCO_3(s) + HCl(aq) \rightarrow CO_2\,(g) + NaCl\,(aq)$ You get bubbles of gas, but it's not hydrogen gas!

DIF: Medium TOP: Lab MSC: 2002 #21 NOT: 48% answered correctly

22. ANS: C
Think of this reaction as you do the autoionization of water. Ammonia is definitely not a catalyst as well as the only reactant present. The ammonium ion accepted a proton (H^+) from ammonia and since it is a reversible reaction, can donate the proton in which case it behaves as an acid. This is not a redox reaction since N has an oxidation number of –3 in each compound listed.

DIF: Medium TOP: Acid-Base MSC: 2002 #22 NOT: 57% answered correctly

23. ANS: D

This is a transmutation reaction. In this reaction, neutrons are being used as “ammo” to induce fission reactions.

It is also essential to know that particles can be ejected from nuclei and that an alpha particle is akin to a helium nucleus, ${}^{4}_{2}\text{He}$, and that a beta particle is akin to an electron shot out of the nucleus, ${}^{0}_{-1}e$ or ${}^{0}_{-1}\beta$ (recall that a neutron consists of a proton plus an electron and a bit of binding energy--when the electron is emitted, there is one less neutron but one more proton). If you know all that the rest is simple math since the law of conservation of mass must be obeyed.

$$ {}^{235}_{92}\text{U} + {}^{1}_{0}n \longrightarrow {}^{141}_{55}\text{Cs} + {}^{1}_{0}n + {}^{1}_{0}n + {}^{1}_{0}n + {}^{?}_{?}X $$

So, ${}^{?}_{?}X$ must be equal to ${}^{(235+1)-(141+3(1))}_{(92+0)-(55+0)}X = {}^{92}_{37}X$, so the element X has a mass of 92 and an atomic number of 37 which is Rb.

DIF: Hard MSC: 2002 #23 NOT: 37% answered correctly

24. ANS: C

Expect easy math! Notice that all of the amounts are simple multiples of the smallest amount given, 0.55 mol. So, simplify into “parts”: K = 2, Te = 1 and O = 3 giving an empirical formula of K_2TeO_3

DIF: Easy TOP: Stoichiometry MSC: 2002 #24
NOT: 82% answered correctly

25. ANS: A

Expect easy math and estimate since the answers are so far apart!

Use Hess’s Law ΔH^{o} = 83 – 3(230). I’d estimate 100 – 700 = – 600+ kJ

A word about units. It has only been in recent years that text books have changed from reporting kJ for enthalpies of reactions and started reporting kJ/mol. This question is from 2002, and that is old enough [as may be your text] to be reporting the “old” way. If this question were asked on the AP exam today, the answers would have units of kJ/mol. When you work problems, you should label reaction enthalpies as kJ/mol (of reaction).

DIF: Easy TOP: Thermochemistry MSC: 2002 #25
NOT: 66% answered correctly

26. ANS: B

Expect easy math! If you prepared 1.0 L of a 1/10 molar solution, you’d use 1/10 of a mole or 25 grams in this case. You are preparing 1/4 of a liter, so use 1/4 of 25 grams or 6ish grams.

DIF: Medium MSC: 2002 #26 NOT: 56% answered correctly

27. ANS: A

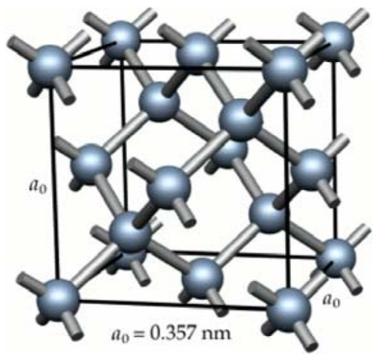
As a team is only as strong as its weakest player, a reaction is only as fast as its slowest step. That’s why we call that elementary step the *rate determining* step. So, writing the rate law expression for the first step we get: *rate* = $k[NO]^2$ since (1) is bimolecular in NO and NO is the only reactant.

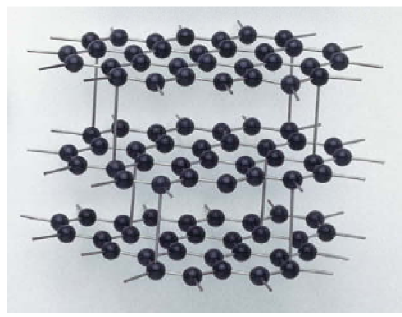
DIF: Medium TOP: Kinetics MSC: 2002 #27 NOT: 45% answered correctly

28. ANS: E
Ionic compounds contain a metal-nonmetal combination. Only $CaCl_2$ contains a metal-nonmetal combination. All the other choices are combinations of nonmetals, thus covalently bound.

DIF: Easy TOP: Bonding & Molecular Structure MSC: 2002 #28
NOT: 68% answered correctly

29. ANS: C
Diamond and graphite are both pure carbon. Diamond is hard, graphite is used as pencil “lead” and to lubricate locks. Examine the difference in structure. In diamond, each carbon is tetrahedrally bound to each of its neighbors. In graphite, neighboring carbon atoms are bound to each other forming sheets that can slide past one another.





diamond graphite

DIF: Medium TOP: Bonding & Molecular Structure MSC: 2002 #29
NOT: 51% answered correctly

30. ANS: C
Expect easy math! If the pH is 8, then the pOH is 14 – 8 = 6, so $[OH^-] = 1 \times 10^{-6}$ *M*.

MSC: 2002 #30 NOT: 72% answered correctly

31. ANS: A
Expect easy math! The word “excess” is your friend and is a hint that you do not need to worry about a limiting reactant. Start with the only quantity given...4 L of CO_2 at STP. The STP part is also your friend since combining volumes of gases at STP has the same proportion as combining moles of gases at STP!

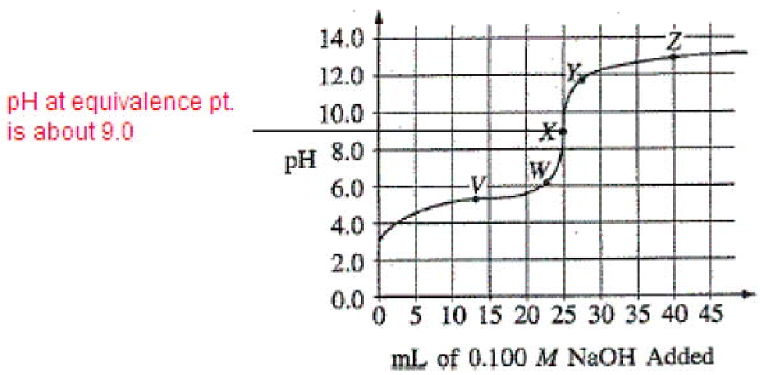
MM: (64 g/mol)				
CS_2	+ 3 O_2	→	+ CO_2	+ 2 SO_2
mole:mole 1	3		1	1
	Then, 3 times as much oxygen is required to react, or 3(4 L) = 12 L		If a coefficient of 1 is matched with 4.0 L	

DIF: Medium TOP: Stoichiometry MSC: 2002 #31
NOT: 56% answered correctly

32. ANS: B
Metal oxides are ionic solids at room temperature and are also basic anhydrides (react with water to form bases--dependent upon solubility). Nonmetal oxides are more likely to be gases at room temperature and are acidic anhydrides, especially SO_x and NO_x (pronounced “socks and knocks) which are responsible for acid rain.

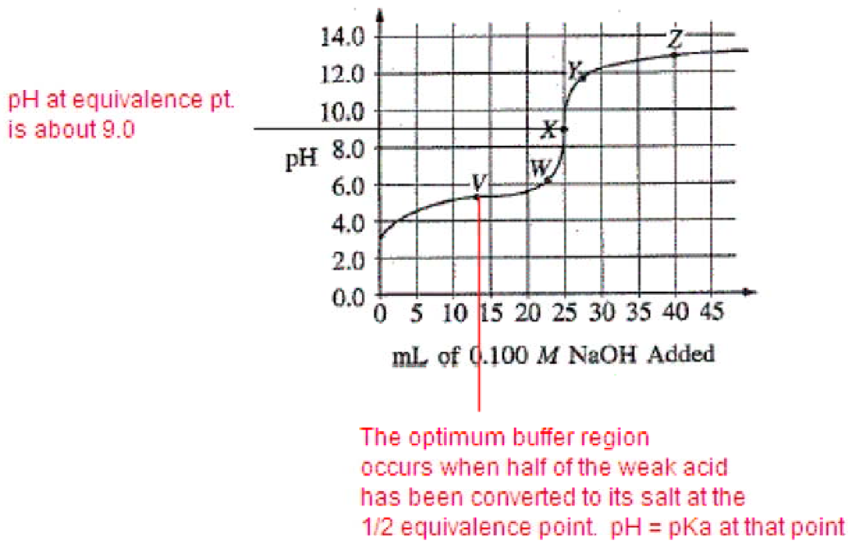
DIF: Easy TOP: Chemical Reactions MSC: 2002 #32
NOT: 69% answered correctly

33. ANS: D
You should choose an indicator that changes color (end point) at a pH that coincides with the stoichiometric equivalence point (moles acid = moles base). That indicator will have a K_a in the neighborhood of 1×10^{-pH}. This question gives you graph and then a table to analyze. The geometric midpoint of the tall vertical region of the graph is the equivalence point. Read the *y*-axis to determine the pH, in this case about 9, so phenolphthalein is the indicator to choose.



DIF: Easy TOP: Acid-Base MSC: 2002 #33 NOT: 70% answered correctly

34. ANS: A
The equivalence point occurs when 25 mL of NaOH has been added. So, when 12.5 mL was added, half of the weak acid was neutralized to form a solution that still contained 1/2 weak acid but also contained 1/2 of its salt (conjugate base). That's an ideal buffer with maximum buffering capacity.



DIF: Hard TOP: Acid-Base MSC: 2002 #34 NOT: 34% answered correctly

35. ANS: A
When a nonvolatile (code for very covalent molecule that does not vaporize at normal temperatures) solute is added to a pure solvent, it disrupts the solvent's IMFs. That causes the solvent's vapor pressure to drop, BP to increase, FP to decrease and ideal character to be diminished.

DIF: Medium TOP: Solutions MSC: 2002 #35 NOT: 53% answered correctly

36. ANS: B
The white ppt. first formed is a chloride ppt. $BaCl_2$ is soluble, so that knocks out answer choices (C), (D) and (E).

Silver chloride is white and upon heating or exposing to light, it turns gray or light purple. Mercury and lead chlorides are also white solids, but lead chloride's solubility increases in hot water, so some of the lead went back into the solution that was then treated with KI. The bright yellow ppt. is lead iodide, so it was lead that was present. If mercury had been present a light yellow ppt. would have formed instead of or in addition to the bright yellow one. Another step would have had to be done to separate them.

Also, the white ppt. that didn't dissolve in hot water was AgCl as is evidenced by its dissolving in ammonia and forming the diammine silver(I) complex ion in solution. This is the reaction your teacher uses to dissolve the silver chloride precipitates we generate in lab!

$AgCl(s) + 2\ NH_3(aq) \rightarrow Ag[(NH_3)_2]^+(aq) + Cl^-(aq)$

DIF: Hard TOP: Lab MSC: 2002 #36 NOT: 28% answered correctly

37. ANS: A
Since you were given a ratio of product over reactant (the expression for K_a), you have to contemplate actions that would increase the product concentration OR decrease the reactant concentration. When you are given an equilibrium reaction and an enthalpy, it is easiest to think about "heat energy" as either a reactant or product. Since this rxn is exothermic, heat is a product.
So, removing a product (cooling the reaction removes heat energy) or adding a reactant will shift the equilibrium so as to increase the ratio of product over reactant.

DIF: Medium MSC: 2002 #37 NOT: 45% answered correctly

38. ANS: D
The substance with the highest concentration of charged particles will be the best electrolyte.
Na_2SO_4 is very soluble and releases 3 charged ions per mole of sodium sulfate while NaCl only release 2 moles of charged ions.

DIF: Medium TOP: Solutions MSC: 2002 #38 NOT: 61% answered correctly

39. ANS: B
The compound with the steepest positive slope exhibits the most dramatic change involving increased solubility coupled with increased temperature. Therefore, KNO_3 will have the highest percentage of solid recovered if cooled.

DIF: Easy TOP: Solutions MSC: 2002 #39 NOT: 73% answered correctly

40. ANS: D
Expect easy math! Only one starting quantity is given, so you've been spared a limiting reactant calculation. ESTIMATE since the answer choices are so far apart!

$$Mg + 2\ HCl \rightarrow H_2 + MgCl_2$$

When in doubt, calculate the number of moles! (0.400 mol/L × 0.1 L) =0.04 mol of HCl.
Cut that in half and you have the moles of H_2 gas formed which is 0.02 mol. Multiply by molar volume since the experiment was conducted at STP and you get: (0.02 mol H_2)(about 20 L/mol) = 0.4 L or about 400 mL.

DIF: Hard TOP: Stoichiometry MSC: 2002 #40
NOT: 29% answered correctly

41. ANS: C
Think:

It's a spontaneous reaction, so ΔG is negative.

Heat energy is *added* into the system if the temperature decreases, so ΔH is positive (endothermic).

Finally, solid + solid → gas, so ΔS is positive

DIF: Medium TOP: Thermodynamics MSC: 2002 #41
NOT: 43% answered correctly

42. ANS: B

Never, ever, forget that generally $K = \frac{[\text{products}]}{[\text{reactants}]}$. So it stands to reason that if you reverse the reaction, you flipped the positions of the products and reactants in the chemical equilibrium equation, thus you also flipped their positions in the new $K_{reverse}$ expression, which is equivalent to taking the reciprocal of 2.0×10^5 which equals $\frac{1}{2.0 \times 10^5} = \frac{1}{2} \times 10^{-5} = 0.5 \times 10^{-5} = 5.0 \times 10^{-6}$

DIF: Hard MSC: 2002 #42 NOT: 24% answered correctly

43. ANS: D

Expect easy math! Since the two isotopes weigh 63 and 65, and the average is *not* 64 (a 50%-50% blend), but rather 63.55, you know answers (A), (B) and (C) can't be correct.
The average lies almost half way between the 50% blend, so 25% it is, Answer (D), but if you need proof...

Your gut probably tells you that 10% of the heavy isotope is not enough and that answer (D) is best, but you should do the quickest and easiest math to eliminating answer (E): (0.10)(65) = 6.5 and (0.90)(63) = 63 – 6.3 = 56.7, so add 56.7 + 6.5 = 63.2 which is too low.

DIF: Medium TOP: Stoichiometry MSC: 2002 #43
NOT: 49% answered correctly

44. ANS: E

The trend is that atomic radius decreases as you move from left to right across a given period and increases as you move down a family.

Remember, a trend is NOT an explanation...but knowing the trends serves you well in the multiple choice! Moving across the periodic table *within a period*, the atomic radius decreases due to and in crease in effective nuclear charge (Z_{eff}) which *generally* increases first ionization energies and electronegativity. Atomic mass increases as you move across.

DIF: Easy TOP: Atomic Structure MSC: 2002 #44
NOT: 70% answered correctly

45. ANS: A

Expect easy math!

46% ethanol by mass translates to 46 g of ethanol (which is one mole of ethanol) and 100 – 46 = 54 grams of water. The moles of water is thus 54/18 = 3 moles of water.

So, the mole fraction of ethanol is $\frac{1}{(1+3)} = \frac{1}{4} = 0.25$.

DIF: Medium MSC: 2002 #45 NOT: 44% answered correctly

46. ANS: B

Na has a Z_{eff} of 1 while Ne has a Z_{eff} of 8. That means neon has a much higher attractive force for its electrons than does sodium. It also means that it takes less energy to remove an electron (first ionization energy) from Na than from Ne.

DIF: Medium TOP: Atomic Structure MSC: 2002 #46
NOT: 62% answered correctly

47. ANS: C
There can be fractional reaction orders. The reaction order can only be determined by analyzing experimental data, never from the coefficients of the balanced equation. Reaction *rate* increases with increasing temperature (usually doubles with each 10°C increase in temperature) due to molecules moving faster with greater energy which in turn, generates more collisions with sufficient energy to overcome the activation energy barrier. Second order reactions can follow two formats: *rate* = $k[A]^2$ or *rate* = $k[A][B]$. Both formats are described as bimolecular.

DIF: Hard TOP: Kinetics MSC: 2002 #47 NOT: 39% answered correctly

48. ANS: B
Solubility is an equilibrium. Adding a common ion causes the equilibrium to shift away from the addition of the common ion. So NaCl is least soluble in CCl_4.

DIF: Medium TOP: Equilibrium MSC: 2002 #48 NOT: 48% answered correctly

49. ANS: D
Start with the half-reactions:

Red: $Cr_2O_7{}^{2-}(aq) \; + \; 14H^+(aq) + 6e^- \longrightarrow \; ...Cr^{3+}(aq) + 7H_2O(l)$

Ox: $H_2S(g) \longrightarrow S(s) + 2H^+ + 2e^-$

Multiply the oxidation half by 3 to give $6e^-$ to cancel. As a result the 2 H^+ become 6 H^+ leaving no H^+ on the right and 8 H^+ on the left. The total balanced equation is:

$$Cr_2O_7{}^{2-}(aq) + 3H_2S(g) + 8H^+(aq) \longrightarrow 2Cr^{3+}(aq) + 3S(s) + 7H_2O(l)$$

DIF: Hard TOP: Chemical Reactions MSC: 2002 #49
NOT: 31% answered correctly

50. ANS: C
The only acceptable practice listed is adding solid acid to a wet flask since you must dissolve the acid or accurate results and adding water to the flask will not change the number of moles of dry acid you added. It should be noted that the solid acid should have been dried in an oven to remove humidity and yield the best results.

Never place a hot object on a balance pan for 2 reasons, you might damage the balance *and* you will get a reading that is too small due to the fact that hot objects heat the surrounding air creating convection currents that cause a slight lift. If you leave water adhering to the inner surface of a buret or pipette or any other volumetric glassware, you just diluted your substance. Using 10 mL of any indicator is too much--indicators are themselves weak acids and bases, a couple of drops are not going to appreciably alter the starting pH, but adding 10 mL will. All solutions should be at room temperature before filling the volumetric flask to its mark.

DIF: Hard TOP: Lab MSC: 2002 #50 NOT: 16% answered correctly

51. ANS: B
"Oxidizing agent" is code for "is itself reduced". Copper's oxidation number increases, so it is definitely not reduced. Statement II is true. Hydrogen ions and the hydrogen atoms of water both have oxidation states of +1.

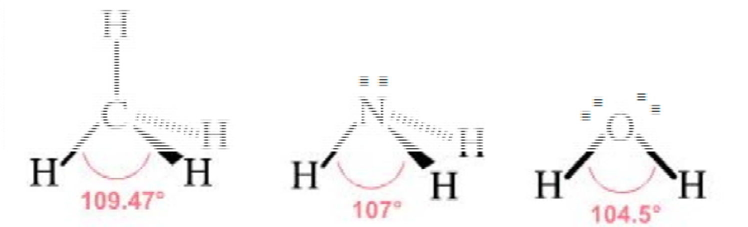
DIF: Medium TOP: Chemical Reactions MSC: 2002 #51
NOT: 49% answered correctly

52. ANS: B

The balanced equation is : C_3H_8 + 5 O_2 $\rightarrow$ 3 CO_2 + 4 H_2O

DIF: Easy TOP: Chemical Reactions MSC: 2002 #52
NOT: 71% answered correctly

53. ANS: D



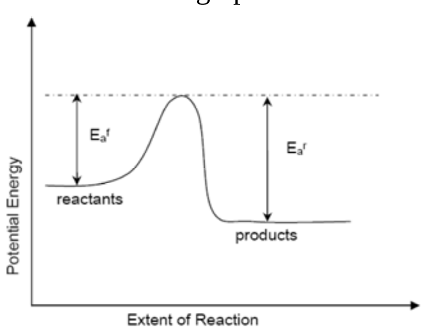
There is greater repulsion among the lone pairs and the bonding pairs which leads to the reduced bond angles in these molecules.

The bonds are all single bonds and the strength of the bonds has nothing to do with the bond angles of the molecules, nor does the size of the central atom since these are all fairly close in size. Increasing electronegativity has to do with the strength of the bond, not the bond angles.

DIF: Medium MSC: 2002 #53 NOT: 62% answered correctly

54. ANS: D

This is the sort of graph that should have popped into your brain:



The potential energy (enthalpy) of the reaction is calculated by subtracting the energy of the products from the energy of the reactants. IF the activation energies for the forward and reverse reactions are equal, then the energies of the reactants and products are equal and the enthalpy of the reaction is zero.

DIF: Medium MSC: 2992 #54 NOT: 43% answered correctly

55. ANS: A

Expect easy math!

Look at the % Reactant remaining--find the number of days that corresponds to 100%, then 50%, then 25%, etc. It’s 3 days. Substances that behave this way follow first order kinetics.

DIF: Medium TOP: Kinetics MSC: 2002 #55 NOT: 55% answered correctly

56. ANS: A
For a substance to boil, the IMFs of the liquid state must be overcome.

All of these gases are noble gases. The more electrons present, the larger the noble gas, the more polarizable the cloud, the more likely induced dipole- induced dipole (London or dispersion) forces are to occur. The halogens make a great example as well.

DIF: Medium TOP: IMFs MSC: 2002 #56 NOT: 62% answered correctly

57. ANS: D
Expect easy math!
Rate = $k[1][1]^2 = 1$ versus Rate = $k[2][2]^2 = 8$

DIF: Medium TOP: Kinetics MSC: 2002 #57 NOT: 52% answered correctly

58. ANS: A
The "trick" to getting this one correct is to recognize that you have entered the "land of limiting reagent"! You were given two starting amounts. Determine the limiting reagent and calculate subsequent moles from that limiting amount of moles using the mole:mole.

$2\ N_2H_4$	+ N_2O_4	$\rightleftarrows$	+ $3\ N_2$	+ $4\ H_2O$
mole:mole 2	1		3	4
# moles (8/32) = 0.25 IF 2 = 0.25 mol, then 1 = 0.125, so this is clearly the LIMITING reactant. Work from this number...	= (92/92) = 1 mol Excess! Not limiting.			4(0.125) = 0.50 mol, therefore 9.0 g since molar mass of water is 18g

DIF: Medium TOP: Stoichiometry MSC: 2002 #58
NOT: 47% answered correctly

59. ANS: B
All of the halogens exist as diatomic nonpolar molecules with completely nonpolar bonds. Fluorine is a colorless gas at room temperature. Chlorine gas is green. Bromine is a red liquid at room temperature and iodine is a purple crystalline solid that sublimes if warmed from room temperature.

DIF: Medium TOP: Periodicity MSC: 2002 #59 NOT: 40% answered correctly

60. ANS: A
Expect easy math! Calculate moles of potassium permanganate (purple). # moles = (0.20 mol/L)(0.020 L) = 0.004 mol $KMnO_4$. Look at the coefficients in the balanced equation. Divide 0.004 mol by 4, to get 0.001 mol, then multiply by 3 to get 0.003 mol.

DIF: Medium TOP: Stoichiometry MSC: 2002 #60
NOT: 53% answered correctly

61. ANS: C
A solution with a pH of 13 differs from a solution with a pH of 12 by a factor of 10. So, dilute the 100 mL to a total volume that is a power of ten higher...1,000 mL. Place the 100 mL of pH 13 NaOH into a 1-L volumetric flask and fill to the mark with deionized water.

DIF: Hard TOP: Acid-Base MSC: 2002 #61 NOT: 22% answered correctly

62. ANS: B
An isomer has the same chemical formula, but a different structural formula. Remember, these are not flat structures and since all singly bonded, the carbons can rotate around the central axis of the chain. In other words, if the Br is attached to either end of a 3-C chain, it is the same structure as presented and NOT an isomer. (E) is a 4-C chain and (A), (C), and (D) all have Br attached to an end carbon. Only answer (B) is an isomer.

DIF: Hard TOP: Bonding & Molecular Structure MSC: 2002 #62
NOT: 28% answered correctly

63. ANS: B
A buffer is a solution of a weak acid or base and its soluble salt (conjugate).

I. nope--contains a strong acid
II. yep--weak acid and its sodium salt
III. nope--contains a strong acid

DIF: Hard TOP: Acid-Base MSC: 2002 #63 NOT: 25% answered correctly

64. ANS: E
Think about the 2 dissociations since this is a diprotic acid.

$H_2A \rightleftarrows H^+ + HA^-$

$HA^- \rightleftarrows H^+ + A^-$

Some of the diprotic acid dissociates, there is more hydrogen ion (hydronium) present since it is a product of both processes, less of HA^- left since it is formed and then dissociates a bit, which means the A^- concentration in solution is so very small since little of it is ever formed due to the very small value of K_2.

DIF: Hard TOP: Acid-Base MSC: 2002 #64 NOT: 37% answered correctly

65. ANS: C

Carbonates are frequently insoluble. Group II carbonates (Ca, Sr, and Ba) are insoluble. Some other insoluble carbonates include $FeCO_3$ and $PbCO_3$.

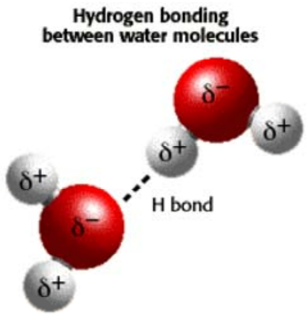
DIF: Medium TOP: Chemical Reactions MSC: 2002 #65
NOT: 45% answered correctly

66. ANS: C
Expect easy math! Estimate!

2 L is about 1/10 of 22.4 L which is the molar volume of any gas. So 4 g is then about 1/10 of the molar mass of the gas we seek which puts us in the neighborhood of 40ish. Since S has a molar mass of 32, the 2 oxygens make it too heavy. Nitrogen has a molar mass of only 28. Carbon dioxide has a molar mass of 44 and is our winner. Butane has 48 in carbons alone and ammonia is a measly 17.

DIF: Medium TOP: Stoichiometry MSC: 2002 #66
NOT: 41% answered correctly

67. ANS: B
Phase changes are about IMFs not chemical bonds! The IMF in water is the special case of the dipole-dipole IMF called a hydrogen bond and it should *never* be confused with a bonded hydrogen!



DIF: Medium MSC: 2002 #67 NOT: 52% answered correctly

68. ANS: C
Phase changes involve overcoming IMFs. The temperature remains constant (therefore KE remains constant) during a phase change. The only plateau on the graph occurs at C.

It is important to note that point B represents a supercooling moment, most likely due to the liquid not being stirred as it cooled. Adding a seed crystal or stirring or scraping the glass container will usually start the crystallization process and the heat of crystallization is released and the substance warms back up to its melting point.

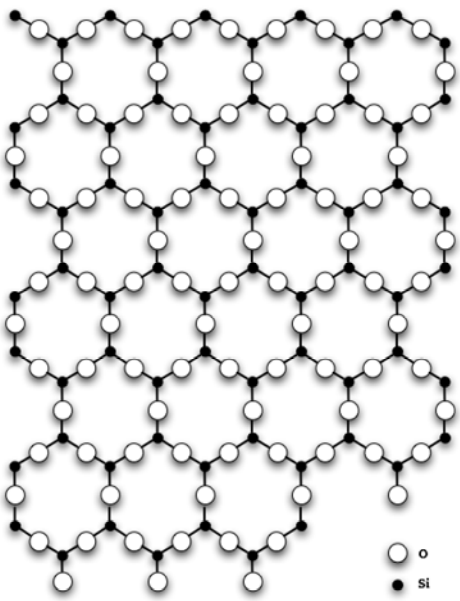
DIF: Medium TOP: States of Matter MSC: 2002 #68
NOT: 57% answered correctly

69. ANS: A
$M = \dfrac{\text{moles of solute}}{\text{liters of solution}}$, rearrange and solve for moles of $MgCl_2$

(0.200 L)(0.60 mol/L) = 0.12 mol $MgCl_2$; now there is 600 mL of total volume, so the new molarity is (0.12 mol)/(0.600 L) = 0.20 *M*.

DIF: Medium TOP: Solutions MSC: 2002 #69 NOT: 46% answered correctly

70. ANS: C
Silicon dioxide is a network covalent solid as are graphite and diamond. Rather than just overcoming IMFs, actual covalent bonds must be broken as well.



DIF: Hard MSC: 2002 #70 NOT: 29% answered correctly

71. ANS: B
A faraday is simply the charge on a mole of electrons. If you have 0.200 faraday, you have 0.200 moles of electrons. Nickel is a +2 metal, so you can make 0.100 moles of it which has a mass of 1/10 of the molar mass of 58.7 grams.

DIF: Hard TOP: Electrochemistry MSC: 2002 #71
NOT: 13% answered correctly

72. ANS: D
Ni^{2+} is green in solution.
Adding H^+ to carbonate ion would form bubbles of carbon dioxide so answer (E) is eliminated.
Adding NH_3 to aluminum ion will cause a complex to form.
Adding SO_4^{2-} to barium ion would form a precipitate.

DIF: Hard TOP: Lab MSC: 2002 #72 NOT: 35% answered correctly

73. ANS: E
Entropy increases and heat is added to the system. Phase changes are equilibriums. At equilibrium ΔG is equal to zero (as is E^0). Therefore, $\Delta G = \Delta H - T\Delta S$, so, $0 = \Delta H - T\Delta S$ which simplifies to $\Delta H = T\Delta S$

DIF: Hard TOP: Thermodynamics MSC: 2002 #73
NOT: 34% answered correctly

74. ANS: B

These are all white solids. Potassium nitrate is a neutral salt, the carbonate will bubble with excess acid added, the hydroxide won't but does obviously form a basic solution. The bisulfate salt will also form a basic solution but the chloride salt is neutral.

DIF: Hard TOP: Lab MSC: 2002 #74 NOT: 27% answered correctly

75. ANS: A

Expect easy math!

$Zn(OH)_2 \rightarrow Zn^{2+} + 2\ OH^-$ therefore, $K_{sp} = [Zn^{2+}]\,[OH^-]^2 = [x][2x]^2 = 4x^3$

If $[OH^-] = 2x = 2.0 \times 10^{-6}\ M$, then $x = 1.0 \times 10^{-6}\ M$ plug in those values and solve.

$K_{sp} = [1.0 \times 10^{-6}][2.0 \times 10^{-6}]^2 = 4.0 \times 10^{-18}$

DIF: Hard TOP: Equilibrium MSC: 2002 #75 NOT: 21% answered correctly

Question 1

AP Chemistry Scoring Guidelines 2002

Total Score 10 Points

$$HOBr(aq) \rightleftarrows H^+(aq) + OBr^-(aq) \qquad K_a = 2.3 \times 10^{-9}$$

1. Hypobromous acid, $HOBr$, is a weak acid that dissociates in water, as represented by the equation above.

(a) Calculate the value of $[H^+]$ in an $HOBr$ solution that has a pH of 4.95.

$pH = -\log[H^+]$ $[H^+] = 10^{-4.95}$ $[H^+] = 1.1 \times 10^{-5}\ M$	1 point earned for correct calculation

(b) Write the equilibrium constant expression for the ionization of $HOBr$ in water, then calculate the concentration of $HOBr(aq)$ in an $HOBr$ solution that has $[H^+]$ equal to $1.8 \times 10^{-5}\ M$.

$K_a = \dfrac{[H^+][OBr^-]}{[HOBr]}$	1 point earned for correct expression for K_a
If $[H^+] = 1.8 \times 10^{-5}\ M$, then $[OBr^-] = 1.8 \times 10^{-5}\ M$. Substituting,	1 point earned for $[H^+] = [OBr^-]$
$2.3 \times 10^{-9} = \dfrac{[H^+][OBr^-]}{[HOBr]} = \dfrac{[1.8\times10^{-5}M][1.8\times10^{-5}M]}{[HOBr]}$ $[HOBr] = \dfrac{[1.8\times10^{-5}M][1.8\times10^{-5}M]}{2.3\times10^{-9}} = 0.14\ M$	1 point earned for correct $[HOBr]$

(c) A solution of $Ba(OH)_2$ is titrated into a solution of $HOBr$.

(i) Calculate the volume of $0.115\ M$ $Ba(OH)_2(aq)$ needed to reach the equivalence point when titrated into a 65.0 mL sample of $0.146\ M$ $HOBr(aq)$.

$0.0650\ L \left(\dfrac{0.146\ mol\ HOBr}{1\ L}\right)\left(\dfrac{1\ mol\ Ba(OH)_2}{2\ mol\ HOBr}\right)\left(\dfrac{1\ L}{0.115\ mol\ Ba(OH)_2}\right)$	1 point earned for stoichiometric ratio
$= 0.0413\ L$ or $41.3\ mL$ Another possible correct method for calculating the volume starts with the expression $\dfrac{V_bM_b}{V_aM_a} = \dfrac{1}{2}$.	1 point earned for correct substitution and calculation

(ii) Indicate whether the pH at the equivalence point is less than 7, equal to 7, or greater than 7. Explain.

The pH is greater than 7. HOBr is a weak acid and OBr^- is a weak base. At the equivalence point, the OBr^- in solution is the pH-determining species and the hydrolysis reaction produces hydroxide ion: $OBr^- + H_2O \rightleftarrows HOBr + OH^-$ **OR** $K_b(OBr^-) = \left(\frac{K_w}{K_a(HOBr)}\right) = \left(\frac{1.0\times10^{-14}}{2.3\times10^{-9}}\right) = 4.3\times10^{-6}$ **OR** the calculated pH = 10.79	1 point earned for explanation

(d) Calculate the number of moles of $NaOBr(s)$ that would have to be added to 125 mL of 0.160 M HOBr to produce a buffer solution with $[H^+] = 5.00\times10^{-9}\ M$. Assume that volume change is negligible.

$K_a = \frac{[H^+][OBr^-]}{[HOBr]}$ $[OBr^-] = \frac{[HOBr]\cdot K_a}{[H^+]} = \frac{(0.160\ M)(2.3\times10^{-9})}{5.00\times10^{-9}\ M}$ $[OBr^-] = 0.074\ M$ $n_{NaOBr} = 0.125\ L\left(\frac{0.074\ mol\ OBr^-}{1\ L}\right) = 9.2\times10^{-3}\ mol$	1 point earned for $[OBr^-]$, the set-up, and the substitution 1 point earned for mol NaOBr

(e) HOBr is a weaker acid than $HBrO_3$. Account for this fact in terms of molecular structure.

The H-O bond is weakened or increasingly polarized by the additional oxygen atoms bonded to the central bromine atom in $HBrO_3$.	1 point earned for a correct explanation

Question 2

AP Chemistry Scoring Guidelines 2002

Total Score 10 points

2. Answer parts (a) through (e) below, which relate to reactions involving silver ion, Ag^+.

The reaction between silver ion and solid zinc is represented by the following equation.

$$2\ Ag^+(aq) + Zn(s) \rightarrow Zn^{2+}(aq) + 2\ Ag(s)$$

(a) A 1.50 g sample of Zn is combined with 250. mL of 0.110 M $AgNO_3$ at 25°C.

(i) Identify the limiting reactant. Show calculations to support your answer.

$n_{Zn} = 1.50\text{ g Zn}\left(\frac{1\text{ mol Zn}}{65.4\text{ g Zn}}\right) = 2.29 \times 10^{-2}\text{ mol Zn}$ $n_{Ag^+} = 0.250\text{ L}\left(\frac{0.110\text{ mol Ag}^+}{1\text{ L}}\right) = 2.75 \times 10^{-2}\text{ mol Ag}^+$ $n_{Ag^+} = 1.50\text{ g Zn}\left(\frac{1\text{ mol Zn}}{65.4\text{ g Zn}}\right)\left(\frac{2\text{ mol Ag}^+}{1\text{ mol Zn}}\right) = 4.59 \times 10^{-2}\text{ mol Ag}^+\text{ required}$	1 point earned for the moles of one reactant <u>and</u> the proper stoichiometry
Since only 2.75×10^{-2} mol Ag^+ available, Ag^+ is the limiting reactant. **OR** $n_{Ag^+} = 0.250\text{ L}\left(\frac{0.110\text{ mol Ag}^+}{1\text{ L}}\right) = 2.75 \times 10^{-2}\text{ mol Ag}^+$ $n_{Zn} = 2.75 \times 10^{-2}\text{ mol Ag}^+\left(\frac{1\text{ mol Zn}}{2\text{ mol Ag}^+}\right) = 1.38 \times 10^{-2}\text{ mol Zn required}$ Since 2.29×10^{-2} mol Zn are available, more is available than required, so Zn is in excess and Ag^+ is limiting. (Correct solutions other than shown above earn both points.)	1 point earned for the limiting reactant <u>and</u> the supporting calculation or explanation

(ii) On the basis of the limiting reactant that you identified in part (i), determine the value of $[Zn^{2+}]$ after the reaction is complete. Assume that volume change is negligible.

$n_{Zn^{2+}} = 2.75 \times 10^{-2}$ mol $Ag^+ \left(\frac{1 \text{ mol } Zn^{2+}}{2 \text{ mol } Ag^+}\right) = 1.38 \times 10^{-2}$ mol Zn^{2+} $\frac{1.38 \times 10^{-2} \text{ mol } Zn^{2+}}{0.250 \text{ L}} = 0.0550\ M\ Zn^{2+}$	1 point earned for mol Zn^{2+} 1 point earned for $[Zn^{2+}]$
OR	**OR**
$[Ag^+]_{\text{initial}} = 0.110\ M$, therefore $[Zn^{2+}] = \frac{1}{2}(0.110\ M) = 0.0550\ M$	2 points earned for $[Zn^{2+}]$
***	*********************
If the student concludes Zn is the limiting reactant, then $1.50 \text{ g Zn}\left(\frac{1 \text{ mol Zn}}{65.4 \text{ g}}\right)\left(\frac{1 \text{ mol } Zn^{2+}}{1 \text{ mol Zn}}\right) = 2.29 \times 10^{-2}$ mol Zn^{2+} formed $\frac{2.29 \times 10^{-2} \text{ mol } Zn^{2+}}{0.250 \text{ L}} = 0.0916\ M\ Zn^{2+}$	1 point earned for mol Zn^{2+} 1 point earned for $[Zn^{2+}]$

Note: There must be consistency between parts a(i) and a(ii).

(b) Determine the value of the standard potential, $E°$, for a galvanic cell based on the reaction between $AgNO_3(aq)$ and solid Zn at 25°C.

$E°_{cell} = E°(\text{reduction}) - E°(\text{reduction})$ $= (0.80 \text{ V}) - (-0.76 \text{ V})$ $= 1.56$ V $2\,Ag^+(aq) + Zn(s) \rightarrow Zn^{2+}(aq) + 2\,Ag(s)$ +1.56 V **OR** $E°$ $Ag^+(aq) + e^- \rightarrow Ag(s)$ +0.80 V $Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$ +0.76 V $2\,Ag^+(aq) + Zn(s) \rightarrow Zn^{2+}(aq) + 2\,Ag(s)$ +1.56 V	1 point earned for correct $E°$

Question 2

AP Chemistry Scoring Guidelines 2002

Another galvanic cell is based on the reaction between $Ag^+(aq)$ and $Cu(s)$, represented by the equation below. At 25°C, the standard potential, $E°$, for the cell is 0.46 V.

$$2\,Ag^+(aq) + Cu(s) \rightarrow Cu^{2+}(aq) + 2\,Ag(s)$$

(c) Determine the value of the standard free-energy change, $\Delta G°$, for the reaction between $Ag^+(aq)$ and $Cu(s)$ at 25°C.

$\Delta G° = -nFE°$ $\Delta G° = (-2 \text{ mol } e^-)(96{,}500 \frac{\text{J}}{\text{V mol}})(+0.46 \text{ V})$ $\Delta G° = -89{,}000 \text{ J}$ or -89 kJ (units required)	1 point earned for n and $E°$ in the correct equation 1 point earned for correct value and sign of $\Delta G°$

(d) The cell is constructed so that $[Cu^{2+}]$ is 0.045 M and $[Ag^+]$ is 0.010 M. Calculate the value of the potential, $E°$, for the cell.

$E_{\text{cell}} = E° - \frac{RT}{nF} \ln Q = E° - \frac{RT}{nF} \ln \frac{[Cu^{2+}]}{[Ag^+]^2} = E° - \frac{.0592}{n} \log \frac{[Cu^{2+}]}{[Ag^+]^2}$ Note: Q must include only ion concentrations $E_{\text{cell}} = +0.46 \text{ V} - \frac{8.314 \frac{\text{J}}{\text{mol} \cdot \text{K}} \cdot 298 \text{ K}}{2 \text{ mol e}^- \cdot 96500 \frac{\text{J}}{\text{V} \cdot \text{mol}}} \ln \frac{[0.045]}{[0.010]^2}$ $E_{\text{cell}} = +0.46 \text{ V} - 0.0128 \text{ V} \ln 450$ $E_{\text{cell}} = +0.46 \text{ V} - 0.0128 \text{ V} \cdot 6.11$ $E_{\text{cell}} = +0.46 \text{ V} - 0.0782 \text{ V}$ $E_{\text{cell}} = +0.38 \text{ V}$	1 point earned for correct substitution 1 point earned for correct answer

(e) Under the conditions specified in part (d), is the reaction in the cell spontaneous? Justify your answer.

$E_{\text{cell}} = +0.38 \text{ V}$ The cell potential under the non-standard conditions in part (d) is positive. Therefore the reaction is spontaneous under the conditions stated in part (d). A correct reference (from answer in part (d)) to a negative ΔG (not $\Delta G°$) is acceptable. If no answer to (d) is given, students must make an assumption or a general statement about E_{cell}, not $E°$.	1 point earned for correct answer <u>and</u> correct explanation

Question 3

AP Chemistry Scoring Guidelines 2002

Total Score 10 points

3. Consider the hydrocarbon pentane, C_5H_{12} (molar mass 72.15 g).

(a) Write the balanced equation for the combustion of pentane to yield carbon dioxide and water.

$C_5H_{12} + 8\ O_2 \rightarrow 5\ CO_2 + 6\ H_2O$	1 point earned for showing O_2 as a reactant and having the equation balanced correctly.

(b) What volume of dry carbon dioxide, measured at 25°C and 785 mm Hg, will result from the complete combustion of 2.50 g of pentane?

$n_{C_5H_{12}} = 2.50\ \text{g}\ C_5H_{12}\left(\dfrac{1\ \text{mol}\ C_5H_{12}}{72.15\ \text{g}\ C_5H_{12}}\right) = 0.0347\ \text{mol}\ C_5H_{12}$	1 point earned for correct mol of CO_2
$n_{CO_2} = 0.0347\ \text{mol}\ C_5H_{12}\left(\dfrac{5\ \text{mol}\ CO_2}{1\ \text{mol}\ C_5H_{12}}\right) = 0.173\ \text{mol}\ CO_2$	1 point earned for correct substitution of *T*, *P*, and *R* and the calculation of *V*
$V = \left(\dfrac{nRT}{P}\right) = \dfrac{0.173\ \text{mol} \cdot 0.0821\ \dfrac{\text{L atm}}{\text{mol K}} \cdot 298\ \text{K}}{\dfrac{785\ \text{mm Hg}}{760\ \text{mm Hg}}} = 4.10\ \text{L}$	1 point earned for correct value for V

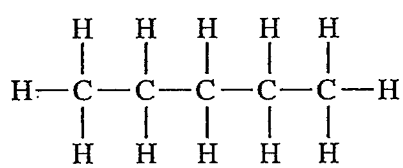
(c) The complete combustion of 5.00 g of pentane releases 243 kJ of heat. On the basis of this information, calculate the value of ΔH for the complete combustion of one mole of pentane.

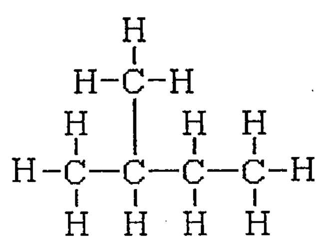
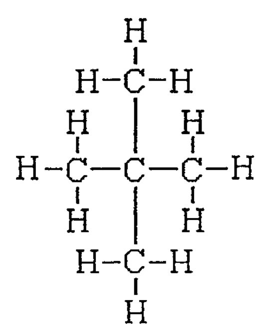
$(5.00\ \text{g}\ C_5H_{12})\left(\dfrac{1\ \text{mol}\ C_5H_{12}}{72.15\ \text{g}\ C_5H_{12}}\right) = 0.0693\ \text{mol}\ C_5H_{12}$	1 point earned for correct value of mol C_5H_{12}
$\left(\dfrac{243\ \text{kJ}}{0.0693\ \text{mol}\ C_5H_{12}}\right) = 3.51 \times 10^3\ \text{kJ mol}^{-1}$ $\Delta H = -3.51 \times 10^3\ \text{kJ mol}^{-1}$	1 point earned for correct substitution and calculation of ΔH (Sign required; if units given, they must be correct)

(d) Under identical conditions, a sample of an unknown gas effuses into a vacuum at twice the rate that a sample of pentane gas effuses. Calculate the molar mass of the unknown gas.

$\frac{\text{rate}_{unknown}}{\text{rate}_{C_5H_{12}}} = \sqrt{\frac{72.15\text{ g mol}^{-1}}{\text{MM}_{unknown}}}$	1 point earned for correct substitution
$\frac{2\times rate_{C_5H_{12}}}{rate_{C_5H_{12}}} = 2 = \sqrt{\frac{72.15\text{ g mol}^{-1}}{\text{MM}_{unknown}}}$	
$2^2 = \frac{72.15\text{ g mol}^{-1}}{\text{MM}_{unknown}} = 4$	
$MM_{unknown} = \frac{72.15\text{ g mol}^{-1}}{4} = 18.04\text{ g mol}^{-1}$	1 point earned for correct value of MM

(e) The structural formula of one isomer of pentane is shown below. Draw the structural formulas for the other two isomers of pentane. Be sure to include all atoms of hydrogen and carbon in your structures.



	
1 point earned for each correct structural formula	

Question 4

AP Chemistry Scoring Guidelines 2002

Total Score 15 points

Note: for reactions with three products, 1 product point is earned for one or two of the products

(a) A solution of sodium iodide is added to a solution of lead(II) acetate.

$I^- + Pb^{2+} \rightarrow PbI_2$	3 points

(b) Pure solid phosphorus (white form) is burned in air.

$P_4 + O_2 \rightarrow P_4O_{10}$	3 points

Note: products other than P_4O_{10} showing correct oxidation states are acceptable.

(c) Solid cesium oxide is added to water.

$Cs_2O + H_2O \rightarrow Cs^+ + OH^-$	3 points

Note: CsOH earns 1 product point if no additional incorrect species are included in the product.

(d) Excess concentrated hydrochloric acid is added to a 1.0 *M* solution of cobalt(II) chloride.

$Cl^- + Co(H_2O)_6^{2+} \rightarrow H_2O + CoCl_4^{2-}$ **OR** $Cl^- + Co^{2+} \rightarrow CoCl_4^{2-}$	3 points

Note: Other species, such as $Co(H_2O)_4^{2+}$ as a reactant or $CoCl_3^-$ as a product, are acceptable.

(e) Solid sodium hydrogen carbonate (sodium bicarbonate) is strongly heated.

$NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$	3 points

(f) An excess of hydrochloric acid is added to solid zinc sulfide.

$H^+ + ZnS \rightarrow Zn^{2+} + H_2S$	3 points

Question 4

AP Chemistry Scoring Guidelines 2002

(g) Acidified solutions of potassium permanganate and iron(II) nitrate are mixed together.

$MnO_4^- + H^+ + Fe^{2+} \bullet H_2O + Fe^{3+} + Mn^{2+}$	3 points

(h) A solution of potassium hydroxide is added to solid ammonium chloride.

$NH_4Cl + OH^- \rightarrow NH_3 + Cl^- + H_2O$	3 points

<u>Note:</u> no product points are earned for NH_4OH

Question 5

AP Chemistry Scoring Guidelines 2002

Total Score 10 Points

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$$

5. A student is asked to determine the molar enthalpy of neutralization, ΔH_{neut}, for the reaction represented above. The student combines equal volumes of 1.0 M HCl and 1.0 M NaOH in an open polystyrene cup calorimeter. The heat released by the reaction is determined by using the equation $q = mc\Delta T$.

Assume the following.

- Both solutions are at the same temperature before they are combined.
- The densities of all the solutions are the same as that of water.
- Any heat lost to the calorimeter or to the air is negligible.
- The specific heat capacity of the combined solutions is the same as that of water.

(a) Give appropriate units for each of the terms in the equation $q = mc\Delta T$.

q has units of joules (or kilojoules or calories or kilocalories) m has units of grams or kilograms c has units of J g^{-1} °C^{-1} or J g^{-1} K^{-1} (calories or kilograms acceptable alternatives) T has units of °C or K	1 point earned for any two units, 2 points earned for all four units

(b) List the measurements that must be made in order to obtain the value of q.

• volume or mass of the HCl or NaOH <u>solutions</u> • initial temperature of HCl or NaOH before mixing • final (highest) temperature of solution after mixing	1 point earned for <u>any</u> volume (mass of reactant) 1 point earned for initial and final (highest) temperature (ΔT is <u>not</u> a measurement)

(c) Explain how to calculate each of the following.

(i) The number of moles of water formed during the experiment

Since there is mixing of equal volumes of the same concentration <u>and</u> the reaction has 1:1 stoichiometry, moles of H_2O = moles of HCl = moles NaOH. To determine the number of moles of HCl: $$(\text{volume HCl})\left(\frac{\text{mol HCl}}{1\text{ L}}\right)\left(\frac{1\text{ mol H}_2\text{O}}{1\text{ mol HCl}}\right) = \text{mol H}_2\text{O}$$ **OR** $$(\text{volume NaOH})\left(\frac{1.0\text{ mol NaOH}}{1\text{ L}}\right)\left(\frac{1\text{ mol H}_2\text{O}}{1\text{ mol NaOH}}\right) = \text{mol H}_2\text{O}$$ **OR** $$n_{H_2O} = n_{HCl} = n_{NaOH} = V_{HCl} \times 1\,M = V_{NaOH} \times 1\,M$$	1 point earned for the number of moles of H_2O using the stoichiometric relationship between HCl (or NaOH) and H_2O

(ii) The value of the molar enthalpy of neutralization, ΔH_{neut}, for the reaction between HCl(aq) and NaOH(aq)

Determine the quantity of the heat produced, q, from $q = mc\Delta T$, where m = <u>total</u> mass of solution; divide q by mol H_2O determined in part (c) (i) to determine ΔH_{neut}: $$\Delta H_{neut} = \frac{-q}{\text{mol H}_2\text{O}} \quad \textbf{OR} \quad \frac{q}{\text{mol H}_2\text{O}}$$ (mol reactant can substitute for mol H_2O)	1 point earned for q 1 point earned for ΔH_{neut}

(d) The student repeats the experiment with the same equal volumes as before, but this time uses 2.0 *M* HCl and 2.0 *M* NaOH.

(i) Indicate whether the value of q increases, decreases, or stays the same when compared to the first experiment. Justify your prediction.

The ΔT will be greater, so q increases. There are more <u>moles</u> of HCl and NaOH reacting so the final temperature of the mixture will be higher.	1 point earned for direction <u>and</u> explanation

<u>Note:</u> Arguments about increased mass are not acceptable because the total mass increase is negligible (the solutions have virtually the same density) and is not the driving force for increases in q.

(ii) Indicate whether the value of the molar enthalpy of neutralization, ΔH_{neut}, increases, decreases, or stays the same when compared to the first experiment. Justify your prediction.

Both q and mol H_2O increase proportionately. However, when the quotient is determined, there is no change in ΔH_{neut} Molar enthalpy is defined as <u>per mole</u> of reaction, therefore it will not change when the number of moles is doubled.	1 point earned for correct direction <u>and</u> explanation

(e) Suppose that a significant amount of heat were lost to the air during the experiment. What effect would this have on the calculated value of the molar enthalpy of neutralization, ΔH_{neut}? Justify your answer.

Heat lost to the air will produce a smaller ΔT. In the equation $q = mc\Delta T$ a smaller ΔT will produce a smaller value for q (heat released) than it should. In the equation $\Delta H_{neut} = \dfrac{-q}{\text{mol } H_2O}$ the smaller magnitude of q and the constant mol H_2O means that ΔH_{neut} will be less negative (more positive).	1 point earned for correct direction <u>and</u> explanation

<u>Notes:</u> ΔH decreases because q decreases earns 1 point
ΔT decreases because ΔH decreases earns 1 point
No points earned for ΔT decreases therefore q decreases

Question 6

AP Chemistry Scoring Guidelines 2002

Total Points 8 Points

6. Use the principles of atomic structure and/or chemical bonding to explain each of the following. In each part, your answer must include references to both substances.

(a) The atomic radius of Li is larger than that of Be.

Both Li and Be have their outer electrons in the same shell (and/or they have the same number of inner core electrons shielding the valence electrons from the nucleus). However, Be has four protons and Li has only three protons. Therefore, the effective nuclear charge experienced (attraction experienced) by the valence (outer) electrons is greater in Be than in Li, so Be has a smaller atomic radius.	1 point earned for indicating that Be has more protons than Li 1 point earned for indicating that since the electrons are at about the same distance from the nucleus, there is more attraction in Be as a result of the larger number of protons

(b) The second ionization energy of K is greater than the second ionization energy of Ca .

The second electron removed from a potassium atom comes from the third level (inner core). The second electron removed from a calcium atom comes from the fourth level (valence level). The electrons in the third level are closer to the nucleus so the attraction is much greater than for electrons in the fourth level.	1 point earned for saying that electrons are removed from an inner (third) level in potassium but one level higher, (fourth level) in calcium 1 point earned for saying that the distance to the nucleus is less for the third level, so attraction is greater and more energy is needed to remove an electron

(c) The carbon-to-carbon bond energy in C_2H_4 is greater than it is in C_2H_6 .

C_2H_4 has a double bond between the two carbon atoms, whereas C_2H_6 has a carbon-carbon single bond. More energy is required to break a double bond in C_2H_4 than to break a single bond in C_2H_6; therefore, the carbon-to-carbon bond energy in C_2H_4 is greater.	1 point earned for indicating that C_2H_4 has a double bond and C_2H_6 has a single bond 1 point earned for indicating that the carbon-carbon double bond in C_2H_4 requires more energy to break (is stronger) than the carbon-carbon bond in C_2H_6

Note: Restatement of the prompt does not earn the second point.

(d) The boiling point of Cl_2 is lower than the boiling point of Br_2.

Both Cl_2 and Br_2 are nonpolar, and the only intermolecular attractive forces are London dispersion forces. Since Br_2 has more electrons than Cl_2, the valence electrons in Br_2 are more polarizable. The more polarizable the valence electrons, the greater the dispersion forces and the higher the boiling point.	1 point earned for indicating that Cl_2 and Br_2 are both nonpolar and/or have only London dispersion forces (or van der Waals). 1 point for indicating that the more electrons, the more polarizable, the greater the dispersion forces, and the higher the boiling point.

Notes: Stating that the bromine electrons are more loosely bound, and thus lead to stronger London dispersion forces is acceptable. The word "polarizable" is not required. Greater mass is not acceptable.
No credit earned if the student implies that covalent bonds break during boiling.

Question 7

AP Chemistry Scoring Guidelines 2002

Total Score 8 points

7. An environmental concern is the depletion of O_3 in Earth's upper atmosphere, where O_3 is normally in equilibrium with O_2 and O. A proposed mechanism for the depletion of O_3 in the upper atmosphere is shown below.

Step I $\quad O_3 + Cl \rightarrow O_2 + ClO$

Step II $\quad ClO + O \rightarrow Cl + O_2$

(a) Write a balanced equation for the overall reaction represented by Step I and Step II above.

$O_3 + O \rightarrow 2\,O_2$	1 point earned for correct overall reaction

(b) Clearly identify the catalyst in the mechanism above. Justify your answer.

Cl is the catalyst in the reaction. It is a reactant in Step I and reappears as a product in Step II.	1 point earned for identifying Cl as the catalyst 1 point earned for justifying Cl as the catalyst

(c) Clearly identify the intermediate in the mechanism above. Justify your answer.

ClO is the intermediate in the reaction. It is a product in Step I and reappears as a reactant in Step II.	1 point earned for identifying ClO as the intermediate 1 point earned for justifying of ClO as the intermediate

(d) If the rate law for the overall reaction is found to be $rate = k[O_3][Cl]$, determine the following.

(i) The overall order of the reaction

(ii) Appropriate units for the rate constant, k

(iii) The rate-determining step of the reaction, along with justification for your answer

(i) overall order is $1 + 1 = 2$	1 point earned for overall order
(ii) $k = \dfrac{rate}{[O_3][Cl]} = \dfrac{M\ \text{time}^{-1}}{M^2} = M^{-1}\ \text{time}^{-1}$	1 point earned for correct units
(iii) Step I is the rate-determining step in the mechanism. The coefficients of the reactants in Step I correspond to the exponents of the species concentrations in the rate law equation. **OR** The reaction rate is affected by the concentrations of $[O_3]$ and $[Cl]$, both appearing only in Step I.	1 point earned for the correct step <u>and</u> justification

Question 8

AP Chemistry Scoring Guidelines 2002

Total Score 8 Points

$$C(s) + CO_2(g) \rightleftarrows 2\,CO(g)$$

8. Carbon (graphite), carbon dioxide, and carbon monoxide form an equilibrium mixture, as represented by the equation above.

(a) Predict the sign for the change in entropy, ΔS, for the reaction. Justify your prediction.

$\Delta S = +$ There is more disorder in a gas than in a solid, so the product is more disordered than the reactants. The change in entropy is therefore positive. **OR** There is 1 mole of gas in the reactants and 2 moles of gas in the product.	1 point earned for indicating that ΔS is positive 1 point earned for explanation

(b) In the table below are data that show the percent of CO in the equilibrium mixture at two different temperatures. Predict the sign for the change in enthalpy, ΔH, for the reaction. Justify your prediction.

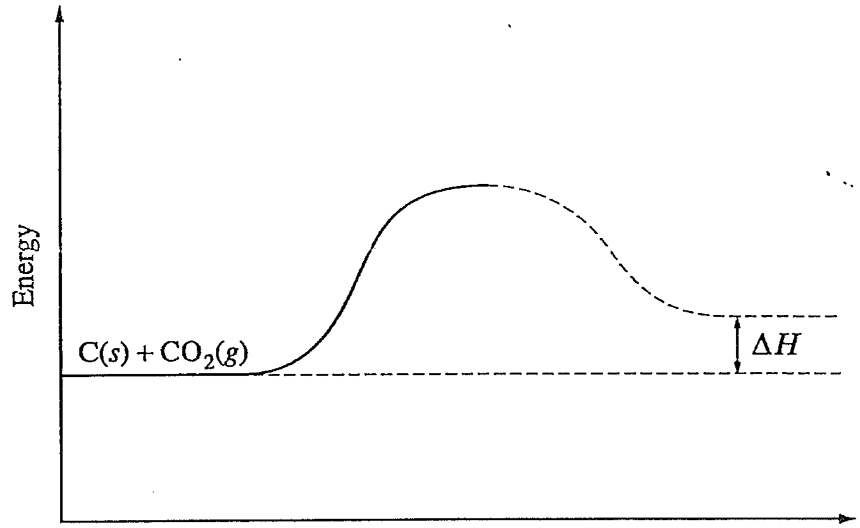
Temperature	**% CO**
700°C	60
850°C	94

$\Delta H = +$ More CO at the higher temperature indicates that the reaction shifts to the right with increasing temperature. For this to occur, the reaction must be endothermic.	1 point earned for indicating that ΔH is positive 1 point earned for explanation

Question 8

AP Chemistry Scoring Guidelines 2002

(c) Appropriately complete the potential energy diagram for the reaction by finishing the curve on the graph below. Also, clearly indicate ΔH for the reaction on the graph.



1 point earned for completing the graph according to the information in part (b) 1 point earned for appropriately labeling ΔH_{rxn} for the reaction as drawn

(d) If the initial amount of $C(s)$ were doubled, what would be the effect on the percent of CO in the equilibrium mixture? Justify your answer.

An increase in the amount of $C(s)$ has no effect. Solids do not appear in the equilibrium expression, so adding more $C(s)$ will not affect the percent of CO in the equilibrium mixture.	1 point earned for indicating no effect 1 point earned for explanation

Note: Since the question asks about "percent of CO" a student might think of % by mass or % by mole. Adding carbon will not shift the equilibrium, so P_{CO} and P_{CO_2} stay the same. The % CO then decreases, because now there are more total moles in the system: $\% \text{ CO} = n_{CO}/(n_{CO} + n_{CO_2} + n_C)$
As n_C is raised, the denominator increases, and % CO decreases.

Student Performance Q&A:

2002 AP® Chemistry Free-Response Questions

The following comments are provided by the Chief Reader regarding the 2002 free-response questions for AP Chemistry. *They are intended to assist AP workshop consultants as they develop training sessions to help teachers better prepare their students for the AP Exams*. They give an overview of each question and its performance, including typical student errors. General comments regarding the skills and content that students frequently have the most problems with are included. Some suggestions for improving student performance in these areas are also included. Consultants are encouraged to use their expertise to create strategies for teachers to improve student performance in specific areas.

Question 1

What was intended by the question?

The question was designed to measure students' understanding and abilities relating to the topics of pH, weak-acid equilibria, titration of a weak acid with a strong base (including pH at equivalence), preparation of a buffer solution, and oxyacid strength. The question involved both quantitative calculations and some short answers.

How well did students perform?

Students performed fairly well, but they were better on the calculation parts than on the short answer parts. Students typically earned points for part (a), part (b), part (c)(i), and part (d).

What were common errors or omissions?

In part (a):

- Responding with the answer for $[H^+]$, but showing no work
- Confusing natural log (ln) with log base 10 ($\log_{10}$)
- Obtaining an excessively high ($10^{4.95}$) or negative $[H^+]$
- Excessive number of digits in answer

In part (b):

- Writing only the ratio of the dissolved species and eliminating any equality to K_a
- Confusing K_a with K_{sp}, K_c, or the rate constant, k
- Writing expressions lacking [HOBr], or equating [HOBr] to $[OBr^-]$

In part (c)(i):

- Ignoring the stoichiometric ratio, or assuming it to be 1:1
- Improperly applying the correct stoichiometric ratio
- Using a direct proportion to calculate volume (from $M_aV_a = M_bV_b$)

In part (c)(ii):

- Attributing pH >7 to the condition that a weak acid is titrated with a strong base
- Ignoring the presence of OBr^- at the equivalence point, citing the cause as the presence of the "strong" base (*vs.* weak acid)
- Citing the cause as the excess ion from $Ba(OH)_2$
- Simply stating the ion is the conjugate base of a weak acid
- Incompletely explaining hydrolysis
- Implying that pH = pK_a at the equivalence point

In part (d):

- Substitution of moles into the equilibrium expression
  (There is no volume change in the problem, so correct answers are obtained. However, there is no evidence that students understand why this happens).

In part (e):

- Assuming the H is bonded directly to Br, especially in $HBrO_3$
- Simply citing the fact that there are more oxygen atoms in $HBrO_3$
- Confusing O atoms in $HBrO_3$ with O atoms in a separate molecule (e.g., O_3)
- Not differentiating between hydrogen bonding (intermolecular) and H–O covalent bonding (intramolecular)

Based on your experience at the AP Reading, what message would you like to send to teachers that could improve the performance of their students on the exam?

Continue to emphasize that an answer should be supported with work, use of units, and use of significant figures (especially significant figures in logs).

Regarding acid-base chemistry, involve students in explaining the chemistry at the particle level for equilibrium and titration problems. Encourage students to explain phenomena more deeply. Discourage responses that simply state rules such as "strong acid-weak base titrations are basic at the equivalence point" or "more oxygen atoms in a formula make the acid stronger."

Encourage your students to use stoichiometry from the balanced neutralization reaction to calculate the volume of acid or base required to neutralize (react with) the base or acid, and not to use the equations $M_1V_1 = M_2V_2$ or $M_aV_a = M_bV_b$. The equation $M_1V_1 = M_2V_2$ should be used for dilutions only.

Emphasize the recognition of which species define the pH at important points during an acid-base titration. (There are four critical points; before any base is added, between the initial pH and the equivalence point, at the equivalence point, and beyond the equivalence point.)

Use the "ICE" table set-up for equilibrium systems. An ICE table specifies the ***i***nitial, ***c***hange, and ***e***quilibrium conditions and, when completed correctly, provides students with all the information required to successfully solve an equilibrium problem.

Question 2

What was intended by the question?

This question tested students' knowledge of chemistry in three areas — stoichiometry (limiting reactant), electrochemistry (cell potential under standard and nonstandard conditions), and thermodynamics (Gibbs free energy under standard and nonstandard conditions).

How well did students perform?

This question was chosen by 43 percent of the students. As a group, these students performed reasonably well on the question; the mean score was 4.56 points out of 10 points. In general, students tended to earn the most points in parts (a), (b), and (c).

What were common errors or omissions?

In part (a)(i):

- Not relating 2 moles of Ag^{+} to 1 mole of Zn
- Getting the proper number of moles of reactants with the correct ratio, but then failing to determine the limiting reactant
- Not explaining how the numbers generated determine the limiting reactant

In part (a)(ii):

- Calculating the moles of Zn^{2+}, but then not using the volume to determine the concentration, or incorrectly calculating the number of moles of Zn^{2+}, even though calculation of concentration was done appropriately
- Stopping at the step in which the number of moles of Zn^{2+} produced is determined
- Being inconsistent with part (a)(i). If Zn is the limiting reactant, then the concentration of $[Zn^{2+}]$ must reflect this
- Using incorrect number of significant digits in answer

In part (b):

- Doubling the voltage of the Ag^{+} half-reaction
- Not changing the sign of the Zn half-reaction
- Subtracting the two half-cell voltages

In part (c):

- Not indicating the sign of the free energy
- Not including appropriate units (J, kJ)
- Using +1.56 volts for the E° value or another calculated value; not recognizing that +0.46 volts is the value of E° to use in the calculation
- Using a value of n other than 2 (e.g., 1, 3, and 6)
- Reporting answer with incorrect number of significant digits

In part (d):

- Calculating the natural log of Q rather than the base 10 log of Q
- Using the wrong value of n, as in part (c)
  (If a student was consistent in part (c) and part (d) with the wrong value for n, no points were lost in part (d).)

- Reporting answer with incorrect number of significant digits
- Incorrectly substituting into the Q expression

  (Common incorrect substitutions were $\frac{[Cu^{2+}]}{[Ag^{+}]}$, $\frac{[Cu^{2+}]}{[Ag^{+}]^2}$, and $\frac{[Ag^{+}]^2}{[Cu^{2+}]}$.)

In part (e):

- Referring to the E for the cell instead of E for the cell under the specified conditions

Based on your experience at the AP Reading, what message would you like to send to teachers that could improve the performance of their students on the exam?

Stoichiometry should be a subject that is reexamined throughout the school year. The balanced chemical reaction is still one of chemistry's best tools.

When teaching students how to determine limiting reactants, perhaps try more than one method. As demonstrated by the student responses, there are many ways to answer (a)(i), and perhaps some of your students will grasp these alternative methods.

Remind students that molarity is moles divided by liters. Many students confused <u>moles</u> of Zn^{2+} with the <u>molarity</u> of Zn^{2+}.

Have students practice using the standard reduction table to calculate cell voltage in cases where the coefficients in the balanced equation are <u>not</u> in a 1:1 ratio.

Have students practice using the Nernst equation. Emphasize both the use of the correct number of electrons in the cell-reaction equation and the proper use of Q.

Help your students relate electrochemistry to thermodynamics. Have them create a table relating E, ΔG, and the spontaneity of the reaction.

Finally, stress that when a question asks for an answer and a justification that BOTH should be given. Too many students lost points because they gave the correct answer, but their justification was too weak. Recommend that any "support your answer" response is best done with a sentence.

Question 3

What was intended by the question?

Using the context of a simple hydrocarbon, this question was designed to evaluate students' knowledge and ability to apply stoichiometry and use the ideal gas law and Graham's Law. In addition, abilities to perform thermochemical calculations and to draw structural isomers of a simple hydrocarbon are assessed.

How well did students perform?

This question was chosen by 57 percent of the students. In general, students were able to balance the equation correctly and recognize the application of the ideal gas law. Some students were adept at substituting in the formula and using the correct mole ratio from the equation. Others broke their calculations down into several steps by calculating moles, used the combined gas law to account for pressure and temperature changes, and then related the results to the equation given. This approach indicated that these students had a sound understanding of the concepts. In calculating the molar mass of the unknown gas, many students used Graham's Law correctly. Others used the root-mean-square formula. Students generally earned points in parts (a), (b), and (c).

What were common errors or omissions?

In part (a):

- Incorrectly balancing the equation for the combustion reaction.

In part (b):

- Not adjusting the volume for the given temperature and pressure conditions
- Using the number of moles of C_5H_{12} rather than moles of CO_2 when substituting in the ideal gas formula
- Using the incorrect value for R

In part (c):

- Neglecting to indicate the negative sign for ΔH

In part (d):

- Incorrectly substituting in the Graham's Law equation
- Dividing the molar mass of C_5H_{12} by 2
- Using the incorrect number of significant figures (e.g., reporting the molar mass of the unknown gas as 18 g mol^{-1})

In part (e):

- Not understanding what isomers are and/or how to draw them using structural formulas (Many students redrew the structure given in the question in different arrangements that suggested they did not understand free rotation about a single bond.)

Based on your experience at the AP Reading, what message would you like to send to teachers that could improve the performance of their students on the exam?

Emphasize to students that they must read each question carefully and then answer what is being asked. For example, in part (c), the value of ΔH was asked for, but many students failed to indicate the negative sign. Also, even though the molar mass of C_5H_{12} was given in the problem, many students did not use this information, but rather they often calculated the molar mass incorrectly or used other numbers.

Advise your students NOT to restate the question in their responses. This is an unnecessary and a wasteful use of limited time and is not in a student's best interest.

Stress to your students that they must show their work in quantitative questions, or risk losing credit. Most of the credit available is focused on process, not on final answers.

Work with your students in drawing structural isomers. Discuss with them the idea of free rotation about C–C single bonds and the difference between a structural isomer and a conformer.

Question 4

What was intended by the question?

This question was designed to assess students' familiarity with chemical nomenclature, knowledge of common classes of chemical reactions, and ability to apply their knowledge (including principles of periodicity) in predicting the products(s) of a variety of chemical reactions.

How well did students perform?

In this question, students choose to answer five of eight reactions. The most popular choices were the lead iodide precipitation reaction (a), the combustion of phosphorus reaction (b), the cesium oxide plus water reaction (c), and the acid/base reactions (f) and (h). Students seemed the most proficient at predicting these products: PbI_2, $Cs^+ + OH^-$, and $Zn^{2+} + H_2S$. Most recognized that a decomposing hydrogen carbonate produced CO_2 and that an acid/base reaction produced water. Many students failed to write the reactant NH_4Cl in equation (h) as a solid. Frequently the only 3 points a student earned for this question were for reaction (a). The mean score was 5.54 points out of 15 points, which is lower than it has been for this question in the past few years.

What were common errors or omissions?

Reaction (a): Many students did not know that NaI and $Pb(C_2H_3O_2)_2$ are soluble compounds, that Pb is a +2 ion, and that I is a –1 ion. Often net ionic equations were done incorrectly.

Reaction (b): Though many students were able to correctly identify that P and O_2 were the reactants, fewer seemed to know the products. Charges were often assigned to the P and O_2 species. Interestingly, a common answer for the products was CO_2 and H_2O, which many students know as the products of burning carbon compounds.

Reaction (c): Many students were unable to correctly identify the symbol for cesium — they often used Ce. Often the charges of the species were incorrect, and cesium hydroxide was often treated as insoluble.

Reaction (d): This reaction was the least frequently chosen of the eight reaction options. Many students did not know that $CoCl_2$ was soluble and that excess HCl drove the reaction to form the complex ion. Some students did not recognize that HCl was a strong acid and dissociates in water to form ions.

Reaction (e): Typically, students who chose this reaction did not know the decomposition products. Both Na and NaOH were sometimes given as products.

Reaction (f): Many students did not know the insolubility of ZnS or the fact that HCl is dissociated in water.

Reaction (g): Students often treated this as a precipitation reaction. Many did not recognize that acidified means having H^+ ion as a reactant. Other frequent errors were indicating the charge of permanganate ion to be –2, and not knowing the reduction product of permanganate in an acidic solution (Mn^{2+}).

Reaction (h): Students who chose this reaction often answered it correctly. A frequent error was not showing the ammonium chloride as a solid on the reactant side of the equation. As with many of the reactions, students often performed poorly because they did not know or apply solubility rules and/or follow the rules for writing net ionic equations.

Based on your experience at the AP Reading, what message would you like to send to teachers that could improve the performance of their students on the exam?

Emphasize the following with your students:

- know the solubility rules
- recognize and write net ionic equations
- understand that strong acids are completely dissociated in water and that strongly heating a substance does not mandate that oxygen is a reactant
- distinguish between oxidation-reduction and precipitation reactions
- write formulas of elements and compounds
- know the charges of common cations and anions

Provide learning opportunities for students to learn descriptive chemistry, and how to predict products and write equations for reactions (include reactions that cannot be performed in the school laboratory.) Also include both complexation reactions and oxidation-reduction reactions in acidic or basic solutions.

Require students to know the symbols for the first twenty elements in the periodic table, plus the more commonly studied elements with atomic numbers greater than 20. Remind students that if they write the oxidation numbers of elements in a compound as a note to themselves as they determine the products of the reaction, they should be careful to delete these numbers in the final answers. It is important for students to write superscript charges for only those species that exist as ions in the final net-ionic equation that will be scored.

Question 5

What was intended by the question?

Required laboratory questions are designed to assess whether students understand the procedures and purposes of commonly performed chemistry laboratory experiments. This year, the question asked a series of specific questions concerning a “coffee-cup calorimeter” determination of the heat of neutralization of an acid-base reaction. In order to keep the arithmetic simple, 1 molar solution of HCl and NaOH were mixed in equal volumes, a neutralization reaction with 1:1 stoichiometry was selected, and the equation $q = mc\Delta T$ was provided. Students were also advised that solution densities were the same as water, their specific heat capacities were the same as water, and that heat losses from the mixed solution were negligible.

How well did students perform?

In general, students did poorly on this question (the mean score was only 3.18 points out of 10 points), although some students had excellent answers. In terms of points earned, parts (a), (b), and (e) were the most successfully answered, while parts (c) and (d) proved to be more difficult for the students. Many students were not careful in answering parts of the question, failing to include sufficient detail.

What were common errors or omissions?

In part (a):

Students were asked to identify the units of the terms in the equation $q = mc\Delta T$. Typically, students did recognize the correct meaning and units of the terms in the equation. Errors demonstrated in this part included:

- Using units for terms in the equation as if they were standard across the fields of chemistry and physics (e.g., c = speed of light, ΔT = time difference, q = charge in coulombs)
- Neglecting units for terms on the left hand side of the equation
- Identifying what the term symbol represented (e.g., m is mass) but not indicating the units

In part (b):

Students were asked to list the measurements that must be made to obtain q. Many students successfully identified the volume or mass of solution (reactants or final mixture) as one measurement and the initial and final temperatures of the mixed solutions as the other vital measurements. Misconceptions or errors demonstrated in this part included:

- Indicating that the mass of water produced in the reaction is needed for the calculation of q
- Indicating that the mass of H^+ is the same as the mass of the HCl solution
- Saying to measure "mass" with no statement as to which mass to measure
- Confusing measurements with a calculation, as in T_i and T_f *vs*. ΔT

In part (c), students were asked to explain how to calculate (i) the number of moles of water formed during the experiment and (ii) the value of the molar enthalpy of neutralization for the reaction. Relatively few recognized that because of the simple stoichiometry and the unit solution molarities, the moles of water produced is directly equal to the number of liters of either reactant used. Students who can reason through such short cuts should earn the credit, with the caveat that they must explain them clearly. Misconceptions or errors demonstrated in part (c)(i) included:

- Giving equations and not explaining how to substitute into them
- Taking valuable time to explain how to determine the limiting reagent (an unnecessary step in this case)

Misconceptions or errors demonstrated in part (c)(ii) included:

- Using the mass of water produced instead of the total mass of solution in the cup for m in the equation for q
- Inappropriately using the equation $\Delta H = \Sigma\ \Delta H_f$ products – $\Sigma\ \Delta H_f$ reactants (perhaps because this equation is listed on the formula sheet)
- Inappropriately using the equation $\Delta H = C_p\Delta T$ (again, listed on the formula sheet)

In part (d), students were asked to justify a prediction of the results for (i) q and for (ii) ΔH_{neut} if the molarities of the reactants were changed to 2 M, while keeping everything else the same.

Misconceptions or errors demonstrated in part (d)(i) included:

- Focusing on the m term instead of the ΔT term in the q equation and stating that if the mass doubles then q must double

Misconceptions or errors demonstrated in part (d)(ii) included:

- Indicating that ΔH_{neut} values are proportional to mass or molarity of reactants
- Stating that a proportion is involved but not clearly identifying what exactly the proportion is

In part (e), students were asked to predict the effect on the value ΔH_{neut} if heat were lost to the surroundings. Most students were able to make the prediction that a lower value would be obtained, however they frequently failed to justify this prediction fully. Misconceptions or errors demonstrated in part (e) included:

- Stating that heat loss does not affect ΔT or q but directly changes ΔH
- Assuming the heat loss was small and thus simply an "error"
- Confusing theoretical determinations of ΔH with the measurement in this experiment

Based on your experience at the AP Reading, what message would you like to send to teachers that could improve the performance of their students on the exam?

Because this may be an experiment done in the first chemistry course for some students, have them review all the laboratories done throughout their chemistry career shortly before the exam.

Make sure that students understand the reasons for all steps in laboratory experiments and calculations and all the terms in any equations used. Construct quizzes, hold classroom discussions or use other strategies to assure that students understand what they are doing and why.

Have students outline procedures for manipulations and calculations for a laboratory experiment some time after doing the experiment WITHOUT the aid of the laboratory write-up to assist with memory.

If you ask students to collect all their laboratory reports neatly in a folder for possible review by colleges, consider doing this before the AP exam so students can review what they have done.

Ask students to describe the measurements that are taken in a laboratory experiment. It is good practice to assume the person reading a laboratory report has not done the experiment, so it is a good idea to explain in detail.

Question 6

What was intended by the question?

This was the required essay question, which has four parts in which students explain chemical observations in terms of principles of atomic structure and chemical bonding. This type of question is designed to assess students' ability to apply their chemical knowledge by formulating coherent responses that fully explain the observations.

How well did students perform?

The students did not perform well on this question (average score 2.93 points out of 8 points), earning an average of less than 1 point per part. In terms of points received, the parts in order of increasing difficulty were (c), (a), (d), and (b).

What were common errors or omissions?

In part (a):

Many students correctly identified that the smaller radius of Be is due to the greater number of protons in Be. However, many failed to earn the second point, which required them to argue in more depth — that it is also important that the valence electrons be in a similar subshell (shell was accepted) for this argument to be valid. A small group of students identified increased effective nuclear charge as the key causative factor, but many of these students showed that they did not really understand this concept.

Students frequently showed misconceptions by stating or implying the following:

- Electron shielding or pairing energy is more important in determining atomic radius than nuclear charge is
- The electron/proton ratio for atoms changes across the period
- Two electrons have twice the attraction to a nucleus as one electron
- Electronegativity is an explanation, not a result
- Electrons are point charges pulling the nucleus towards them
- Atomic radius is determined by the size of the nucleus

In part (b):

Most students identified that for K, the second electron must be taken from a more stable (octet) core, whereas only a valence electron is removed from Ca. However, they typically neglected to explain <u>why</u> it requires more energy to remove an octet electron.

Students frequently showed misconceptions by stating or implying the following:

- Electrons in Ca "want" to become an octet so the second ionization energy is "very low," perhaps even lower than the first ionization energy
- K becomes the element Ar when it ionizes; when Ca loses one electron, it becomes the element K
- Filled shells have extra screening from the nucleus so they are more stable than half-filled shells
- The octet rule completely explains this difference
- Ar is a "happy" element that others want to become or remain as
- Ionization energy is defined as energy needed to add electrons
- It is easier to ionize unpaired electrons than paired electrons

In part (c):

Students were not expected to know the names of these compounds, and most identified by words or diagrams that the ethene molecule has a C–C double bond and the ethane molecule has a C–C single bond. However, many did not go on to explain <u>why</u> the C–C bond in ethene has greater energy than the C–C bond in ethane. Many students repeated or paraphrased the phrase in the question "the bond in C_2H_4 has a greater bond energy than in C_2H_6" and earned no points for this "explanation."

Students frequently showed misconceptions by stating or implying the following:

- When bonds form, energy is absorbed (rather than released)
- Pi bonds are stronger than sigma bonds
- A double bond is twice as strong as a single bond
- Hydrogen bonding occurs in hydrocarbons
- Since there are more bonds in C_2H_6 compared to C_2H_4 , the bonds in C_2H_4 are stronger

In part (d):

Most students identified that the higher boiling point is the result of greater intermolecular forces and that these forces are London dispersion (or Van der Waals) forces. Students had more difficulty explaining why bromine has greater forces, though a significant number did identify the size of the electron cloud as leading to greater possibilities for induced-dipole forces.

Students frequently showed misconceptions by stating or implying the following:

- Bromine is denser (or heavier) so it takes longer to heat up
- Bromine has more particles so it heats up more slowly
- Boiling relates to how fast molecules are moving and how fast things can heat up
- Boiling involves breaking covalent bonds in molecules
- London dispersion forces are only dependent on mass, or on electronegativity
- Boiling point of an element is a colligative property and depends on molarity

Based on your experience at the AP Reading, what message would you like to send to teachers that could improve the performance of their students on the exam?

Students exhibited the following difficulties in answering this question:

- Presenting trends as explanations (no credit was earned for this)
- Presenting circular arguments or tautologies (e.g., Li is larger than Be because Be is smaller than Li)
- Presenting partial explanations (earning 1 but not 2 points)
- Anthropomorphizing atoms (using "lecture language"), describing "happy" atoms, or atoms that "want" to lose electrons
- Being sloppy with language and interchanging terms (e.g., neutron for proton, neon for argon, bond for force, period for group, atom for molecule, and molecule for atom)

To better educate students and prepare them to earn possible credit and or placement by getting a higher grade on the AP Chemistry Examination, teachers should do the following:

- Review the problem issues and misconceptions identified above
- Emphasize that in questions involving energy and charge there are always <u>two</u> parameters to consider: (1) the magnitudes of the charges, and (2) the distance separating them
- Practice with students to challenge "necessary, but not sufficient" explanations
- Emphasize that anthropomorphic language/terminology is not acceptable on the examination (even though it may help understanding initially)
- Emphasize the importance of using correct terminology
- Emphasize that trends and rules (e.g., the octet rule) are NOT explanations

- Emphasize that well organized, clear answers are more likely to get partial credit than disorganized ones. Train your students to read their own answers for meaning, that is to look for bad logic (tautologies), lack of clarity, and needless repetition
- Emphasize that it is an unnecessary waste of time to rewrite the question in an answer
- Instruct students to construct their answers so they make reference to all parts of the question in a way that the scorer (AP Reader) can understand what is being answered

Question 7

What was intended by the question?

This question was designed to assess students' ability to apply their knowledge of chemical kinetics in a real-world context.

How well did students perform?

This question, one of the two options for the "other" essay question, was chosen by 58 percent of the students. Many students performed well on this question, which had an average score of 4.20 points out of 8 points. Students seemed to have the most difficulty with part (d)(iii).

What were common errors or omissions?

In part (a):

- Some students included the intermediate on both sides of the equation and did not earn the point. (Students were not penalized if they included the catalyst, Cl, on both sides of the equation.)

In part (b):

- Most students correctly identified Cl as the catalyst. Their justification was often given as a textbook definition of a catalyst rather than describing the connection of the catalyst to the steps in the mechanism.
- A common misconception appeared to be the belief that if a catalyst does not appear in the final balanced equation, then it has no effect on the reaction

In part (c):

- Most students correctly identified ClO as the intermediate
- Typically, students did not earn the justification point because they did not connect the intermediate to a product formed in one step and a subsequent reaction in a following step
- Students often had trouble clearly discriminating between the catalyst in part (b) and the intermediate in part (c)
- More students were able to explain why ClO was an intermediate than were able to explain why Cl was the catalyst

In part (d)(i):

- Most students correctly identified the overall reaction order
- A common error was to conclude that the reaction was first order because both exponents in the rate law were equal to 1

In part (d)(ii):

- Many good students (as judged by their performance on the other parts of the question) appeared to have difficulty with the algebra involved with the units
- No point was earned for correct units for zero or first-order reactions because the specific rate law was given in the question
- Student answers often showed little difference among the symbols written for M (molarity), m, and mol
- Students sometimes confused the rate constant with K_{eq}

In part (d)(iii):

- Most students correctly identified the rate determining step as Step I by explaining that Step I contained the reactants that were also contained in the given rate law expression
- A common error was failure to connect the slow step to the given rate law

Based on your experience at the AP Reading, what message would you like to send to teachers that could improve the performance of their students on the exam?

Teachers should emphasize that textbook definitions alone do not constitute good explanations or justifications. Students should practice writing out brief explanations so that careless or incorrect use of terminology can be avoided.

Teachers should give their students practice in writing units associated with first and second order reactions. Students should be able to see the connection between the reaction order and the units. Careful distinction should be made between a particular reactant's order and the overall reaction order.

Simple reaction mechanisms should be taught. Students should have practice writing simple mechanisms from a given rate law. They should also have practice predicting a given rate law from a simple mechanism.

Question 8

What was intended by the question?

This question was rather straightforward and was designed to assess students' understanding of thermodynamics, including changes in entropy, changes in enthalpy, and the effect of solids in reactions that are at equilibrium.

How well did students perform?

This question was less popular than question 7, and was chosen by 42 percent of the examinees. The average score was 3.71 points out of 8 points. Points were most often earned in parts (a), (b), and (c).

What were common errors or omissions?

In part (a):

- Some students thought that the change in entropy was negative, since two substances produced only one product
- Students often assigned the wrong sign to the value of ΔS even though they provided a correct explanation

In part (b):

- Often students did not fully explain both the reaction shift and placement of the heat term in the equation

In part (c):

- Many students did not seem to be familiar with an energy diagram for a reaction. When they did draw it correctly, frequent errors were to leave out E_a (no penalty) and to label the change in enthalpy incorrectly.

In part (d):

- Many students did not know that solids, when present in a reaction, have a constant concentration and are not included in expressions for equilibria
- Many students correctly answered that [CO] did not change, but then attributed this to a limiting reactant situation

Based on your experience at the AP Reading, what message would you like to send to teachers that could improve the performance of their students on the exam?

Teachers can improve their students' performance by emphasizing:

1) the implication of signs in changes of entropy, enthalpy, and Gibbs' free energy,
2) the need for practice in drawing energy diagrams, and
3) that all explanations should be organized and complete.

AP Chemistry Free-Response Question Means for Practice Exams

2002 AP Chemistry

Q1	4.30 (all students answer)
Q2	4.57 (students choose Q2 or Q3—the mean for Q2 was lower)
Q3	5.15
Q4	5.52 (all students answer, remember 15 point Q)
Q5	3.15 (all students answer)
Q6	2.92 (all students answer)
Q7	4.21 (students choose between Q7 and Q8—mean is lower for Q8)
Q8	3.71

Multiple Choice Diagnostics Guide for the 2002 AP* Chemistry Exam

Place a ✓in the box below the question number if you answered the question correctly.
Place a ✗ in the box below the question number if you answered the question incorrectly.
If you skipped the question, simply leave the box below the question number blank.
Calculate your section averages and compare them to the national average. (Award yourself 1 pt for each correct answer and deduct 0.25 pts for each incorrect answer.)

Compare your answers to the "% of Students Answering Correctly". If 50+% of the testing population answered correctly, you should as well! If your skips pile up in any one section, then you need to study that topic. Performing this analysis will help you target your areas of weakness and better structure your remaining study time. Remember your goal is to get at least 75% of the points (56.25 points in this case).

Please note that one item may appear in several different categories, as questions can cross over different topics.

Structure of Matter/Atomic Theory & Atomic Structure (Average number correct 4.6 out of 7)

Question #	1	2	17	19	43	44	46
Correct or Incorrect							
% of Students Answering Correctly	*63*	*70*	*70*	*72*	*49*	*70*	*62*

Structure of Matter/Chemical Bonding (Average number correct 5.0 out of 8)

Question #	3	4	5	28	29	53	56	67
Correct or Incorrect								
% of Students Answering Correctly	*74*	*54*	*75*	*68*	*51*	*62*	*62*	*52*

Structure of Matter/Nuclear Chemistry (Average number correct 0.4 out of 1)

Question #	23
Correct or Incorrect	
% of Students Answering Correctly	*37*

Structure of Matter/Gases (Average number correct 3.4 out of 6)

Question #	8	9	10	20	31	66
Correct or Incorrect						
% of Students Answering Correctly	*41*	*71*	*59*	*67*	*56*	*41*

States of Matter/Liquids and Solids (Average number correct 2.4 out of 4)

Question #	15	16	18	68
Correct or Incorrect				
% of Students Answering Correctly	*56*	*58*	*69*	*57*

States of Matter/Solutions (Average number correct 4.0 out of 8)

Question #	26	35	38	39	45	48	61	69
Correct or Incorrect								
% of Students Answering Correctly	*56*	*53*	*61*	*73*	*44*	*48*	*22*	*46*

Reactions/Reaction Types (Average number correct 6.3 out of 12)

Question #	11	12	13	14	19	22	30	33	51	61	63	71
Correct or Incorrect												
% of Students Answering Correctly	*82*	*30*	*67*	*74*	*72*	*57*	*72*	*70*	*49*	*22*	*25*	*13*

Reactions/Stoichiometry (Average number correct 4.2 out of 8)

Question #	24	31	40	43	49	52	58	60
Correct or Incorrect								
% of Students Answering Correctly	*82*	*56*	*29*	*49*	*31*	*71*	*47*	*53*

Reactions/Equilibrium (Average number correct 1.6 out of 5)

Question #	34	37	42	64	75
Correct or Incorrect					
% of Students Answering Correctly	*34*	*45*	*24*	*38*	*21*

Reactions/Kinetics (Average number correct 2.3 out of 5)

Question #	27	47	54	55	57
Correct or Incorrect					
% of Students Answering Correctly	*45*	*39*	*43*	*55*	*52*

Reactions/Thermodynamics (Average number correct 1.9 out of 4)

Question #	25	41	54	73
Correct or Incorrect				
% of Students Answering Correctly	*66*	*43*	*43*	*34*

Descriptive Chemistry (Average number correct 4.7 out of 10)

Question #	6	7	21	32	44	59	62	65	70	74
Correct or Incorrect										
% of Students Answering Correctly	*55*	*61*	*48*	*69*	*70*	*40*	*28*	*45*	*29*	*27*

Laboratory (Average number correct 2.1 out of 5)

Question #	33	36	50	68	72
Correct or Incorrect					
% of Students Answering Correctly	*70*	*28*	*16*	*57*	*35*

Quantitative* (Average number correct 6.9 out of 15)

Question #	20	24	25	26	40	42	43	45	57	58	60	66	69	71	75
75Correct or Incorrect															
% of Students Answering Correctly	*67*	*82*	*66*	*56*	*29*	*24*	*49*	*44*	*52*	*47*	*53*	*41*	*46*	*16*	*21*

***Problems using simple numbers or simple quantitative reasoning are not included in this list.**

NATIONAL MATH + SCIENCE INITIATIVE

AP* Chemistry 2002 Practice Exam Scoring Worksheet

Section I: Multiple Choice

$$\left[\underset{\substack{\text{Number Correct}\\(\text{out of } 75)}}{\underline{\hspace{3cm}}} - \left(0.25 \times \underset{\text{Number Wrong}}{\underline{\hspace{3cm}}}\right)\right] \times 0.9600 = \underset{\text{Multiple-Choice Score}}{\underline{\hspace{3cm}}} = \underset{\textbf{Weighted Section I Score}}{\underline{\hspace{3cm}}}$$

Section II: Free Response

Question 1 $\underset{(\text{out of } 10)}{\underline{\hspace{2cm}}} \times 1.7600 = \underset{(\text{Do not round})}{\underline{\hspace{3cm}}}$

Question 2 *or* 3 $\underset{(\text{out of } 10)}{\underline{\hspace{2cm}}} \times 1.7600 = \underset{(\text{Do not round})}{\underline{\hspace{3cm}}}$

Question 4 $\underset{(\text{out of } 15)}{\underline{\hspace{2cm}}} \times 0.8800 = \underset{(\text{Do not round})}{\underline{\hspace{3cm}}}$

Question 5 $\underset{(\text{out of } 10)}{\underline{\hspace{2cm}}} \times 1.3200 = \underset{(\text{Do not round})}{\underline{\hspace{3cm}}}$

Question 6 $\underset{(\text{out of } 8)}{\underline{\hspace{2cm}}} \times 1.6500 = \underset{(\text{Do not round})}{\underline{\hspace{3cm}}}$

Question 7 *or* 8 $\underset{(\text{out of } 8)}{\underline{\hspace{2cm}}} \times 1.6500 = \underset{(\text{Do not round})}{\underline{\hspace{3cm}}}$

Total Section II Free Response SUM = $\underset{\textbf{Weighted Section II Score}}{\underline{\hspace{3cm}}}$

AP Grade Conversion Chart

Composite Score Range*	AP Grade
107-160	5
85-109	4
61-84	3
42-60	2
0-41	1

*The candidates' scores are weighted as indicated on the exam sections. The Chief Faculty Consultant is responsible for converting composite scores to the 5-point AP scale.

Final Composite Score

$$\underset{\textbf{Weighted Section I Score}}{\underline{\hspace{3cm}}} + \underset{\textbf{Weighted Section II Score}}{\underline{\hspace{3cm}}} = \underset{\substack{\textbf{Composite Score}\\(\text{round to the nearest integer})}}{\underline{\hspace{4cm}}}$$