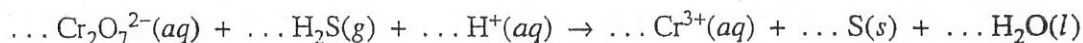40. An excess of $Mg(s)$ is added to 100. mL of 0.400 M HCl. At 0°C and 1 atm pressure, what volume of H_2 gas can be obtained?

    (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)	+	–	–

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

42. 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 only 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.

GO ON TO THE NEXT PAGE

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

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

49. 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

GO ON TO THE NEXT PAGE

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

---

$$3\ Cu(s) + 8\ H^+(aq) + 2\ NO_3^-(aq) \rightarrow 3\ Cu^{2+}(aq) + 2\ NO(g) + 4\ H_2O(l)$$
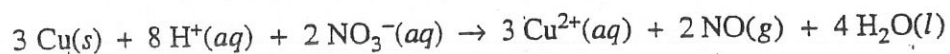
51. True statements about the reaction represented above include which of the following?

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
(E) II and III

---

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.

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

55. 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?

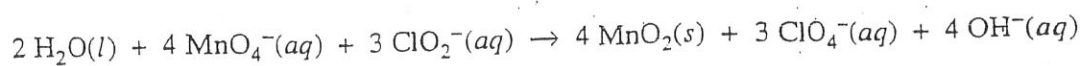|	Reaction Order	Half-life (days)
(A)	First	3
(B)	First	10
(C)	Second	3
(D)	Second	6
(E)	Second	10

GO ON TO THE NEXT PAGE

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.

$$Rate = k[M][N]^2$$

57. 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

$$2\,N_2H_4(g) + N_2O_4(g) \rightarrow 3\,N_2(g) + 4\,H_2O(g)$$
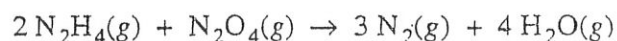
58. When 8.0 g of N_2H_4 (32 g mol^{-1}) and 92 g of N_2O_4 (92 g mol^{-1}) are mixed together and react according to the equation above, what is the maximum mass of H_2O that can be produced?

    (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 25°C and 1 atm are

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

GO ON TO THE NEXT PAGE

$$2 H_2O(l) + 4 MnO_4^-(aq) + 3 ClO_2^-(aq) \rightarrow 4 MnO_2(s) + 3 ClO_4^-(aq) + 4 OH^-(aq)$$
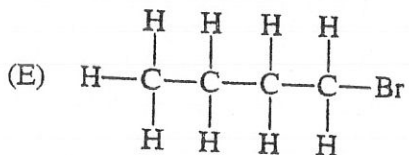
60. According to the balanced equation above, how many moles of $ClO_2^-(aq)$ are needed to react completely with 20. mL of 0.20 M KMnO$_4$ solution?

(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

GO ON TO THE NEXT PAGE

$$H-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-Br$$
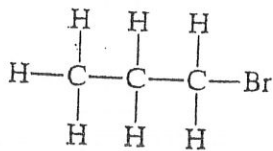
62. Which of the following structural formulas represents an isomer of the compound that has the structural formula represented above?

(A) $Br-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-H$

(B) $H-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-\underset{\underset{Br}{|}}{\overset{\overset{H}{|}}{C}}-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-H$

(C) $H-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-\underset{\underset{Br}{|}}{\overset{\overset{H}{|}}{C}}-H$

(D) $Br-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-Br$

(E) $H-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-\underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}}-Br$
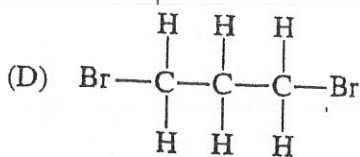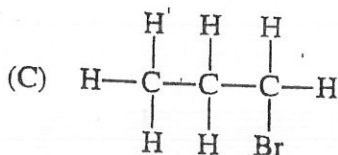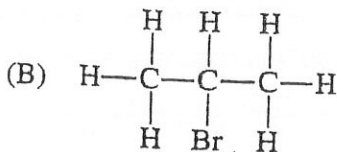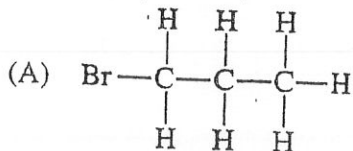
63. Mixtures that would be considered buffers include which of the following?

    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 lowest 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 at 0°C and 1 atm?

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

GO ON TO THE NEXT PAGE

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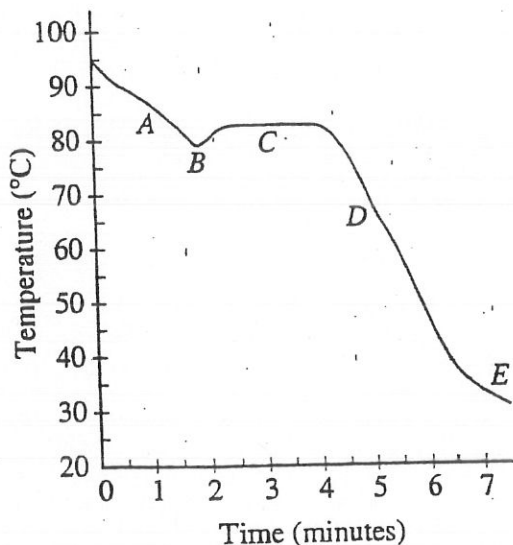
68. Liquid naphthalene at 95°C was cooled to 30°C, as represented in the cooling curve above. From which section of the curve can the melting point of naphthalene be determined?

    (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)   2.94 g
    (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) $CO_3^{2-}(aq)$

GO ON TO THE NEXT PAGE

$$X(s) \rightleftarrows X(l)$$
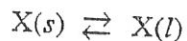
73. Which of the following is true for any substance undergoing the process represented above at its normal melting point?

   (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 25°C, the value of $[OH^-]$ is $2.0 \times 10^{-6}\ M$. What is value of the solubility-product constant, K_{sp}, f $Zn(OH)_2$ at 25°C ?

   (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}

END OF SECTION I

Chapter III — Answers to the 2002 AP Chemistry Exam

- Section I: Multiple Choice
  - Section I Answer Key and Percent Answering Correctly
  - Analyzing Your Students' Performance on the Multiple-Choice Section
  - Diagnostic Guide for the 2002 AP Chemistry Exam
- Section II: Free Response
  - Comments from the Chief Reader

- Scoring Guidelines, Sample Student Responses, and Commentary
  - Question 1
  - Question 2
  - Question 3
  - Question 4
  - Question 5
  - Question 6
  - Question 7
  - Question 8

Section I: Multiple Choice

Listed below are the correct answers to the multiple-choice questions, the percent of AP students who answered each question correctly by AP grade, and the total percent answering correctly.

Section I Answer Key and Percent Answering Correctly

Item No.	Correct Answer	Percent Correct by Grade 5	4	3	2	1	Total Percent Correct	Item No.	Correct Answer	Percent Correct by Grade 5	4	3	2	1	Total Percent Correct
1	A	80	71	65	59	46	63	39	B	94	87	76	66	53	73
2	C	95	87	77	64	39	70	40	D	69	47	25	12	8	29
3	D	91	85	79	72	52	74	41	C	85	63	42	25	16	43
4	B	85	70	57	45	29	54	42	B	62	35	20	11	5	24
5	E	90	82	77	72	61	75	43	D	78	63	51	40	26	49
6	C	81	67	56	46	35	55	44	E	92	85	76	65	42	70
7	D	84	71	62	53	43	61	45	A	88	67	44	24	15	44
8	D	81	59	40	26	15	41	46	B	85	74	65	56	38	62
9	B	88	80	73	67	55	71	47	C	69	52	39	29	17	39
10	A	91	79	63	49	23	59	48	B	85	66	48	35	23	48
11	D	99	98	92	82	49	82	49	D	64	39	27	21	16	31
12	E	69	42	25	16	11	30	50	C	38	22	14	8	6	16
13	C	94	84	73	59	40	67	51	B	88	72	54	34	14	49
14	B	97	91	82	68	44	74	52	B	93	88	79	66	39	71
15	B	90	74	56	42	32	56	53	D	94	83	67	50	30	62
16	A	89	75	60	47	32	58	54	D	79	60	43	29	18	43
17	A	97	91	80	64	35	70	55	A	74	63	57	51	38	55
18	D	97	92	79	61	31	69	56	A	93	81	66	51	32	62
19	E	97	91	81	65	38	72	57	D	92	77	58	37	15	52
20	E	94	85	74	60	36	67	58	A	87	72	52	31	12	47
21	B	85	67	51	36	19	48	59	B	70	53	40	30	20	40
22	C	85	73	61	48	32	57	60	A	93	81	60	35	15	53
23	D	63	49	38	29	18	37	61	C	62	29	13	7	11	22
24	C	98	95	88	79	55	82	62	B	57	38	27	18	12	28
25	A	92	83	73	60	36	66	63	B	65	37	20	10	8	25
26	B	89	77	63	44	25	56	64	E	88	61	34	17	9	38
27	A	83	63	47	32	16	45	65	C	81	60	43	33	22	45
28	E	93	84	74	61	34	68	66	C	82	61	40	24	17	41
29	C	86	68	54	39	24	51	67	B	88	70	52	40	26	52
30	C	94	87	80	69	42	72	68	C	89	73	59	46	34	57
31	A	92	78	60	43	23	56	69	A	86	70	47	29	15	46
32	B	89	79	71	64	52	69	70	C	58	38	26	18	15	29
33	D	94	86	76	63	43	70	71	B	43	14	6	5	8	13
34	A	75	50	32	19	10	34	72	D	75	48	30	21	18	35
35	A	91	74	53	39	25	53	73	E	65	43	31	23	20	34
36	B	51	35	26	21	17	28	74	B	67	35	21	15	12	27
37	A	85	65	44	29	20	45	75	A	64	30	13	7	7	21

(handwritten margin note: 38 = D)