Free-Response Questions

26. The following observations, A-D, are made about reactions of sodium hydroxide, NaOH. Discuss the chemical processes involved in each case. Use principles from acid-base theory, oxidation-reduction and bonding and/or intermolecular forces to support your answers.

    (A) When a few drops of 3 *M* NaOH solution are added to 10 mL of 0.50 *M* aluminum chloride, $AlCl_3$, a white precipitate forms. When excess NaOH solution is added to the mixture containing the precipitate, the precipitate dissolves.

    (B) When pellets of NaOH are added to water, there is substantial increase in the temperature of the system as the pellets dissolve.

    (C) When 15 mL of 1 *M* sodium hydroxide, NaOH, is added to 10 mL of 1 *M* hydrochloric acid, HCl, the resulting mixture has pH greater than 7. When 15 mL of 1 *M* NaOH is added to 10 mL of 1 *M* phosphoric acid, H_3PO_4, the resulting mixture has pH less than 7.

    (D) When a solution of 0.10 *M* NaOH is exposed to the atmosphere for several days, both its volume and its pH decrease.

27. A student is given samples of five separate solutions, each containing equal molarities of one of these salts:

    $AgNO_3$
    NaCl
    Na_2S
    $KMnO_4$
    $CuSO_4$

    The samples are unmarked. The student is assigned to identify each solution. No external devices or additional materials are allowed. Using observations of the individual solutions and by mixing them in pairs, describe a strategy that permits identification of each solution. Tasting is not permitted.

28. Explain each observation in terms of chemical reactions.

    (A) Solid $Zn(OH)_2$ will dissolve in concentrated HCl or in concentrated NaOH.

    (B) Bubbles and heat are generated when sodium metal is added to water at room temperature but neither is observed when aluminum is added to room temperature water.

    (C) A dilute solution of $Cu(NO_3)_2$ is a light blue color but addition of a solution of ammonia causes a dark blue solution.

    (D) A sample of solid $CuSO_4 \cdot 5H_2O$ is blue initially but turns white after being heated in a crucible for five minutes over a Bunsen burner.

SAMPLE EXAMINATION I

Section I – Multiple Choice

Questions 1–5: The set of lettered choices is a list of the oxides of five different elements. The numbered statements immediately following refer to that list. Select the one lettered choice from the list that best fits each statement. A choice may be used once, more than once, or not at all.

(A) Na_2O
(B) MgO
(C) Al_2O_3
(D) SO_2
(E) Cl_2O

Identify the oxide

1. of the element that exhibits the highest oxidation number
2. that is most soluble in water, forming a strong base
3. that is most closely associated with acid rain
4. that dissolves in water to form a weak molecular monoprotic acid
5. whose Lewis structure indicates the existence of resonance structures

---

Questions 6–10: Each question below refers to a mixture prepared by adding 100 mL of 0.10 *M* $AgNO_3$ to a 500 mL beaker containing 100 mL of 0.10 *M* Na_2CrO_4. A precipitate forms in this mixture.

6. Which describes the contents of the beaker before and after the mixture is prepared?

	before	**after**
(A)	colorless solution	red precipitate
(B)	yellow solution	red precipitate
(C)	yellow solution	yellow precipitate
(D)	colorless solution	yellow precipitate
(E)	colorless solution	white precipitate

7. What is the formula of the precipitate?
   (A) Ag_2O
   (B) Cr_2O_3
   (C) $NaNO_3$
   (D) Ag_2CrO_4
   (E) $NaNO_3$

8. What is $[Na^+]$ in the liquid phase of the mixture?
   (A) 0.040 *M*
   (B) 0.050 *M*
   (C) 0.060 *M*
   (D) 0.10 *M*
   (E) 0.20 *M*

9. What is the number of moles of Ag^+ in the precipitate?
   (A) 0.010
   (B) 0.0050
   (C) 0.0025
   (D) 0.0010
   (E) 0.00050

10. Which series lists the three ions, chromate, sodium and nitrate, in order of increasing concentration in the solution after the precipitation reaction has occurred?
   (A) CrO_4^{2-} Na^+ NO_3^-
   (B) CrO_4^{2-} NO_3^- Na^+
   (C) NO_3^- Na^+ CrO_4^{2-}
   (D) Na^+ CrO_4^{2-} NO_3^-
   (E) Na^+ NO_3^- CrO_4^{2-}

---

11. Adding some substances to water causes large amounts of energy to be liberated. All of the following substances illustrate that behavior EXCEPT
   (A) pellets of KOH
   (B) concentrated H_2SO_4
   (C) metallic Na
   (D) crystals of NH_4NO_3
   (E) anhydrous $CuSO_4$

12. Which is the correct comparison of the Cl^0 atom to the Cl^- ion?

I. The radius of the Cl^0 atom is greater than the radius of the Cl^- ion.

II. The mass of the Cl^0 atom is about 1 amu greater than the mass of the Cl^- ion.

III. The Cl^0 atom contains fewer electrons than the Cl^- ion.

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

13. What is the number of shared pairs of electrons in a molecule of propyne, C_3H_4?

(A) three
(B) four
(C) six
(D) seven
(E) eight

14. In which series are the elements listed in order of increasing atomic radius?

(A) $_{35}Br$, $_{17}Cl$, $_{9}F$
(B) $_{11}Na$, $_{19}K$, $_{37}Rb$
(C) $_{36}Kr$, $_{18}Ar$, $_{10}Ne$
(D) $_{11}Na$, $_{12}Mg$, $_{13}Al$
(E) $_{34}Se$, $_{16}S$, $_{8}O$

15. What is the number of occupied orbitals in the third principal energy level of a manganese atom in the ground state?

(A) three
(B) four
(C) five
(D) eight
(E) nine

16. The electron configuration of an atom of element X is $1s^2 2s^2 2p^5$. Which is the best electron dot diagram for an atom of this element?

(A) 

(B) 

(C) 

(D) 

(E) 

17. The term "weighted average atomic mass" refers to a calculated atomic mass that takes into account

(A) ionization energy
(B) number of positive valences
(C) charge on the monatomic ion
(D) mass defect in the nucleus
(E) naturally-occurring distribution of isotopes

18. Which set of quantum numbers matches the spectographic notation, $3d^4$?

(A) 3, 3, 4, $-\frac{1}{2}$
(B) 3, 2, 3, $-\frac{1}{2}$
(C) 3, 2, 1, $+\frac{1}{2}$
(D) 4, 3, 0, $-\frac{1}{2}$
(E) 4, 3, 1, $+\frac{1}{2}$

19. What is the number of possible isomers of the complex ion, $[Co(H_2O)_4(NH_3)_2]^{2+}$?

(A) two
(B) three
(C) four
(D) six
(E) eight

20. Which classifies all the bonds in a molecule of methyl methanoate, $HCOOCH_3$?

(A) 3 *sigma* bonds and 1 *pi* bond

(B) 4 *sigma* bonds and 2 *pi* bonds

(C) 5 *sigma* bonds and 2 *pi* bonds

(D) 6 *sigma* bonds and 1 *pi* bond

(E) 7 *sigma* bonds and 1 *pi* bond

21. Which of the following is closest to the measurement of the O–C–O bond angle in methyl methanoate, $HCOOCH_3$?

(A) 60°

(B) 90°

(C) 109°

(D) 120°

(E) 180°

22. Which is the most likely formula for hydrogen arsenide?

(A) HAs

(B) HAs_2

(C) H_2As

(D) H_3As_2

(E) H_3As

23. The symbols, ${}^1_1H$, ${}^2_1H$ and ${}^3_1H$, represent three different

(A) homologs

(B) isotopes

(C) isomers

(D) allotropes

(E) conformations

24. Which element has the greatest difference between its first and second ionization energies?

(A) bromine

(B) calcium

(C) germanium

(D) potassium

(E) scandium

25. In the methyl ethanoate molecule, CH_3COOCH_3, for which other bond angle is its measurement closest to the measurement of its O–C–O bond angle?

(A) H–C–O
(B) C–C–O
(C) H–C–H
(D) H–C–C
(E) C–O–C

26. All of the following apply to bonding in the PF_5 molecule EXCEPT

(A) d^2sp^3 hybridization
(B) F–P–F bond angles of 90°
(C) F–P–F bond angles of 120°
(D) expanded octet of electrons
(E) trigonal bipyramidal geometry

27. Which pair of formulas is most closely associated with the Law of Multiple Proportions?

(A) CuCl and $CuCl_2$

(B) C_2H_2 and C_2H_6

(C) $CuBr_2$ and CuI_2

(D) $C_2H_5OC_2H_5$ and C_4H_9OH

(E) CH_2Br_2 and $CHBr_3$

28. Which term completes this unbalanced nuclear equation?

$$^{238}_{94}\text{Pu} + 2\ ^{1}_{0}\text{n} \rightarrow \ \_?\_ \ + \ ^{0}_{-1}\text{e}$$

(A) $^{237}_{93}\text{Np}$

(B) $^{239}_{93}\text{Np}$

(C) $^{239}_{95}\text{Am}$

(D) $^{240}_{93}\text{Np}$

(E) $^{240}_{95}\text{Am}$

29. What is the best description of the species found at the lattice points of the mineral calcite, $CaCO_3$?

(A) $CaCO_3$ molecules

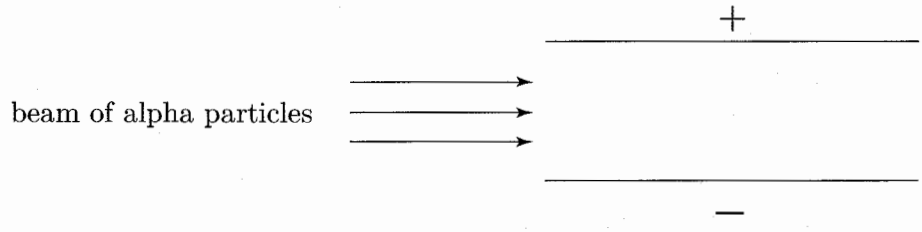
(B) Ca^{2+} ions and CO_3^{2-} ions

(C) Ca atoms, C atoms and O atoms

(D) Ca^{2+} ions, C^{4+} ions and O^{2-} ions

(E) CaO molecules and CO_2 molecules

30.



Which describes the behavior of a beam of alpha particles as it passes through the electric field between two charged plates as shown above?

(A) The beam passes through unchanged.

(B) The beam is destroyed by the electric field.

(C) The beam is deflected back toward its origin.

(D) The beam is deflected toward the negative plate.

(E) The beam is deflected toward the positive plate.

31. Which property is the same for any two samples of $SO_{2(g)}$ and $SO_{3(g)}$ at the same temperature?

(A) critical temperature

(B) number of molecules

(C) average kinetic energy

(D) pressure-volume product

(E) average molecular velocity

32. The molar mass of an unidentified gas is 68 g. Assuming ideal behavior, its density in grams per liter at STP is closest to

(A) 1.0

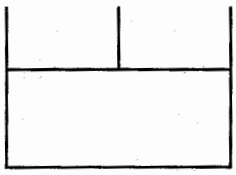
(B) 1.5

(C) 2.0

(D) 2.5

(E) 3.0

33. Consider a sample of gas confined at constant temperature and pressure in the piston system shown below. If more of this same gas is added to the piston at constant temperature, what effect is observed on volume and average molecular velocity?



Piston

(A) Both volume and average molecular velocity increase.

(B) Both volume and average molecular velocity remain the same.

(C) Volume remains the same and average molecular velocity increases.

(D) Volume remains the same and average molecular velocity decreases.

(E) Volume increases and average molecular velocity remains the same.

34. Consider the three sealed identical flasks represented below, each containing 0.100 mole of the gas specified at 1 atm and 273 K.

A — 0.100 mol Ar

B — 0.100 mol Kr

C — 0.100 mol Ne

Which is a correct comparison of the contents of the flasks?

I. The mass of the contents of flask B is the greatest.

II. The number of molecules in each flask is the same.

III. The density of the contents of each flask is the same.

(A) I only

(B) II only

(C) I and II only

(D) II and III only

(E) I, II, and III

35. A system is prepared by sealing a flask half-filled with 1.0 m solution of NaCl. The system is kept at constant temperature. Which description applies to the processes of condensation and evaporation of water in that system?

(A) Both evaporation and condensation occur continuously.

(B) Since the flask is sealed, neither evaporation nor condensation occurs.

(C) Only evaporation occurs, which stops when equilibrium is achieved.

(D) Only condensation occurs, which stops when equilibrium is achieved.

(E) Both evaporation and condensation occur, stopping when the air above the solution is saturated with $H_2O_{(g)}$.

36. The van der Waals equation of state for real gases is

$$\left(\mathrm{P} + \frac{n^2\mathrm{a}}{\mathrm{V}^2}\right)(\mathrm{V} - n\mathrm{b}) = n\mathrm{RT}$$

where the values for the a and b coefficients have been determined experimentally. Which property of the molecules in a sample is most closely related to the value of the a coefficient?

(A) the mass of the molecules

(B) the volume of the molecules

(C) number of molecules in the sample

(D) forces of attraction between molecules

(E) the root mean velocity of the molecules

37. Which applies to a dilute solution of sodium chloride in water?

I. Adding sodium chloride lowers the freezing point.

II. Adding sodium chloride decreases the vapor pressure of the solution.

III. Adding sodium chloride decreases the density of the solution.

(A) II only

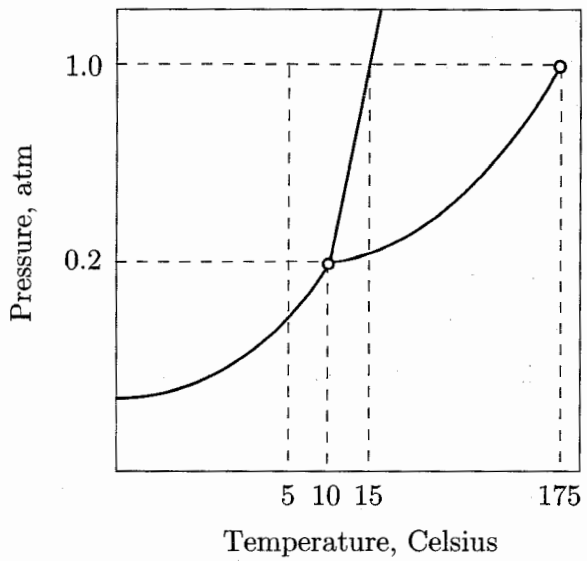
(B) III only

(C) I and II only

(D) I and III only

(E) I, II, and III

Questions 38 and 39: The phase diagram below represents a hypothetical substance.



38. Which temperature range includes the boiling point of the substance at an elevation 5,000 feet above sea level?

(A) greater than 175°C
(B) 100° to 175°C
(C) 15°C to 100°C
(D) −5° to 15°C
(E) less than −15°C

39. Which gives correct information about the substance as represented in the phase diagram?

I. The vapor pressure of the liquid phase at 15°C is less than 0.5 atm.
II. At any pressure less than 0.2 atm, the solid undergoes sublimation.
III. The density of the solid phase is greater than the density of the liquid phase.

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

40. All of the following are colligative properties of a solution EXCEPT

(A) boiling point elevation

(B) freezing point depression

(C) molar conductance

(D) osmotic pressure

(E) vapor pressure

41. Consider the list of nitrogen-containing species below.

$$N^{3-},\ NH^{2-},\ NH_2{}^-,\ NO_3{}^-,\ NO_2{}^-,\ NH_3,\ NH_4{}^+$$

Which answer includes all of the species from the list above that cannot behave as Lewis bases?

(A) N^{3-} only

(B) $NH_4{}^+$ only

(C) NH_3 only

(D) $NO_3{}^-$ and $NO_2{}^-$ only

(E) N^{3-}, NH^{2-} and $NH_2{}^-$ only

42. Which observations support the claim that $Al(OH)_3$ behaves as an amphoteric substance?

I. The solid present in a suspension of $Al(OH)_3$ dissolves upon the addition of $HCl_{(aq)}$.

II. The solid present in a suspension of $Al(OH)_3$ dissolves upon the addition of $NaOH_{(aq)}$.

III. No change is observed when NaCl is added to a suspension of $Al(OH)_3$.

(A) I only

(B) I and II only

(C) I and III only

(D) II and III only

(E) I, II, and III

43. A quantity of liquid solution, specified as 20 mL, is to be added to a reaction mixture. Which vessel provides the most precise measurement of the volume of that liquid?

(A) 25 mL volumetric flask

(B) 25 mL graduated cylinder

(C) 25 mL volumetric pipette

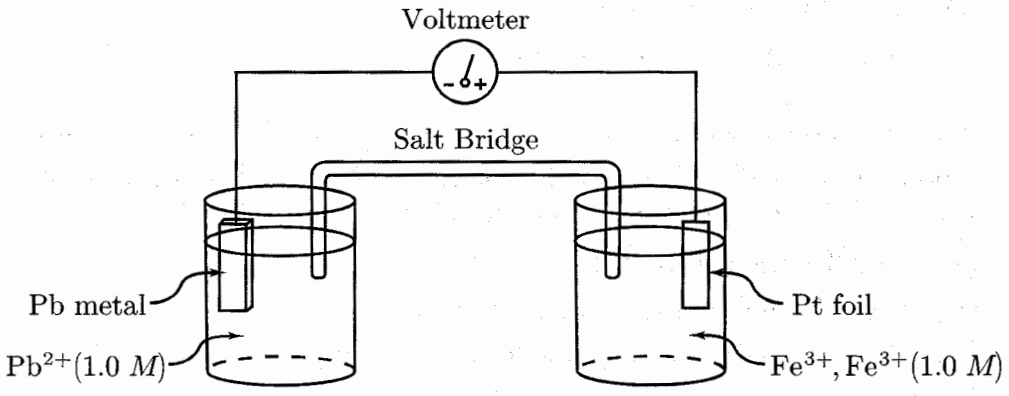
(D) 50 mL buret

(E) 50 mL Erlenmeyer flask

Questions 44-47: Consider the electrochemical cell represented below using the following reduction half-reactions and their E° values:

$$Fe^{3+} + e^- \rightarrow Fe^{2+} \qquad E° = 0.77 \text{ volts}$$

$$Pb^{2+} + 2e^- \rightarrow Pb^0 \qquad E° = -0.13 \text{ volts}$$



44. Which describes change in concentration of Pb^{2+} and the movement of charge in this electrochemical cell as the cell undergoes discharge?

	movement of electrons in the external circuit	**movement of positive ions in the salt bridge**	**change in $[Pb^{2+}]$**
(A)	toward the cathode	toward the cathode	increases
(B)	toward the anode	toward the anode	increases
(C)	toward the cathode	toward the anode	decreases
(D)	toward the anode	toward the cathode	decreases
(E)	toward the cathode	toward the anode	increases

45. Which expression gives the change in mass expected at the lead electrode after this cell has produced 150 milli-amps for 2.0 hours?

(A) $\dfrac{3{,}600 \times 207}{0.150 \times 96{,}500}$

(B) $\dfrac{0.150 \times 3{,}600 \times 207}{2 \times 96{,}500}$

(C) $\dfrac{2 \times 0.150 \times 207}{96{,}500}$

(D) $\dfrac{3{,}600 \times 0.150 \times 207}{96{,}500}$

(E) $\dfrac{2 \times 0.150 \times 3{,}600 \times 207}{96{,}500}$

46. Which expression gives the voltage for this standard chemical cell?

(A) $0.13 + 0.77$ volts

(B) $-0.13 + 0.77$ volts

(C) $0.13 + (2 \times 0.77)$ volts

(D) $(2 \times 0.13) + (2 \times 0.77)$ volts

(E) $\big(2 \times (-0.13)\big) + (2 \times 0.77)$ volts

47. A similar electrochemical cell is assembled using standard electrodes except that the concentration of Pb^{2+} is changed to 0.010 M. Which is the best comparison of the voltage of the original standard cell to this non-standard cell?

(A) No difference is expected.

(B) The voltage increases by about 0.06 volts.

(C) The voltage decreases by about 0.06 volts.

(D) The voltage increases by about 0.12 volts.

(E) The voltage decreases by about 0.12 volts.

---

48. How many moles of methanol should be added to 6.0 moles of water to produce a solution that is 0.75 mole fraction in methanol?

(A) 2.0

(B) 8.0

(C) 12

(D) 15

(E) 18

49. Which is the best description of the change that occurs when $Na_2O_{(s)}$ is dissolved in water?

(A) The oxide ion accepts a share in a pair of electrons.

(B) The oxide ion donates a share in a pair of electrons.

(C) The oxidation number of oxygen increases.

(D) The oxidation number of sodium increases.

(E) The oxidation number of sodium decreases.

50. Which species is present at the lowest concentration in a 0.10 M solution of $KHSO_4$?

(A) K^+

(B) HSO_4^-

(C) SO_4^{2-}

(D) H_3O^+

(E) H_2SO_4

51. Compared to the value of ΔH_f° for $H_2O_{(s)}$, the value of ΔH_f° for $H_2O_{(\ell)}$ has the

(A) opposite sign and the same absolute value

(B) same sign and smaller absolute value

(C) same sign and greater absolute value

(D) opposite sign and greater absolute value

(E) opposite sign and smaller absolute value

52. In an ordinary alkaline flashlight cell, zinc metal is oxidized to Zn^{2+} as an electromotive force (E°) of 1.5 volts is produced. The value for ΔG° in kilojoules per mole of Zn oxidized in this cell is closest to

(A) 300

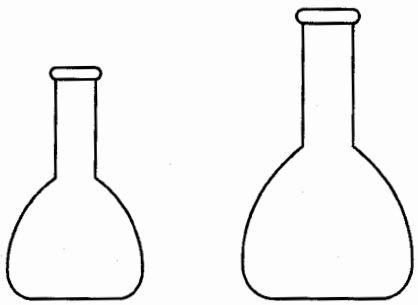
(B) 150

(C) 0

(D) −150

(E) −300

53. Consider two sealed flasks with different volumes each containing 0.10 mol of gas at the same temperature as shown below.



0.10 mol Ne 0.10 mol Ar

Which is a correct comparison of the contents of these flasks?

I. The mass of the contents of each flask is the same.
II. The number of molecules in each flask is the same.
III. The average molecular velocity of the molecules in each flask is the same.

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

54. Which of the following oxides of nitrogen has the greatest percent oxygen by mass?

(A) NO
(B) NO_2
(C) N_2O
(D) N_2O_4
(E) N_2O_5

55. $$2Na_2O_2 + 2H_2O \rightarrow 4NaOH + O_2$$

Which expression gives the mass of O_2 produced when 15.0 g Na_2O_2 (molar mass: 78 g) reacts with water, according to the equation above?

(A) $15.0 \times \frac{78}{1} \times \frac{1}{2} \times \frac{32}{1}$
(B) $15.0 \times \frac{1}{78} \times \frac{1}{2} \times \frac{32}{1}$
(C) $15.0 \times \frac{1}{78} \times \frac{1}{2} \times \frac{1}{32}$
(D) $15.0 \times \frac{1}{78} \times \frac{2}{1} \times \frac{1}{32}$
(E) $15.0 \times \frac{78}{1} \times \frac{1}{2} \times \frac{32}{1}$

Questions 56 and 57: Nitrous acid ionizes according to the equation below:

$$HNO_{2(aq)} \rightleftharpoons H^{+}{}_{(aq)} + NO_2{}^{-}{}_{(aq)} \qquad K_a = 7.2 \times 10^{-4}$$

56. Which occurs as more water is added to an equilibrium system of nitrous acid at constant temperature?

	total number of cations and anions	**percent ionization of HNO_2 molecules**
(A)	decreases	increases
(B)	decreases	decreases
(C)	decreases	remains the same
(D)	increases	increases
(E)	increases	remains the same

57. Which occurs when equal volumes of 1.0 M $NaNO_2$ and 1.0 M HNO_2 are mixed together in a suitable container?

	$[HNO_2]$	**total number of ions in solution**	**percent ionization of HNO_2 molecules**
(A)	decreases	increases	decreases
(B)	remains the same	increases	remains the same
(C)	decreases	increases	remains the same
(D)	remains the same	decreases	decreases
(E)	remains the same	decreases	increases

---

58. Given $K_a = 1.8 \times 10^{-5}$ and $[H^+] = 4.2 \times 10^{-3}$ for 1.0 M CH_3COOH at 298 K. As temperature increases, the percent ionization increases. Which describes the corresponding effects on pK_a and pH?

	pK_a	**pH**
(A)	remains the same	increases
(B)	remains the same	decreases
(C)	increases	increases
(D)	decreases	decreases
(E)	decreases	increases

59. The K_{sp} for AgI at 25°C is 8.3×10^{-17}. Which expression is closest to the molar solubility of AgI?

(A) 9×10^{-8}

(B) 9×10^{-9}

(C) $\frac{8.3}{235} \times 10^{-9}$

(D) $\frac{235}{8.3} \times 10^{-8}$

(E) $8.3 \times 235 \times 10^{-8}$

60. $BaSO_4 \rightleftharpoons Ba^{2+} + SO_4{}^{2-}$ $\qquad K_{sp} = 1 \times 10^{-10}$

Which range includes the minimum number of moles of $BaCl_2$ that must be added to 1.0 liter of a saturated solution of $BaSO_4$ to change $[SO_4{}^{2-}]$ to 5×10^{-10} M?

(A) less than 0.1×10^{-10}

(B) from 1×10^{-10} to 6×10^{-10}

(C) from 6×10^{-10} to 6×10^{-6}

(D) from 6×10^{-6} to 6×10^{-3}

(E) more than 6×10^{-3}

61. Which of the following has the least effect on the rate of a reaction in the gas phase?

(A) adding a solid surface catalyst

(B) adding inert gas at constant volume

(C) decreasing the volume of the reaction system

(D) increasing the temperature of the reaction system

(E) decreasing the concentration of one of the reactants

62. In any first order reaction, as the reaction proceeds at constant temperature, which describes the corresponding effects on k (the rate constant) and *rate*?

	k	***rate***
(A)	remains the same	decreases
(B)	remains the same	remains the same
(C)	remains the same	increases
(D)	decreases	decreases
(E)	decreases	remains the same

Questions 63 and 64: The steps below represent a mechanism proposed for the reaction of nitrogen(II) oxide with hydrogen.

$$NO_{(g)} + NO_{(g)} \rightleftharpoons N_2O_{2(g)} \qquad \text{fast equilibrium}$$

$$N_2O_{2(g)} + H_{2(g)} \rightleftharpoons N_2O_{(g)} + H_2O_{(g)} \qquad \text{slow}$$

$$N_2O_{(g)} + H_{2(g)} \rightleftharpoons N_{2(g)} + H_2O_{(g)} \qquad \text{fast}$$

63. Which rate law is consistent with this mechanism?

(A) rate $= k[NO]^2$

(B) rate $= k[NO]^2[H_2]$

(C) rate $= k[N_2O][H_2]$

(D) rate $= k[N_2O_2][H_2]$

(E) rate $= k[N_2O_2][H_2][NO]^2$

64. Which is the equation for the overall reaction?

(A) $NO_{(g)} + NO_{(g)} \rightarrow N_{2(g)} + H_2O_{(g)}$

(B) $2NO_{(g)} + 2H_{2(g)} \rightarrow N_{2(g)} + 2H_2O_{(g)}$

(C) $NO_{(g)} + N_2O_{(g)} + H_{2(g)} \rightarrow N_{2(g)} + H_2O_{(g)}$

(D) $2NO_{(g)} + 2H_{2(g)} + N_2O_{2(g)} \rightarrow N_2O_{(g)} + N_{2(g)} + 2H_2O_{(g)}$

(E) $NO_{(g)} + 2H_{2(g)} + N_2O_{2(g)} + N_2O_{(g)} \rightarrow N_2O_{(g)} + N_2O_{2(g)} + N_{2(g)} + 2H_2O_{(g)}$

---

65. Which characteristic of a closed reaction system is most affected by the presence of a catalyst?

(A) free energy change

(B) enthalpy of reaction

(C) standard entropy of formation

(D) time required to reach equilibrium

(E) percent conversion to products at equilibrium

66. Which describes the direction of changes in enthalpy and entropy for an endothermic dissolving process of an ionic solute in water at constant temperature?

(A) Enthalpy increases and entropy decreases.

(B) Enthalpy decreases and entropy increases.

(C) Both enthalpy and entropy decrease.

(D) Both enthalpy and entropy increase.

(E) Enthalpy decreases and entropy remains the same.

67. Which of the following is most closely associated with relatively slow rates of chemical reaction?

(A) low enthalpy of reaction

(B) low energy of activation

(C) the presence of a catalyst

(D) high concentration of reactants

(E) strong bonds in reaction molecules

68. Which applies to any changes in entropy and enthalpy associated with the vaporization of any liquid at any temperature?

(A) Both entropy and enthalpy increase.

(B) Entropy increases and enthalpy decreases.

(C) Entropy remains the same and enthalpy increases.

(D) Entropy remains the same and enthalpy decreases.

(E) Entropy increases and enthalpy remains the same.

69. Consider the reaction system for the endothermic decomposition below at equilibrium in a 2.0 liter sealed rigid flask at 298 K.

$$PH_3PCl_{3(s)} \rightleftharpoons PH_{3(g)} + PCl_{3(g)} \qquad K_{eq} = 3.5 \times 10^{-2}$$

When the vessel containing the system is immersed in an ice bath, all of the following occur EXCEPT

(A) The total pressure decreases.

(B) The volume of $PH_{3(g)}$ decreases.

(C) The total number of all molecules decreases.

(D) The partial pressure of $PCl_{3(g)}$ decreases.

(E) The number of molecules of $PH_3PCl_{3(s)}$ increases.

70. Which process is accompanied by a decrease in entropy?

(A) melting of a metallic solid

(B) dissolving of an ionic solid

(C) evaporation of a molecular liquid

(D) increase in volume of a confined sample of gas

(E) formation of a crystalline solid from a supersaturated solution

71. In an experiment to determine the concentration of a solution of hydrochloric acid, a worker placed precisely 25.0 mL of the unknown acid solution in a beaker that contained about 50 mL of water and 4 drops of phenolphthalein solution. The worker then filled a 50 mL buret to the zero mark with 0.300 M NaOH solution and began titration immediately. Which describes a mistake in this procedure?

I. Because phenolphthalein does not change color until $[H^+]$ is about 10^{-9}, this substance is not a suitable indicator for this experiment.

II. Because the worker added the unknown acid solution to an unmeasured quantity of water, the concentration of the unknown acid solution cannot be determined.

III. Because the worker did not fill the tip of the buret before beginning the titration, an accurate measurement of the volume of base used cannot be obtained.

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

72. Which compound of potassium is a colored solid?

(A) $KBrO_3$
(B) $KAl(SO_4)_2$
(C) K_2PtCl_6
(D) K_2SeO_3
(E) $K_2Si_2O_5$

73. Which is the best description of the concentration of ions in solution when 0.050 mol $OH^-_{(aq)}$ is added to 1.0 liter of 0.10 M solution of NaH_2PO_4? (Assume no change in volume.)

	$[H_2PO_4^-]$	$[HPO_4^{2-}]$	$[PO_4^{3-}]$
(A)	negligibly small	0.050	negligibly small
(B)	negligibly small	negligibly small	0.050
(C)	0.050	0.050	negligibly small
(D)	0.050	negligibly small	0.050
(E)	0.075	negligibly small	0.025

74. The essential elements in every amino acid include each of the following EXCEPT

(A) carbon
(B) oxygen
(C) nitrogen
(D) hydrogen
(E) phosphorus

75. When 10 mL of 3.0 M $NH_{3(aq)}$ is added to 100 mL of a colorless solution, the change in pH is observed to be less than 0.10 of a pH unit. The colorless solution could have been.

I. 3 M HCl
II. 3 M NaOH
III. 3 M NaCl

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

Section II

Section II - Free Response Total Time – 90 Minutes
(Multiple-Choice Questions are found in Section I.)

Part A: Question 76
and
Question 77 or Question 78
Time: 40 minutes

Access to calculators, Periodic Table, lists of standard reduction potentials, and *Equations and Constants*

(2004 Examination directions) Clearly show the method used and the steps involved in arriving at your answers. It is to your advantage to do this, because 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 76 below. The Section II score weighting for this question is 20 percent.

76. Methylamine, CH_3NH_2, is an organic base, accepting a proton from water to form the methylammonium ion. The value of K_{eq} for this system is 4.0×10^{-4} at 298 K.

(a) Write the chemical equation for the equilibrium as described above.

(b) Calculate the concentration of hydroxide ions in a 0.25 M solution of methylamine.

(c) How is the equilibrium affected when solid NaOH is added to a solution of methylamine? Calculate the $[CH_3NH_3^+]$ when 0.020 mol OH^- is added to 500. mL of 0.25 M methylamine, CH_3NH_2. (Assume no change in volume.)

(d) A buffer solution is prepared that is 0.20 M in $CH_3NH_3^+$ and 0.25 M in CH_3NH_2. Calculate the pH of this solution.

(e) Calculate the number of moles of H^+ that must be added to 200. mL of the solution in part (d) in order to change the pH to 10.00.

Answer either question 77 or question 78 below.

(2004 examination directions) 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 that you choose is 20 percent.

77. Answer the following questions about a chromium/hydrogen electrochemical cell.

(a) Make a labeled sketch of an electrochemical cell using a standard Cr/Cr^{3+} half cell connected to a standard hydrogen half-cell. Your labels should include

- anode
- cathode
- chemical components and concentration(s) in the chromium half cell
- direction of electron flow in the external circuit
- path for ion migration.

Include a labeled voltmeter in the external circuit.

(b) Write the half reactions and the balanced overall equation for this cell.

(c) Calculate the voltage for this standard cell.

(d) Calculate the voltage when the concentration of Cr^{3+} is 0.050 M.

78. Answer all four questions below about the samples of gases described. Consider separate samples of H_2S gas and SO_2 gas. The mass of each sample is 10.0 g.

(a) What is the ratio of the number of sulfur atoms in the sample of $H_2S_{(g)}$ compared to the number of sulfur atoms in the sample of $SO_{2(g)}$?

(b) What is the volume occupied by the H_2S gas, when measured at 25°C and 745 mm Hg?

(c) Calculate the ratio of the average velocity of H_2S gas molecules to that of SO_2 gas molecules when both samples are measured at the same temperature.

(d) Separate sources of $H_2S_{(g)}$ and $SO_{2(g)}$ are placed in opposite ends of a 100 cm tube. When these gases meet, they react to form solid sulfur. At what distance from the SO_2 end will the gases meet and the deposit of solid sulfur first be observed?

Part B: Questions 79, 80, 81 and
Question 82 or Question 83
Time: 50 minutes

Access to Periodic Table, lists of standard reduction potentials
and *Equations and Constants*
No access to calculators

Answer question 79 below: The Section II score weighting for this question is 15 percent.

79. (2004 Examination directions) Write the formulas to show the reactants and products for 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 a 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.

(a) Excess hydrochloric acid is added to a solution of sodium hydrogen phosphate.

(b) A sample of solid lithium oxide is added to water.

(c) Hydrogen peroxide solution is added to a solution of iron(II) chloride.

(d) A solution of potassium iodide is electrolyzed.

(e) A strip of copper is immersed in dilute nitric acid.

(f) A few crystals of calcium fluoride are added to hot concentrated sulfuric acid.

(g) A sample of ethanol is ignited in excess oxygen.

(h) Solutions of ammonium thiocyanate and iron(III) chloride are mixed.

(2004 Examination directions) 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.

(2004 examination directions) **Answer both Question 80 and Question 81 below.** Both questions will be graded.

The Section II score weighting for these questions is 30 percent (15 percent each).

80. Periodic Relationships

(a) Ionization Energies

	Ionization energies, kJ mol^{-1}		
	Na	**Mg**	**Al**
First Ionization Energy	496	738	578
Second Ionization Energy	4,560	1,450	1,820
Third Ionization Energy	6,917	7,730	2,750

(i) The second ionization for each element is greater than the first ionization energy for that element. Explain.

(ii) The difference between first and second ionization energies is much greater for Na than for Mg. Explain.

(b) Atomic/Ionic Radius

	$_{16}$**S**	$_{16}$**S^{2-}**	$_{20}$**Ca**	$_{20}$**Ca^{2+}**
Atomic/ionic radius, nm	0.104	0.184	.197	0.099

(i) The radius of $_{16}S$ is less than the radius of $_{16}S^{2-}$. Explain.

(ii) The $_{16}S^{2-}$ and $_{20}Ca^{2+}$ are isoelectronic species. However, the radius of $_{16}S^{2-}$ is greater than the radius of $_{20}Ca^{2+}$. Explain.

81. Answer all four questions about the laboratory procedures below.
The questions below are related to the exothermic dissolving of $CaCl_{2(s)}$ in water.

(a) Describe the energy changes that occur as $CaCl_{2(s)}$ dissolves.

(b) Describe how to use 0.50 mol (55.5 g) of $CaCl_{2(s)}$ to make each of the aqueous solutions specified below. For each, specify the mass or volume of the solution produced and specify how the amount of liquid solvent or solution is to be measured.

(i) a quantity of 1.0 molar (1.0 M) solution
(ii) a quantity of 1.0 molal (1.0 m) solution

(c) Describe how to use solid $CaCl_2$ to determine its heat of solution in kJ mol^{-1}. A styrofoam cup is available to use as a calorimeter. A thermometer, a balance, water and ordinary lab equipment are also available. Specify the procedure and the measurements to be recorded. (Calculation or description of calculation is not required.)

(2004 examination directions) **Answer either question 82 or question 83 below.** 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 that you choose is 15 percent.

82. Answer all four questions about the burning of octane.

$$C_8H_{18(\ell)} + \frac{25}{2}O_{2(g)} \rightarrow 8CO_{2(g)} + 9H_2O_{(g)} + \text{heat}$$

The combustion reaction above is the source of the energy produced by the burning of octane in an automobile engine. This reaction is spontaneous at 298 K.

(a) Predict the sign of ΔS in the reaction. Explain.

(b) Predict the sign for ΔG for this reaction at 298 K. Explain.

(c) $\Delta H^\circ_{f,CO_{2(g)}} = -393.5 \text{ kJ mol}^{-1}$; $\Delta H^\circ_{f,CO_{(g)}} = -110.5 \text{ kJ mol}^{-1}$

If some of the reactants were converted to CO rather than CO_2, how would the total amount of energy produced be affected? Explain.

(d) If this reaction were carried out at a temperature greater than 298 K, for which of the three parameters, ΔH, ΔG or ΔS, would the change in value have the greatest magnitude? Explain.

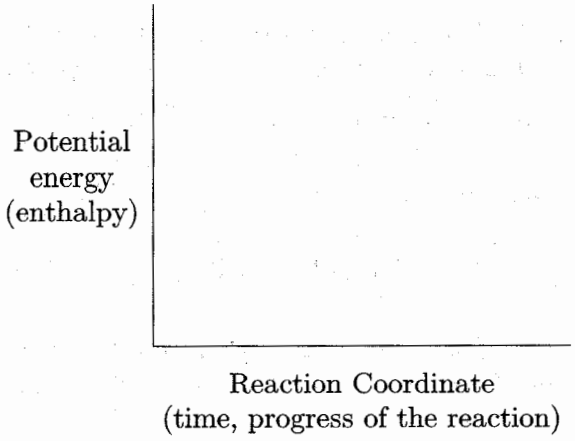
83. Answer all three questions below about this reaction:

$$A_{(g)} + B_{(g)} \rightarrow AB_{(g)} + \text{energy}$$

The rate of the reaction above is known to be first order in A and first order in B.

The rate increases when a suitable catalyst is added.

Use the axis below for the answers to part (a) and (b).



(a) On the labeled axes above, draw a diagram of potential energy versus reaction coordinate for the uncatalyzed reaction. Use a line labeled (A) to show the progress of this reaction. On the diagram, label:

(i) relative potential energy of the

- reactants
- activated complex
- product

(ii) the intervals that correspond to

- heat of reaction, ΔH
- activation energy for the forward reaction, $E_{a,f}$
- activation energy for the reverse reaction, $E_{a,r}$

(b) On the set of axes, use a line labeled (B) to show the change or changes in the values in part (a) (i), above, that result from the addition of the catalyst.

(c) At ordinary conditions, $RATE_f$ is much greater than $RATE_r$. The symbols k_f and k_r represent the rate constants for the forward and reverse reactions respectively. How does the value of the ratio $\frac{k_f}{k_r}$ change, when temperature increases? Explain.

No testing material printed on this page.

SAMPLE EXAMINATION II

Section I – Multiple Choice

Questions 1-5: The set of lettered choices below is a list of chemical elements. The list refers to the numbered statements immediately following it. Select the one lettered choice that best fits each numbered statement. A choice may be used once, more than once or not at all.

(A) silicon
(B) phosphorus
(C) nitrogen
(D) magnesium
(E) bromine

1. the element whose oxide is a molecular solid at ordinary conditions
2. the element with the lowest melting point
3. the element that is best conductor of electricity
4. the element that is a molecular solid at ordinary conditions
5. the element whose oxide is an ionic solid

Questions 6-10: The set of lettered choices below is a list of formulas for chemical compounds. The list refers to the numbered questions immediately following it. Select the one lettered choice that best answers each question. A choice may be used once, more than once or not at all.

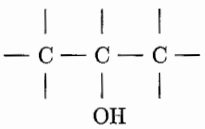
(A) $(NH_4)_2SO_4$
(B) K_2S
(C) CO_2
(D) $CaCl_2$
(E) $NaClO_4$

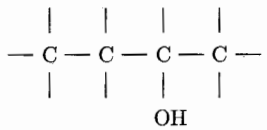
Which formula represents or includes

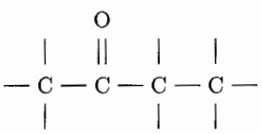
6. a cation that precipitates from aqueous solution when a solution containing carbonate anion is added
7. an atom with an oxidation number of -3
8. a molecule that contains two *sigma* (σ) and two *pi* (π) bonds
9. a species which, when heated along with a catalyst, yields a salt containing a halide in addition to oxygen gas.
10. a gas, when measured under standard conditions

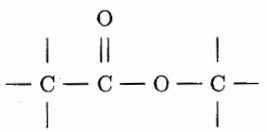
Questions 11-16: The set of lettered choices below is a list of categories of hydrocarbon derivatives. It refers to the set of numbered structural formulas immediately following. For each structural formula select the one lettered choice that identifies the category of hydrocarbon derivative illustrated. A choice may be used once, more than once, or not at all.

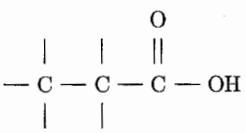
(A) secondary alcohol
(B) tertiary alcohol
(C) organic acid
(D) ketone
(E) ester

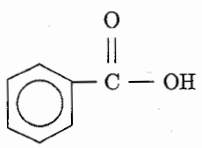
11. 

14. 

12. 

15. 

13. 

16. 

---

17. All of the following are polar molecules EXCEPT

(A) H_2S
(B) NH_3
(C) PCl_3
(D) PF_5
(E) HNO_3

18. Which distribution of electrons in hybrid orbitals is associated with the structure of the sulfur tetrafluoride, SF_4, molecule?

(A) sp
(B) sp^2
(C) sp^3
(D) dsp^3
(E) d^2sp^3

19. When each member of the following pairs of solutes is dissolved in separate containers of water, each member of the pair of solutions has a different color EXCEPT for the pair

(A) $ZnSO_4$ and $CaCl_2$

(B) $CoCl_2$ and $CrCl_3$

(C) K_2CrO_4 and $Na_2Cr_2O_7$

(D) $Ni(NO_3)_2$ and $CuBr_2$

(E) $AlCl_3$ and $KMnO_4$

20. An atom with the electron configuration $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^5$ has an occupied but incomplete

(A) $2s$ sublevel
(B) $3s$ sublevel
(C) $3p$ sublevel
(D) $3d$ sublevel
(E) $4s$ sublevel

21. The correct name for the compound $(NH_4)_2CuCl_4$ is

(A) diammine copper(IV) chloride
(B) diammine tetrachlorocopper
(C) diammonium copper chlorate
(D) ammonium tetrachlorocopper
(E) ammonium tetrachlorocuprate(II)

22. What is the charge on the anion of the compound potassium hexachloroferrate(II)?

(A) 1^-
(B) 2^-
(C) 3^-
(D) 4^-
(E) 6^-

23. Which forms cations with charge 1+ and 2+?

(A) Zn
(B) Sn
(C) Fe
(D) Sc
(E) Cu

24. In the nitrite anion, NO_2^-, the O-N-O bond angle is slightly less than 120°. Which hybridization of orbitals around the central atom, nitrogen, provides the best explanation for this bond angle.

(A) sp
(B) sp^2
(C) sp^3
(D) dsp^3
(E) d^2sp^3

Questions 25 and 26: A mixture of gases is prepared by placing 00.20 mol NO and 0.20 mol NO_2 in a 2.0 liter flask at 300 K. (Assume no chemical reaction occurs.)

25. Which range of values includes the total pressure of the system?

(A) 1.5 atm to 3.0 atm
(B) 3.0 atm to 6.0 atm
(C) 6.0 atm to 12 atm
(D) 12 atm to 24 atm
(E) 24 atm to 48 atm

26. Which comparison correctly describes this system?

I. The partial pressure of NO is the same as the partial pressure of NO_2.
II. The number of molecules of NO is the same as the number of molecules of NO_2.
III. The number of nitrogen atoms is the same as the number of oxygen atoms.

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

---

27. Carbon-14 decays by the emission of a particle to form nitrogen-14. What is the missing particle?

$$^{14}_{6}\mathrm{C} \rightarrow {}^{14}_{7}\mathrm{N} + ..?..$$

(A) alpha
(B) beta
(C) gamma
(D) positron
(E) neutron

28. According to the Kinetic Molecular Theory, all of the following apply to a mixture of gases EXCEPT

(A) All gas molecules travel at the same speed.
(B) The collisions of the gas molecules are perfectly elastic.
(C) The forces of attraction between the gas molecules are negligibly small.
(D) The gas molecules exert pressure on the wall of the container of the system.
(E) Compared to the volume of the system, the absolute volume of the gas molecules is negligibly small.

29. Consider two identical flasks under identical conditions of temperature and pressure. One is filled with carbon monoxide, CO, while the other contains nitrogen, N_2. Which of the following characteristics is the same for each sample?

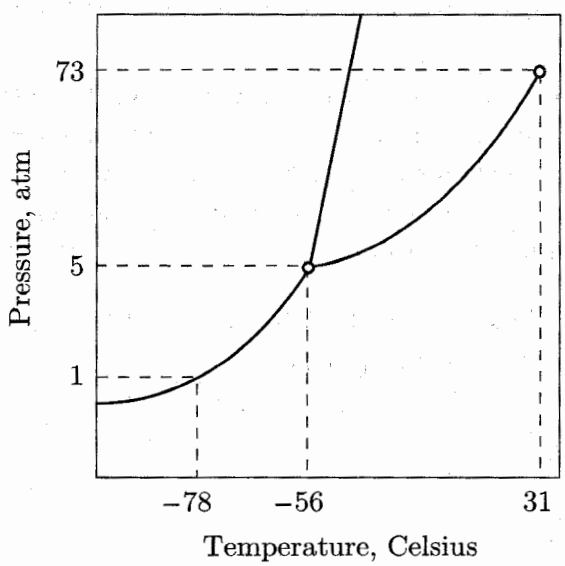
I. molar mass
II. average molecular velocity
III. average kinetic energy

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

30. Relatively high values for all the following physical properties are associated with strong intermolecular forces EXCEPT

(A) viscosity
(B) boiling point
(C) melting point
(D) vapor pressure
(E) critical temperature

Questions 31 and 32: Refer to the phase diagram for carbon dioxide given below.



One sample of CO_2 is held at 10 atm and heated from −60°C to 30°C. A second sample of CO_2 is held at 1 atm and heated over the same temperature range.

31. Which of the following describes the expected properties of these samples?

I. The melting point for the first sample is observed at a temperature between −78°C and −56°C.

II. No melting occurs in the second example.

III. The boiling point for the first sample is greater than the sublimation point for the second sample.

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

32. At 25°C and 1 atm, solid carbon dioxide does not melt but undergoes sublimation. Which information from the phase diagram supports the statement?

(A) The pressure at the triple point is greater than 1 atm.
(B) The boiling point at 1 atm is less than 25°C.
(C) The pressure at the critical point is greater than 1 atm.
(D) The temperature at the critical point is greater than 25°C.
(E) The boiling point at 73 atm is greater than the boiling point at 5 atm.

33. The radionuclide, ^{32}P, is used to trace metabolic pathways. A 1.00 gram sample of ^{32}P decays to 0.50 grams in 14.3 days. Over the period of time of its use, the half-life of the nuclide

(A) increases as rate of nuclear decay in grams per day increases.
(B) increases as rate of nuclear decay in grams per day decreases.
(C) remains unchanged as rate of nuclear decay in grams per day increases.
(D) remains unchanged as rate of nuclear decay in grams per day decreases.
(E) decreases as rate of nuclear decay in grams per day remains unchanged.

34. Which expression gives the density predicted for $PH_{3(g)}$ (molar mass: 34 g) at 740 mmHg and 20°C? (Assume ideal behavior.)

(A) $\dfrac{34}{22.4 \times 740 \times 293}$

(B) $\dfrac{34 \times 740 \times 293}{22.4}$

(C) $\dfrac{34 \times 740 \times 273}{22.4 \times 760 \times 293}$

(D) $\dfrac{34 \times 740 \times 293}{22.4 \times 760 \times 273}$

(E) $\dfrac{34 \times 760 \times 273}{22.4 \times 740 \times 293}$

35. When excess HCl reacts with 0.250 mole of NH_3, a total of 11.0 kJ of heat energy is released. What is the value of ΔH in kJ per mol NH_3 consumed?

(A) −44.0 kJ
(B) −11.0 kJ
(C) −2.75 kJ
(D) +11.0 kJ
(E) +44.0 kJ

Questions 36 and 37: Information about NaCl at 298 K is given below:

$NaCl_{(s)}$	$\Delta H_f^\circ = -410$ kJ mol^{-1}	$\Delta G_f^\circ = -384$ kJ mol^{-1}
$NaCl_{(aq)}$	$\Delta H_f^\circ = -407$ kJ mol^{-1}	$\Delta G_f^\circ = -393$ kJ mol^{-1}

36. According to the information above, which characteristics apply to the dissolving process for $NaCl_{(s)}$ at 298 K?

(A) spontaneous and endothermic
(B) spontaneous and exothermic
(C) not spontaneous and endothermic
(D) not spontaneous and exothermic
(E) equilibrated at standard conditions

37. If the temperature is increased to 50°C, the value of ΔG for the dissolving process

(A) decreases as the value of $T\Delta S$ increases
(B) decreases as the value of $T\Delta S$ decreases
(C) decreases as the value of $T\Delta S$ remains the same
(D) remains the same as the value of $T\Delta S$ increases
(E) remains the same as the value of $T\Delta S$ decreases

---

38. Which 0.1 m aqueous solution has the lowest freezing point at 1 atm?

(A) $CaCl_2$
(B) $NaNO_3$
(C) CH_3OH
(D) $C_6H_{12}O_6$
(E) $(NH_4)_3PO_4$

39. What mass of H_3PO_4 should be added to 800 grams of water to produce a solution that is 20% H_3PO_4 by mass?

(A) 150 g
(B) 200 g
(C) 900 g
(D) 1,800 g
(E) 2,400 g

40. A solution of HCl of unknown concentration is analyzed using a solution of $Ba(OH)_2$. Exact neutralization occurs after 15. mL of 0.30 M $Ba(OH)_2$ has been added to 30. mL of HCl. What is the concentration of the unknown HCl solution?

(A) 0.075 M
(B) 0.10 M
(C) 0.15 M
(D) 0.17 M
(E) 0.30 M

41. Many sedimentary rocks include the carbonate ion, a remnant of the shells of ancient sea creatures. A geologist tests for the presence of carbonate ions by placing several drops of concentrated acid on the rock, then waits to see if bubbles occur. Which property accounts for this behavior?

(A) Calcium carbonate is an ionic solid.
(B) Carbonate ion is a strong proton acceptor.
(C) Acidic groundwater acts as a dehydrating agent.
(D) In acid solution, carbonate reacts with oxygen.
(E) In acid solution, carbonate is reduced to oxalate.

42. $$C_2H_5OH_{(\ell)} + 3O_{2(g)} \rightarrow 2CO_{2(g)} + 3H_2O_{(\ell)}$$

Which expression gives the volume of oxygen measured at 1 atm and 273 K that is consumed when 50 g C_2H_5OH burns in excess oxygen according to the equation above?

(A) $50 \times 3 \times 22.4$

(B) $\dfrac{50 \times 22.4}{3 \times 46}$

(C) $\dfrac{50 \times 3}{46 \times 22.4}$

(D) $\dfrac{50 \times 22.4}{46}$

(E) $\dfrac{50 \times 3 \times 22.4}{46}$

43. According to the Bronsted-Lowry theory of acid-base behavior, HPO_4^{2-} is classified as amphiprotic because

(A) it reacts with OH^-
(B) it reacts with H_3O^+
(C) its ionic charge is 2^-
(D) its parent molecule is polyprotic
(E) it can accept and donate protons

44. $$2Al_{(s)} + 3Cl_{2(g)} \rightarrow 2AlCl_{3(s)}$$

A mixture containing 0.40 mol Al in contact with 0.75 mol Cl_2 is ignited in a closed container. Assuming complete reaction, which gives the maximum quantity of $AlCl_3$ produced and the quantity of unconsumed reactant?

(A) 0.40 mol $AlCl_3$ and 0.15 mol Al unreacted
(B) 0.40 mol $AlCl_3$ and 0.15 mol Cl_2 unreacted
(C) 0.40 mol $AlCl_3$ and 0.35 mol Cl_2 unreacted
(D) 0.50 mol $AlCl_3$ and 0.10 mol Al unreacted
(E) 0.50 mol $AlCl_3$ and 0.15 mol Cl_2 unreacted

45. How many of the halide salts listed below have percent halogen by mass that is less than 50%?

AgI BaF_2 $CaCl_2$ $FeBr_2$ $PbCl_2$

(A) one
(B) two
(C) three
(D) four
(E) five

46. What is the final concentration of chloride ion when 50 mL of 0.20 M $MgCl_{2(aq)}$ is mixed with 100 mL of 0.10 M $KCl_{(aq)}$?

(A) 0.10 M
(B) 0.15 M
(C) 0.20 M
(D) 0.30 M
(E) 0.40 M

47. At 50°C, the vapor pressures of carbon tetrachloride and chloroform are approximately 300 mmHg and 500 mmHg, respectively. Which expression gives the vapor pressure, in mmHg, of a solution that is 0.20 mole fraction carbon tetrachloride in chloroform?

(A) $0.20 \times (300 + 500)$
(B) $0.20 \times (500 - 300)$
(C) $\dfrac{0.20 \times 300}{0.80 \times 500}$
(D) $\dfrac{0.20 \times 500}{0.80 \times 300}$
(E) $(0.20 \times 300) + (0.80 \times 500)$

48. Which is the best net ionic equation for the reaction between a solution of sodium sulfite and excess phosphoric acid solution?

(A) $SO_3^{2-} + 2H^+ \rightarrow H_2O + SO_2$

(B) $3Na^+ + PO_4^{3-} \rightarrow Na_3(PO_4)_2$

(C) $Na_2SO_3 + 2H^+ \rightarrow Ca^{2+} + H_2O + SO_2$

(D) $3SO_3^{2-} + 2H_3PO_4 \rightarrow 3H_2O + 3SO_2 + 2PO_4^{3-}$

(E) $3Na_2SO_3 + 2H_3PO_4 \rightarrow 2Na_3PO_4 + 3H_2O + 3SO_2$

49. $\ldots H_2S_{(aq)} + \ldots IO_3^-{}_{(aq)} \rightarrow \ldots I_{2(aq)} + \ldots SO_3^{2-}{}_{(aq)} + \ldots H_2O + \ldots H^+{}_{(aq)}$

When the reaction above is balanced and all of the coefficients are reduced to their lowest whole-number values, how many moles of electrons are transferred?

(A) 4
(B) 6
(C) 8
(D) 12
(E) 30

50. Which of the following is least likely to behave as a Lewis base?

(A) H_2O

(B) Cl^-

(C) BF_3

(D) OH^-

(E) NH_3

51.

Acid	pK_a
H_3PO_4	2.1
$H_2PO_4^-$	7.1
HPO_4^{2-}	12.3

A buffer prepared by mixing equimolar solutions of H_3PO_4 and NaH_2PO_4 and Na_2HPO_4 will have a pH closest to

(A) 2
(B) 4
(C) 7
(D) 10
(E) 12

52. Consider the equilibrium

$$H_{2(g)} + I_{2(g)} \rightleftharpoons 2HI_{(g)}$$

In a closed system, the initial partial pressure of hydrogen is 1.25 atm and the initial partial pressure of iodine is 1.75 atm. At equilibrium, the partial pressure of hydrogen is 1.00 atm. Which expression gives the value of K_p for this system?

(A) $\dfrac{(0.50)^2}{(1.00)(1.75)}$

(B) $\dfrac{(0.50)^2}{(1.50)^2}$

(C) $\dfrac{(0.25)^2}{(1.25)(1.75)}$

(D) $\dfrac{(0.50)^2}{(1.00)(1.50)}$

(E) $\dfrac{(0.25)^2}{(1.00)(1.50)}$

53. The pH of 0.10 M solution of $NaHSO_4$ is closest to

(A) 1
(B) 3
(C) 7
(D) 11
(E) 14

54. $$H_3O^+ + NH_2^- \rightleftharpoons NH_3 + H_2O$$

In the proton transfer shown in the equation above, all of the following are correct EXCEPT

(A) NH_3 acts as a Bronsted acid.
(B) The value of K is greater than 1.
(C) The H-NH_2 bond is weaker than the H-H_2O bond.
(D) One of the conjugate acid/base pairs is H_3O^+ and H_2O.
(E) NH_2^- and H_2O have the same number of unshared electron pairs.

55. Which value is closest to the molar solubility of $Ca(OH)_2$?

$$Ca(OH)_{2(s)} \rightleftharpoons Ca^{2+}{}_{(aq)} + 2\ OH^{-}{}_{(aq)} \qquad K_{sp} = 8 \times 10^{-6}$$

(A) 1×10^{-2}
(B) 2×10^{-2}
(C) 3×10^{-3}
(D) 2×10^{-6}
(E) 8×10^{-6}

56. Approximately what minimum quantity of charge, measured in coulombs, is needed to produce 0.15 moles of chromium metal in an electrolytic cell that contains 0.75 M solution of $Cr(NO_3)_3$?

(A) 5,000 coulombs
(B) 15,000 coulombs
(C) 25,000 coulombs
(D) 45,000 coulombs
(E) 225,000 coulombs

57.
$$Ag^{+} + e^{-} \rightarrow Ag^{0} \qquad E^{\circ} = 0.80 \text{ volts}$$
$$Cd^{2+} + 2e^{-} \rightarrow Cd^{0} \qquad E^{\circ} = -0.40 \text{ volts}$$

Which expression gives the voltage produced in a standard chemical cell using the half-reactions above?

(A) $0.80 + 0.40$
(B) $0.80 - 0.40$
(C) $0.40 - 0.80$
(D) $0.80 + \big(2 \times (-0.40)\big)$
(E) $\big(2 \times (-0.80)\big) + 0.40$

58.
$$Cu_{(s)} + 2Ag^{+}{}_{(aq)} \rightarrow Cu^{2+}{}_{(aq)} + 2Ag_{(s)} \qquad K_{eq} = 3.75 \times 10^{15}$$

Which describes the standard voltage and standard free energy change for this reaction?

(A) $E^{\circ} < 0;\ \Delta G^{\circ} > 0$
(B) $E^{\circ} > 0;\ \Delta G^{\circ} < 0$
(C) $E^{\circ} > 0;\ \Delta G^{\circ} > 0$
(D) $E^{\circ} < 0;\ \Delta G^{\circ} < 0$
(E) $E^{\circ} = \Delta G^{\circ} = 0$

59. $Zn^{2+} + 2e^- \rightarrow Zn^0$ $\quad E^\circ = -0.76$ volts

$Al^{3+} + 3e^- \rightarrow Al^0$ $\quad E^\circ = -1.66$ volts

When half-cells based on the half-reactions above are used to construct an electrochemical cell, the overall reaction becomes

$$2Al + 3Zn^{2+} \rightarrow 3Zn + 2Al^{3+}$$

Which gives the effect on the cell voltage when a standard aluminum-zinc cell is changed to a cell in which all ions have 0.01 M concentration?

(A) No change is observed.
(B) The voltage decreases by about 0.02 volts.
(C) The voltage decreases by about 0.12 volts.
(D) The voltage increases by about 0.02 volts.
(E) The voltage increases by about 0.12 volts.

60. Consider a system at equilibrium according to the equation

$$N_{2(g)} + 3H_{2(g)} \rightleftharpoons 2NH_{3(g)}$$

If $Ar_{(g)}$ is added to such an equilibrium system at constant volume and temperature, the total pressure

(A) increases and the number of NH_3 molecules present increases
(B) decreases and the number of NH_3 molecules present increases
(C) remains the same and the number of NH_3 molecules present increases
(D) remains the same and the number of NH_3 molecules present decreases
(E) increases and the number of NH_3 molecules present remains the same

61. Which is a correct comparison of the characteristics of a catalyzed reaction to the corresponding characteristics of the same reaction without a catalyst present?

I. Their energies of activation are the same.
II. Their enthalpies of reaction are the same.
III. Their free energies of reaction are the same.

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

62. Consider a system at equilibrium based on the equation

$$2NO_{(g)} + Cl_{2(g)} \rightleftharpoons 2NOCl_{(g)}$$

Which is a correct statement about this equilibrium system at constant temperature?

I. The concentration of NOCl is constant.

II. The rate of loss of Cl_2 is equal to the rate of formation of NOCl.

III. The rate of formation of NO is equal to the rate of loss of NOCl.

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

Questions 63 and 64: The reaction between chlorine and chloroform in the gas phase is known to proceed according to the mechanism below

$Cl_{2(g)} \rightleftharpoons 2Cl_{(g)}$	fast equilibrium
$Cl_{(g)} + CHCl_{3(g)} \rightarrow HCl_{(g)} + CCl_{3(g)}$	slow
$CCl_{3(g)} + Cl_{(g)} \rightarrow CCl_{4(g)}$	fast

63. According to this mechanism, what is the overall reaction?

(A) $Cl_{2(g)} \rightarrow CCl_{4(g)}$
(B) $CHCl_{3(g)} + Cl_{2(g)} \rightarrow HCl_{(g)} + CCl_{4(g)}$
(C) $Cl_{(g)} + CHCl_{3(g)} \rightarrow H_{(g)} + CCl_{4(g)}$
(D) $Cl_{(g)} + CHCl_{3(g)} \rightarrow HCl_{(g)} + CCl_{3(g)}$
(E) $2CHCl_{3(g)} + Cl_{2(g)} \rightarrow 2HCl_{(g)} + CCl_{4(g)} + CCl_{3(g)}$

64. According to this mechanism, what is the rate law?

(A) $\text{RATE} = k[Cl_2]^2$
(B) $\text{RATE} = k[Cl_2]^2[CHCl_3]$
(C) $\text{RATE} = k[Cl_2]^{\frac{1}{2}}[CHCl_3]$
(D) $\text{RATE} = k\dfrac{[CHCl_3]}{[Cl_2]^{\frac{1}{2}}}$
(E) $\text{RATE} = k\dfrac{[CHCl_3]}{[Cl]^2}$

65. Zinc oxalate, ZnC_2O_4, and lead fluoride, PbF_2, have the same K_{sp} value at 25°C, 2.7×10^{-8}. Which can be concluded from this information?

(A) Their absolute entropies in J mol^{-1} K^{-1} are equal.

(B) The molar solubility of lead fluoride is greater.

(C) Their K_{sp} values are equal at all temperatures.

(D) The heat of solution in kJ mol^{-1} for zinc oxalate is greater.

(E) Their solubilities in grams of solute per liter of solution are equal.

66. Consider the equilibrium represented by the equation

$$H_{2(g)} + F_{2(g)} \rightleftharpoons 2HF_{(g)}$$

Which applies to this system at equilibrium?

I. $K_p = K_c$

II. ΔG = zero

III. $Rate_{forward} = Rate_{reverse}$

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

67. The reaction between H_2 and NO occurs according to the equation

$$2H_{2(g)} + 2NO_{(g)} \rightarrow 2H_2O_{(g)} + N_{2(g)}$$

Six trials of the reaction were carried out. The initial rate of change of pressure for each trial was measured and recorded.

	Initial Pressure (atm)		**Initial Rate**
Trial	$\mathbf{P_{NO}}$	$\mathbf{P_{H_2}}$	**Δatm min^{-1}**
I	0.50	0.09	0.025
II	0.50	0.18	0.050
III	0.50	0.27	0.075
IV	0.09	0.80	0.0063
V	0.18	0.80	0.025
VI	0.27	0.80	0.056

Based on these results, what is the rate law for this reaction?

(A) RATE = $k(P_{NO})^0(P_{H_2})^2$

(B) RATE = $k(P_{NO})^1(P_{H_2})^2$

(C) RATE = $k(P_{NO})^2(P_{H_2})^0$

(D) RATE = $k(P_{NO})^2(P_{H_2})^1$

(E) RATE = $k(P_{NO})^2(P_{H_2})^2$

68. A worker was assigned to prepare a 1.0 molal aqueous solution of ethanol, C_2H_5OH (molar mass 46, density 0.79 g mL^{-1}), using 0.50 kg water. The worker used a volumetric flask to measure 500 mL of water which was poured into a 1-liter beaker. The worker then used a buret to measure 23 mL of ethanol which was added to the contents of the beaker. Which describes the resulting solution?

(A) The solution was correctly prepared to the assigned concentration.
(B) The concentration of the solution will be greater than 1.0 m because too much water was used.
(C) The concentration of the solution will be less than 1.0 m because too much water was used.
(D) The concentration of the solution will be greater than 1.0 m because too much ethanol was used.
(E) The concentration of the solution will be less than 1.0 m because too little ethanol was used.

69. The combustion of ethyne occurs according to the equation

$$2C_2H_{2(g)} + 5O_{2(g)} \rightarrow 4CO_{2(g)} + 2H_2O_{(\ell)} \qquad \Delta H^\circ = ?\ \text{kJ}$$

$$\Delta H_f^\circ \text{ for } H_2O_{(\ell)} = -300\ \text{kJ mol}^{-1}$$
$$\Delta H_f^\circ \text{ for } CO_{2(g)} = -400\ \text{kJ mol}^{-1}$$
$$\Delta H_f^\circ \text{ for } C_2H_{(g)} = 200\ \text{kJ mol}^{-1}$$

The approximate standard heats of formation for water, carbon dioxide and ethyne are given above. Based on this information, which of the following values is closest to ΔH° in kJ mol^{-1} for this reaction?

(A) -900 kJ mol^{-1}
(B) -1300 kJ mol^{-1}
(C) -1800 kJ mol^{-1}
(D) -2300 kJ mol^{-1}
(E) -2600 kJ mol^{-1}

70. Which is a common ingredient of agricultural fertilizers?

(A) copper sulfate
(B) calcium sulfide
(C) barium phosphate
(D) aluminum chloride
(E) ammonium nitrate

71. $Ba(OH)_2 \cdot 8H_2O_{(s)} + 2NH_4SCN_{(s)} \rightarrow Ba(SCN)_{2(aq)} + 2NH_{3(aq)} + 10H_2O_{(\ell)}$

When solid samples of barium hydroxide and ammonium thiocyanate are mixed in a test tube, the outside of the test tube becomes noticeably cool to the touch. Which gives the correct signs for the thermodynamic parameters for such a spontaneous endothermic dissolving process?

	ΔG_{soln}	ΔH_{soln}	ΔS_{soln}
(A)	+	+	+
(B)	+	+	−
(C)	−	−	+
(D)	−	+	+
(E)	−	−	−

72. An experiment to determine the percent of water in a hydrated salt was carried out by heating the hydrated salt over an intense flame. During the heating process, and unknown to the worker, some of the material being heated was accidentally spilled. Which describes the effect on the reported results of the experiment?

(A) Both the mass of the hydrated salt and the percent water will be reported too larger.
(B) The mass of the hydrated salt will be reported correctly and the percent water will be reported too small.
(C) The mass of the hydrated salt will be reported correctly and the percent water will be reported too large.
(D) The mass of the hydrated salt will be reported too large and the percent water will be reported too small.
(E) The mass of the hydrated salt will be reported too small and the percent water will be reported too large.

73. Which products are formed when crystals of $FeSO_4$ are dissolved in an acidified solution of $KMnO_4$?

(A) Mn^{2+} and Fe^{3+}
(B) Mn^{2+} and Fe
(C) Mn^{2+} and SO_2
(D) MnO_2 and Fe
(E) MnO_2 and SO_2

74. Which element is most likely to be found in compounds taken internally to be used for x-ray diagnosis of disorders of the intestinal tract?

(A) barium
(B) lead
(C) lithium
(D) magnesium
(E) zinc

75. Ceramics are materials known for their strength, brittleness, and resistance to heat and chemical corrosion. The inclusion of which of the following is responsible for these characteristics?

(A) silicates
(B) organometallics
(C) high temperature metals
(D) polymers
(E) semiconductors

Section II

Section II - Free Response Total Time – 90 Minutes
(Multiple-Choice Questions are found in Section I.)

Part A: Question 76
and
Question 77 or Question 78
Time: 40 minutes

Access to calculators, Periodic Table, lists of standard reduction potentials, and *Equations and Constants*

(2004 Examination directions) Clearly show the method used and the steps involved in arriving at your answers. It is to your advantage to do this, because 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 76 below. The Section II score weighting for this question is 20 percent.

76. Answer the following questions concerning the homogeneous gaseous equilibrium system represented by the equation below.

$$2\ HI_{(g)} \rightleftharpoons H_{2(g)} + I_{2(g)}$$

At a certain temperature, $HI_{(g)}$ is inserted into a tank until the pressure is 1.00 atm. After the system reaches equilibrium, the partial pressure of the HI is 0.80 atm.

(a) Write the equilibrium expression, K_p, for this reaction.
(b) Calculate the partial pressure of $H_{2(g)}$ and $I_{2(g)}$ at equilibrium.
(c) Calculate the value of K_p for this reaction.
(d) Calculate the value of K_c for this reaction.
(e) What additional information would you need to be able to calculate the number of moles of HI present in the tank at equilibrium?

Answer either question 77 or question 78 below.

(2004 examination directions) 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 that you choose is 20 percent.

77. Answer all five questions below related to an aqueous solution of the weak acid, HF. Hydrogen fluoride, HF, a weak acid, dissolves in water to form hydrofluoric acid according to the following equation.

$$HF_{(aq)} \rightleftharpoons H^+{}_{(aq)} + F^-{}_{(aq)}$$

(a) Available in the laboratory are 40.0 grams of HF and 2.00 kg water. Determine the mass of each substance which is needed to make the maximum quantity of 0.100 molal HF solution.

(b) Determine the molality of F^- ions and the molality of HF molecules in the solution prepared as directed in part (a).

(c) Determine the percent ionization of HF in this solution.

(d) The freezing point of the 0.100 m solution of HF in water is $-0.201°C$. Determine the apparent molality of all dissolved particles.

(e) Determine the number of moles of HF molecules in the solution described in part (a).

78. Use the information in this table of standard heats of formation and standard entropies to answer all four questions below related to the combustion of acetic acid.

	ΔH_f° kJ mol^{-1}	S° J mol^{-1} K^{-1}
$CO_{2(g)}$	−393.5	213.6
$C_{(s)}$	0	5.69
$H_{2(g)}$	0	130.58
$H_2O_{(\ell)}$	−285.83	69.96
$CO_{2(g)}$	0	205.0
$CH_3COOH_{(\ell)}$	?	159.81

All values taken at 298 K.

At 298 K, the standard heat (enthalpy) of combustion, ΔH°_{comb}, of acetic acid, $CH_3COOH_{(\ell)}$, is -874.5 kJ mol^{-1}.

(a) Write the balanced equation for the complete combustion of acetic acid, $CH_3COOH_{(\ell)}$, in pure oxygen.

(b) Calculate the standard entropy change, $\Delta S°$, for this combustion reaction at 298 K. Specify units.

(c) Calculate the standard enthalpy of formation, ΔH°_f, for acetic acid at 298 K. Specify units.

(d) Calculate the standard Gibbs free energy change, $\Delta G°$, for this combustion reaction at 298 K. Specify units.

Part B: Questions 79, 80, 81 and
Question 82 or Question 83
Time: 50 minutes

Access to Periodic Table, lists of standard reduction potentials
and *Equations and Constants*
No access to calculators

Answer question 79 below: The Section II score weighting for this question is 15 percent.

79. (2004 Examination directions) Write the formulas to show the reactants and products for 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 a 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.

(a) Solutions of mercury(I) nitrate and hydrochloric acid are mixed.

(b) Sulfur dioxide gas is bubbled through water.

(c) A bar of manganese metal is added to a solution of zinc nitrate.

(d) Excess concentrated ammonia is added to a solution of copper(II) nitrate.

(e) A quantity of 1-propanol is burned in oxygen.

(f) Solutions of iron(II) chloride and gold(III) nitrate are mixed.

(g) Solutions of ammonium chloride and sodium fluoride are mixed.

(h) Solutions of potassium sulfate and strontium bromide are mixed.

(2004 Examination directions) 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.

(2004 examination directions) **Answer both Question 80 and Question 81 below.** Both questions will be graded.

The Section II score weighting for these questions is 30 percent (15 percent each).

80. Use principles of chemical bonding with appropriate Lewis dot structures to answer the four questions below.

(a) Draw the Lewis electron-dot structure and predict the shape of the two halide species below.

SF_4, ICl_4^-

(b) Use the valence shell electron pair repulsion (VSEPR) model to explain the geometry of the electron pair distribution for each of the species in part (a).

(c) Use Lewis electron-dot structures to show how each of the molecules below is an illustration of an exception to the octet rule.

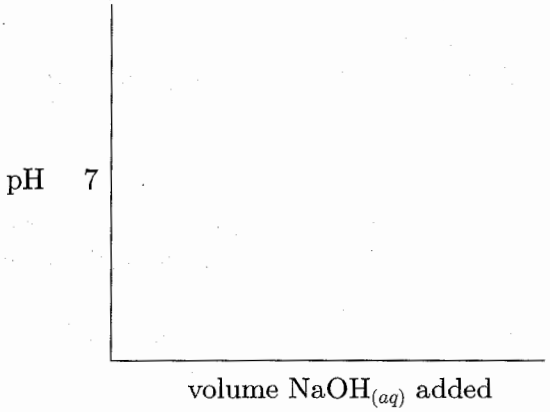
electron deficient molecule: BF_3
(fewer than eight electrons)

expanded octet: ICl_3

81. Answer all four questions below about the experimental determination of the concentration of an unknown solution of acetic acid, CH_3COOH.

A dilute solution of NaOH of known concentration can be used to determine the unknown concentration of a solution of CH_3COOH. The solution of NaOH can be titrated against a measured quantity of the unknown CH_3COOH solution. The endpoint can be determined by using a few drops an appropriate indicator added to the acid or by monitoring the pH of the reaction mixture.

Use the axes below for the answers to part (a) and part (b). Note that a line for pH = 7 has been given.



(a) On the axes above, draw a curve labeled (A) to show how $[H^+]$ changes in the reaction mixture as $NaOH_{(aq)}$ is added to $CH_3COOH_{(aq)}$. Explain.

(b) Explain the changes $[CH_3COO^-]$ as this reaction proceeds.

(c) On the same axes used for part (a), draw a new curve labeled (C) to show how the results would be different if the volume of acid neutralized were increased. Indicate on your new graph where neutralization is observed. Explain.

(d) Of the indicators described below, choose the one that would be most unsatisfactory for detection of the neutralization for this reaction. Explain.

Indicator	pH range for color change
methyl red	4.8 – 6.0
bromthymol blue	6.0 – 7.6
thymol blue	8.0 – 9.6

(2004 examination directions) **Answer either question 82 or question 83 below.** 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 that you choose is 15 percent.

82. Answer the four questions below about the chemical reaction.

$$H_{2(g)} + I_{2(g)} \rightarrow 2HI_{(g)}$$

For the exothermic reaction represented above, carried out at 298 K, the Rate Law is RATE = $k[H_2][I_2]$. Four each of the four changes, (a) through (d), below, predict the effect of that change on the initial rate of the reaction. Explain each in terms of the collision theory of reaction kinetics.

(a) **Addition of $H_{2(g)}$ at constant temperature and volume.** Include an energy distribution diagram showing number of molecules as function of energy before and after the addition of $H_{2(g)}$.

(b) **Increase in volume of reaction vessel at constant temperature.** Include an energy distribution diagram showing $[H_2]$ as function of energy before and after the increase in volume.

(c) **Addition of catalyst.** Include a diagram where potential energy is plotted on the reaction coordinate. Indicate potential energy for the activated complex with and without the catalyst. Label the curve that represents the catalyzed reaction.

(d) **Increase in temperature.** Include an energy distribution diagram showing number of molecules as function of energy before and after the increase in temperature. Locate E_a. Use features of your diagram to help explain why increase in temperature causes an increase in rate of reaction.

83. Answer all four questions below related to properties of the alkali metal, potassium.

(a) The atomic radius of potassium is greater than the atomic radius of zinc. Explain.

(b) The radius of the K^+ ion is smaller than the radius of the K^0 atom. Explain.

(c) The ionic radius of Cl^- is greater than the ionic radius of K^+. Explain.

(d) The second ionization energy of potassium is greater than the second ionization energy of calcium. Explain.

SAMPLE EXAMINATION III

Section I – Multiple Choice

Questions 1-5. The set of lettered choices below, a list of frequently used ions, refers to the set of numbered statements immediately following it. Select the one lettered choice that is most closely associated with each numbered statement. Each lettered choice can be used once, more than once or not at all.

(A) Cl^-

(B) Br^-

(C) Ca^{2+}

(D) NH_4^+

(E) OH^-

Assume that you have an "unknown" that is an aqueous solution of a substance which contains one or more of the ions listed above. Which ion must be ABSENT based upon each of the following observations of the "unknown"?

1. The pH of the unknown solution decreases immediately and rapidly as dilute $HNO_{3(aq)}$ is added dropwise.

2. No ammonia odor is detected when dilute NaOH solution is added to a sample of the unknown solution and warmed.

3. No white precipitate is observed when Na_2CO_3 solution is added to a sample of the unknown solution.

4. No reddish-brown precipitate is observed when $FeCl_3$ solution is added to a sample of the unknown solution.

5. No yellow precipitate is observed when $AgNO_3$ solution is added to a sample of the unknown solution.

---

6. When Fe^0 changes to Fe^{3+} the number of occupied orbitals changes from

(A) 15 to 14
(B) 15 to 12
(C) 15 to 9
(D) 13 to 12
(E) 13 to 11

15. Both chlorine and bromine exist as two naturally-occurring isotopes, distributed as shown below. The "percent natural occurrence" is based on distribution of isotopes. Chlorine reacts with bromine to form ClBr.

isotope	percent natural occurrence
chlorine – 35	76%
chlorine – 37	24%
bromine – 79	51%
bromine – 81	49%

Thus there are three different possible molar masses for ClBr: 114, 116, and 118. Which of the following gives the approximate fractional distribution in naturally-occurring compounds of the three possible molar masses?

	molar masses		
	114	**116**	**118**
(A)	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{4}$
(B)	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$
(C)	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{1}{8}$
(D)	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$
(E)	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{8}$

16. Which is a correct statement of a trend within a group of elements on the Periodic Table as atomic number increases?

I. The number of valence electrons increases.
II. The radius of the most common ion of each element increases.
III. The ionization energy increases.

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

17. Consider the oxides, XO_2 and YO_2, where X and Y are nonmetals with nearly equal atomic mass. The molecular shape of XO_2 is linear; that of YO_2 is bent (V-shaped). Which gives a correct comparison of their properties?

I. The critical temperature of YO_2 is higher than that of XO_2.
II. The normal boiling point of YO_2 is higher than that of XO_2.
III. The molar heat of vaporization of YO_2 is greater than that of XO_2.

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

18. In general, the melting points of ionic solids are higher than the melting points of molecular solids. Which accounts for this difference?

(A) Attractions between particles with opposite charge are stronger than covalent bonds.
(B) Repulsions between ions with the same charge are negligibly small.
(C) Delocalized electron clouds in molecular solids are produced by the formation of *pi* bonds.
(D) Attractions between ions with opposite charge are stronger than intermolecular forces.
(E) The distance between oppositely charged ions is less than the corresponding distance between bonded atoms.

19. Compared to a molecule of $C_2H_4Cl_2$, a molecule of $C_2H_2Cl_2$ contains

I. two fewer *sigma* bonds
II. one more *pi* bond
III. two fewer shared electron pairs

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

20. For the compound PF_3, which describes the molecular shape and the distribution of valence shell electron pairs on the central atom?

	distribution of valence shell electron pairs	**molecular shape**
(A)	trigonal bipyramidal	trigonal planar
(B)	trigonal bipyramidal	T-shaped
(C)	tetrahedral	trigonal pyramidal
(D)	tetrahedral	tetrahedral
(E)	trigonal bipyramidal	tetrahedral

21. In which one of the following five compounds is the number of elements different from the number of elements in the other four?

(A) potassium permanganate
(B) potassium acetate
(C) potassium oxalate
(D) potassium perchlorate
(E) potassium selenate

22. Which will cause an increase in the mean free path for molecules in a sample of gas?

(A) increase pressure at constant volume
(B) increase temperature at constant volume
(C) increase density at constant temperature
(D) increase temperature at constant pressure
(E) increase pressure at constant temperature

23. The density of an unknown gas is determined to be 1.50 g L^{-1}. At the same conditions of temperature and pressure, the density of oxygen is determined to be 1.25 g L^{-1}. Which expression gives the molar mass of the unknown gas?

(A) $\dfrac{32 \times 1.25}{1.50}$

(B) $\dfrac{32 \times 1.50}{1.25}$

(C) $\dfrac{32 \times 1.25}{2 \times 1.50}$

(D) $\dfrac{32 \times (1.25)^2}{(1.50)^2}$

(E) $\dfrac{32 \times (1.50)^2}{(1.25)^2}$

24. Which occurs during the vaporization of a liquid at its normal boiling point?

(A) The potential energy of the molecules decreases.
(B) The average kinetic energy of the molecules increases.
(C) The vapor pressure of the liquid decreases as the liquid is converted to vapor.
(D) Attractive forces between atoms in a molecule are overcome as translational motion increases.
(E) Attractive forces between molecules in a liquid are overcome as translational motion increases.

25. Which is an example of a *p*-type semiconductor; that is, a semiconductor in which a transport of charge is produced by moving spaces that accommodate valence electrons?

(A) arsenic with some silicon added
(B) germanium with some silicon added
(C) silicon with some gallium added
(D) silicon with some germanium added
(E) germanium with some arsenic added

26. How many moles of water must be added to 20 moles of ethanol in order to prepare a solution that is 0.25 mole fraction in ethanol?

(A) 5.0
(B) 15
(C) 60.
(D) 80.
(E) 75

27. At 298 K, as the salt MX dissolves spontaneously to form an aqueous solution, ΔS and ΔH are positive. Which describes the value of ΔG and the absolute values of its components, $T\Delta S$ and ΔH?

(A) $\Delta G < 0$; $|T\Delta S| > |\Delta H|$
(B) $\Delta G < 0$; $|T\Delta S| < |\Delta H|$
(C) $\Delta G > 0$; $|T\Delta S| > |\Delta H|$
(D) $\Delta G > 0$; $|T\Delta S| < |\Delta H|$
(E) $\Delta G = 0$; $|T\Delta S| = |\Delta H|$

28. A 0.420 g sample of hemimellitic acid, $C_9H_6O_6$ (molar mass: 210 g), is neutralized by 0.020 L of 0.300 *M* NaOH. What is the number of protons per mole of $C_9H_6O_6$ available for donation to OH^- in water solution?

(A) one
(B) three
(C) four
(D) six
(E) nine

29. What mass of water must be added to 100. g CH_3OH in order to make a solution that is 25% by mass CH_3OH?

(A) 25.0 grams
(B) 75.0 grams
(C) 150. grams
(D) 300. grams
(E) 400. grams

30. Which of the following compounds has the lowest vapor pressure?

(A) C_8H_{18}
(B) $CHCl_3$
(C) CH_3Cl
(D) C_2H_5OH
(E) $C_3H_5(OH)_3$

31. The vapor pressure of water is 80°C at 355 mmHg. Which expression gives the fraction of water molecules in a sample of nitrogen gas saturated with water vapor at 80°C and 740 mmHg total pressure?

(A) $\frac{355}{740}$
(B) $\frac{355}{760}$
(C) $\frac{355}{355+740}$
(D) $\frac{355}{355+760}$
(E) $\frac{355 \times 18}{740 \times 28}$

32. Which structure best accounts for the properties of metals in the solid state?

(A) atoms in fixed geometric positions
(B) cations and anions in fixed geometric positions
(C) multi-atom molecules in fixed geometric positions
(D) cations in fixed geometric positions surrounded by a diffuse electron cloud
(E) anions in fixed geometric positions surrounded by a diffuse electron cloud

33. According to the Kinetic Molecular Theory, which characteristic applies to an ideal gas?

(A) An ideal gas has no critical temperature.
(B) An ideal gas liquifies at temperatures below its critical temperature.
(C) An ideal gas liquifies at temperatures above its critical temperature.
(D) The critical temperature of an ideal gas is less than its triple point temperature.
(E) The critical temperature of an ideal gas is greater than its triple point temperature.

34. Resonance helps to account for all of the following properties EXCEPT

(A) the equal S–O bond energies in SO_2

(B) the low reactivity of C in benzene, C_6H_6

(C) the charge of 3^+ on the aluminum ion, Al^{3+}

(D) the equal bond strengths in the nitrate ion, NO_3^-

(E) the equal bond lengths in the carbonate ion, CO_3^{2-}

35. What is the shape of the SF_6 molecule?

(A) linear
(B) see-saw
(C) octahedral
(D) tetrahedral
(E) trigonal bipyramidal

36. Which is formed when the nuclide $^{253}_{99}Es$ captures an alpha particle and emits a free neutron?

(A) $^{258}_{98}Cf$

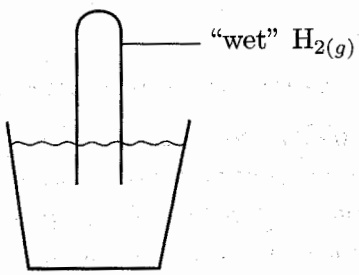
(B) $^{256}_{99}Es$

(C) $^{257}_{100}Fm$

(D) $^{256}_{101}Md$

(E) $^{258}_{101}Md$

37.



A 50 mL sample of hydrogen gas is collected over water at 25°C and 745 mmHg as shown in the diagram above. All of the following describe properties of the system EXCEPT

(A) The volume of $H_2O_{(g)}$ is equal to the volume of $H_{2(g)}$.

(B) The pressure of $H_2O_{(g)}$ is equal to the pressure of $H_{2(g)}$.

(C) The temperature of $H_2O_{(g)}$ is equal to the temperature of $H_{2(g)}$.

(D) The number of molecules of $H_2O_{(g)}$ is less than the number of molecules of $H_{2(g)}$.

(E) The average molecular velocity of $H_2O_{(g)}$ is less than the average molecular velocity of $H_{2(g)}$.

38. Which equation best illustrates the behavior of Fe^{3+} as a Lewis acid?

(A) $Fe^{3+}{}_{(aq)} + SCN^{-}{}_{(aq)} \rightarrow FeSCN^{2+}{}_{(aq)}$

(B) $Fe_2O_{3(s)} + FeO_{(s)} \rightarrow Fe_3O_{4(s)}$

(C) $Fe^{3+}{}_{(aq)} + PO_4{}^{3-}{}_{(aq)} \rightarrow FePO_{4(s)}$

(D) $Fe(NO_3)_{3(s)} \rightarrow Fe^{3+}{}_{(aq)} + 3NO_3{}^{-}{}_{(aq)}$

(E) $Fe_{(s)} + \frac{3}{2}Cl_{2(g)} \rightarrow Fe^{3+}{}_{(aq)} + 3Cl^{-}{}_{(aq)}$

39. Equal masses of barium chloride dihydrate ($BaCl_2 \cdot 2H_2O$; molar mass: 244 g) and copper(II) sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$; molar mass: 250 g) are placed in separate crucibles and heated until no further loss of mass is observed. Which expression is closest to the ratio of the mass of the contents of the $BaCl_2$ crucible to that of the $CuSO_4$ crucible after the heating is completed?

(A) $\frac{36}{90}$

(B) $\frac{160}{208}$

(C) $\frac{208}{160}$

(D) $\frac{244}{250}$

(E) $\frac{208 + 160}{244 + 250}$

40. Which equation best illustrates the ionization behavior of liquid ammonia?

(A) $NH_3 \rightleftharpoons N^{3-} + 3H^{+}$

(B) $NH_3 \rightleftharpoons H^{+} + NH_2{}^{-}$

(C) $NH_3 + H_2O \rightleftharpoons NH_4{}^{+} + OH^{-}$

(D) $NH_3 + NH_3 \rightleftharpoons NH_4{}^{+} + NH_2{}^{-}$

(E) $NH_3 + H_2O \rightleftharpoons H_3O^{+} + NH_2{}^{-}$

41. The normal boiling points of CH_3OH and H_2O are 65°C and 100°C, respectively. Which is another correct comparison of the properties of CH_3OH and H_2O?

I. The average molecular velocity of CH_3OH at 65°C is the same as the average molecular velocity of H_2O at 100°C.

II. The vapor pressure of CH_3OH at 65°C is the same as the vapor pressure of H_2O at 100°C.

III. The heat of vaporization of CH_3OH at 65°C is the same as the heat of vaporization of H_2O at 100°C.

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

42. Of the following pairs of substances, which should be chosen to react with $Al(OH)_3$ to demonstrate its behavior as an amphiprotic compound?

(A) oxygen and hydrogen
(B) ethanol and methanol
(C) sodium nitrate and sodium phosphate
(D) sodium hydroxide and hydrochloric acid
(E) potassium chloride and sodium chloride

43. Which describes the changes in the concentrations of all the solute ions present after 100 mL of 0.20 M $KI_{(aq)}$ is mixed with 100 mL of 0.10 M $BaI_{2(aq)}$?

	$[Ba^{2+}]$	$[K^+]$	$[I^-]$
(A)	remains the same	remains the same	decreases
(B)	decreases	decreases	remains the same
(C)	decreases	remains the same	remains the same
(D)	remains the same	decreases	decreases
(E)	decreases	remains the same	remains the same

44. Which species that contains S in the +6 oxidation state is most likely to be found in greatest concentration in a water solution that has pOH = 1.0?

(A) H_2SO_4
(B) $H_2S_2O_7$
(C) SO_3
(D) HSO_4^-
(E) SO_4^{2-}

45. During the electrolysis of a solution of potassium iodide, which process occurs at the anode?

(A) oxidation of I^- to form I_2
(B) oxidation of H_2O to form O_2
(C) reduction of K^+ to form KOH
(D) reduction of K^+ to form K
(E) reduction of H_2O to form H_2

46. What is the formula of the oxide of manganese that contains the smallest percent oxygen by mass?

(A) MnO
(B) MnO_2
(C) MnO_3
(D) Mn_2O_3
(E) Mn_3O_4

47. Which reaction involves neither oxidation nor reduction?

(A) burning of tin in chlorine gas
(B) ignition of iron in powdered sulfur
(C) decomposition of potassium chlorate
(D) dissolving of calcium carbonate in hydrochloric acid
(E) catalytic decomposition of hydrogen peroxide on manganese dioxide

48. $$2Al_{(s)} + 3Cl_{2(g)} \rightarrow 2AlCl_{3(s)}$$

A mixture containing 0.60 mol Al in contact with 0.75 mol Cl_2 is ignited in a closed container. Assuming complete reaction, which gives the maximum quantity of $AlCl_3$ produced and the corresponding quantity of unconsumed reactant?

(A) 0.45 mol $AlCl_3$ and 0.15 mol Al unreacted
(B) 0.45 mol $AlCl_3$ and 0.15 mol Cl_2 unreacted
(C) 0.50 mol $AlCl_3$ and 0.10 mol Al unreacted
(D) 0.45 mol $AlCl_3$ and 0.10 mol Cl_2 unreacted
(E) 0.50 mol $AlCl_3$ and 0.15 mol Cl_2 unreacted

49. Which describes some of the contents of the solution that results when 667 mL of 0.10 *M* $NaNO_3$ solution is mixed with 333 mL of 0.10 *M* $Ba(NO_3)_2$ solution?

	$[Na^+]$	$[NO_3^-]$
(A)	0.10 *M*	0.20 *M*
(B)	0.10	0.30
(C)	0.067	0.13
(D)	0.067	0.20
(E)	0.15	0.10

Questions 50-52: The substance AB is 20% dissociated in dilute water solution according to the equation

$$AB_{(aq)} \rightleftharpoons A^+{}_{(aq)} + B^-{}_{(aq)}$$

50. Which gives the predicted freezing point in °C for a 0.050 m solution of AB?

(A) -1.86×0.040

(B) -1.86×0.060

(C) -1.86×0.070

(D) -1.86×0.20

(E) $-1.86 \times 0.20 \times 0.050$

51. Which gives the ratio of ions to molecules in this solution?

(A) $\frac{1}{5}$

(B) $\frac{1}{4}$

(C) $\frac{1}{2}$

(D) $\frac{2}{5}$

(E) $\frac{2}{3}$

52. Which expression gives the value of K_i for this ionization in a 0.050 M solution?

(A) $\frac{0.010 \times 0.010}{0.050}$

(B) $\frac{0.010 \times 0.010}{0.040}$

(C) $\frac{0.010 \times 0.010}{0.030}$

(D) $\frac{0.010 \times 0.010}{0.20 \times 0.050}$

(E) $\frac{0.20 \times 0.010 \times 0.010}{0.050}$

---

53. $$...Cr_2O_7{}^{2-} + ...C_2H_5OH + ...H^+ \rightarrow ...Cr^{3+} + ...CO_2 + ...H_2O$$

When the skeleton equation above is balanced using lowest integer coefficients, what is the sum of the coefficients?

(A) 12

(B) 18

(C) 24

(D) 30

(E) 36

54. Which applies to a saturated solution of $Ca_3(PO_4)_{2(s)}$ in contact with excess $Ca_3(PO_4)_{2(s)}$?

$$Ca_3(PO_4)_{2(s)} \rightleftharpoons 3Ca^{2+}{}_{(aq)} + 2PO_4{}^{3-}{}_{(aq)} \qquad K_{sp} = 1.3 \times 10^{-32}$$

I. The free energy, G, of the products is equal to the free energy of the reactants.

II. The rate of precipitation is equal to the rate of dissolving.

III. The concentration of the reactants is equal to the concentration of the products.

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

55.

Acid	K_a
H_3PO_4	8×10^{-3}
$H_2PO_4{}^-$	8×10^{-8}
$HPO_4{}^{2-}$	5×10^{-13}

A mixture is prepared by adding 1.0 mole each of H_3PO_4, Na_2HPO_4 and NaH_2PO_4 to enough water to make 1.0 liter of solution. The $[H^+]$ in this solution is closest to

(A) 8×10^{-3}
(B) 5×10^{-4}
(C) 4×10^{-4}
(D) 2×10^{-8}
(E) 1×10^{-8}

56. The pH of 0.10 M solution of $NH_4C_2H_3O_2$ is closest to

(A) 1
(B) 3
(C) 7
(D) 11
(E) 14

57. $Ag_2CrO_{4(s)} \rightleftharpoons 2Ag^+{}_{(aq)} + CrO_4{}^{2-}{}_{(aq)}$

The molar solubility of $Ag_2CrO_{4(s)}$ is 1.3×10^{-4} mol L^{-1}. Which expression gives the value for K_{sp}, the solubility product constant?

(A) $(1.3 \times 10^{-4})(1.3 \times 10^{-4})^2$

(B) $(2.6 \times 10^{-4})^2(1.3 \times 10^{-4})$

(C) $(2.6 \times 10^{-4})(1.3 \times 10^{-4})$

(D $\dfrac{(2.6 \times 10^{-4})^2}{1.3 \times 10^{-4}}$

(E) $\dfrac{1.3 \times 10^{-4}}{(2.6 \times 10^{-4})^2}$

58. Which expression gives the percent H_3PO_4 (molar mass: 98 g) by mass in 2.0 molal solution of H_3PO_4 in water?

(A) $\dfrac{98 \times 100}{2 + 1000}$

(B) $\dfrac{98 \times 100}{98 + 1000}$

(C) $\dfrac{2 \times 98 \times 100}{98 + 1000}$

(D) $\dfrac{2 \times 98 \times 100}{1000}$

(E) $\dfrac{2 \times 98 \times 100}{(2 \times 98) + 1000}$

59. $NaI_{(s)} \rightleftharpoons Na^+{}_{(aq)} + I^-{}_{(aq)} \qquad \Delta H = -7.5$ kJ

The equation above represents the solubility equilibrium in a saturated solution of NaI in contact with solid NaI. Which of the following is the best way to increase the rate at which the dissolving process occurs?

(A) adding $NaI_{(s)}$

(B) adding saturated $NaI_{(aq)}$

(C) cooling the mixture

(D) warming the mixture

(E) increasing the external pressure

60. Which species should be used to precipitate Pb^{2+}, as the only cation, from a mixture of Pb^{2+} and Ca^{2+} ions in aqueous solution?

(A) Cl^-
(B) NO_3^-
(C) NH_4^+
(D) H_3O^+
(E) CH_3COO^-

61. $$CH_3OH_{(\ell)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(\ell)} \qquad \Delta H^\circ = ?$$

$$\Delta H_f^\circ \text{ for } H_2O_{(\ell)} = -300 \text{ kJ mol}^{-1}$$
$$\Delta H_f^\circ \text{ for } CO_{2(g)} = -400 \text{ kJ mol}^{-1}$$
$$\Delta H_f^\circ \text{ for } CH_3OH_{(\ell)} = -300 \text{ kJ mol}^{-1}$$

The approximate standard heats of formation for water, carbon dioxide, and methanol, are given above. Based on this information, the standard heat of combustion for methanol in kJ mol^{-1} is closest to

(A) +1,700
(B) zero
(C) −300
(D) −700
(E) −1,700

62. Which of the following has the least effect on the rate of a reaction?

(A) adding a solid catalyst to a gas phase reaction
(B) adding a solid catalyst to a liquid phase reaction
(C) adding inert miscible liquid to a liquid phase reaction
(D) adding inert gas to a gas phase reaction at constant volume
(E) adding excess base to neutralization reaction for a nearly insoluble weak acid

63.

ethene ($C_2H_{4(g)}$)	$\Delta G_f^\circ = 68$ kJ mol^{-1}	$\Delta H_f^\circ = 52$ kJ mol^{-1}
ethyne ($C_2H_{2(g)}$)	$\Delta G_f^\circ = 209$ kJ mol^{-1}	$\Delta H_f^\circ = 227$ kJ mol^{-1}

Based on the information above, what can be concluded about the relative stability and the standard entropies of formation of these compounds at 298 K?

(A) Both compounds have the same stability and the same sign for ΔS_f°.
(B) Ethene is more stable than ethyne and both have the same sign for ΔS_f°.
(C) Ethene is less stable than ethyne and both have the same sign for ΔS_f°.
(D) Ethene is more stable than ethyne and they have opposite signs for ΔS_f°.
(E) Ethene is less stable than ethyne and they have opposite signs for ΔS_f°.

64. Information about NaCl is given below

$NaCl_{(s)}$	$\Delta H_f^\circ = -410$ kJ mol^{-1}	$\Delta G_f^\circ = -384$ kJ mol^{-1}
$NaCl_{(aq)}$	$\Delta H_f^\circ = -407$ kJ mol^{-1}	$\Delta G_f^\circ = -393$ kJ mol^{-1}

Which range includes the value in J mol^{-1} K^{-1} for ΔS° for the dissolving process at 298 K?

(A) greater than 30 J mol^{-1} K^{-1}
(B) $1 - 30$ J mol^{-1} K^{-1}
(C) $0.1 - 1$ J mol^{-1} K^{-1}
(D) $0.001 - 0.1$ J mol^{-1} K^{-1}
(E) less than 0.001 J mol^{-1} K^{-1}

Questions 65 and 66: $2A + B + C \rightarrow$ products

Four trials of the reaction above were carried out in order to determine its rate law. The following data were collected.

Trial	[A]	[B]	[C]	Initial rate M sec^{-1}
1	0.02	0.02	0.02	1.6×10^{-3}
2	0.01	0.02	0.02	8.0×10^{-4}
3	0.01	0.04	0.02	1.6×10^{-3}
4	0.01	0.04	0.03	1.6×10^{-3}

65. Based on these observations, what is the rate law?

(A) Rate = k[A]^2
(B) Rate = k[B][C]
(C) Rate = k[A][B]
(D) Rate = k[A]^2[B]^2
(E) Rate = k[A]^2[B][C]

66. As any trial of this reaction proceeds at constant temperature, the rate of the reaction

(A) remains the same because no catalyst is added
(B) remains the same because the temperature is constant
(C) increases because the rate constant is a positive number
(D) decreases because the concentrations of the reactants decrease
(E) decreases because the effectiveness of collisions between molecules decreases

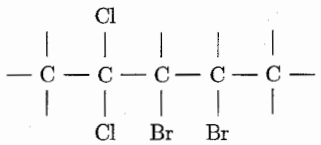
67. Which of the following identifies a pair of isomers of diethyl ether?

(A) 1-propanol and 1-pentanol
(B) 2-butanol and 2-methyl-2-propanol
(C) 2-butanol and 2-methyl-1-butanol
(D) 2-methyl-1-butanol and 2-methyl-2-butanol
(E) 2-methyl-1-propanol and 2-methyl-1-pentanol

68. Which is the best net ionic equation for the reaction of a piece of mossy zinc with excess dilute sulfuric acid?

(A) $Zn_{(s)} + H_2SO_{4(aq)} \rightarrow H_{2(g)} + ZnSO_{4(s)}$
(B) $Zn^{2+}{}_{(aq)} + HSO_4{}^-{}_{(aq)} \rightarrow Zn(HSO_4)_{2(s)}$
(C) $Zn^{2+}{}_{(aq)} + SO_4{}^{2-}{}_{(aq)} \rightarrow ZnSO_{4(s)}$
(D) $Zn_{(s)} + 2\ H^-{}_{(aq)} \rightarrow ZnH_{2(s)}$
(E) $Zn_{(s)} + 2\ H_3O^+{}_{(aq)} \rightarrow Zn^{2+}{}_{(aq)} + H_{2(g)} + 2\ H_2O_{(\ell)}$

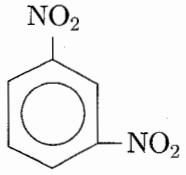
69. In the correct IUPAC name for the molecule,



the prefix, di, is used .?. and the numeral, 4, is used .?.

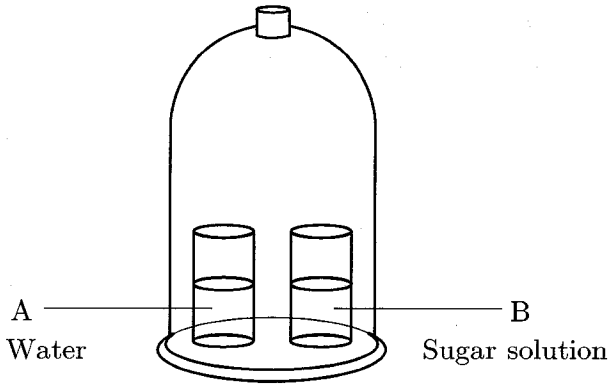
(A) never, twice
(B) once, once
(C) once, twice
(D) twice, once
(E) twice, twice

70. What molecular formula is represented by the structural formula



(A) $C_4N_2O_4$
(B) $C_6N_2O_4$
(C) $C_4H_4N_2O_4$
(D) $C_6H_4N_2O_4$
(E) $C_6H_6N_2O_4$

71. The diagram below represents a sample of pure water in beaker A and an equal volume of a solution of sugar in water in beaker B. Both beakers are placed under a bell jar. Which of the following changes is most likely to occur as this apparatus is observed over several weeks?



(A) The contents of both beakers evaporate to dryness.
(B) The volume of liquid in beaker B becomes greater than the volume of liquid in beaker A.
(C) The mass of the solute in beaker B decreases as the mass of the solute in beaker A increases.
(D) The concentration of the solute in beaker B decreases as the mass of the solute in beaker A increases.
(E) The concentration of the solute in beaker B increases as the volume of liquid in beaker A increases.

72. In a mercury cell, often used as a calculator battery, which element is used as the anode?

(A) carbon
(B) chromium
(C) manganese
(D) sodium
(E) zinc

73. In the ordinary use of a styrofoam cup as a calorimeter for an exothermic dissolving reaction, which property requires the least precision and accuracy in its measurement?

(A) final temperature of the solution
(B) initial temperature of the solvent
(C) mass of water as solvent is added to a calorimeter
(D) mass of the solute that is added to the calorimeter
(E) change in volume of the system as the reaction proceeds.

74. When pure (18 M) sulfuric acid dissolves in water, a significant increase in the temperature of the system occurs. Which gives the correct signs for the thermodynamic parameters for this dissolving process?

	ΔG_{soln}	ΔH_{soln}	ΔS_{soln}
(A)	+	+	+
(B)	+	+	−
(C)	−	−	+
(D)	−	+	+
(E)	−	−	−

75. Which gives the thermodynamic parameters for the phase change in a system that begins as an open container of liquid water placed in a constant temperature environment of 230 K?

I. $\Delta G < 0$
II. $\Delta H < 0$
III. $\Delta S < 0$

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

Section II

Section II - Free Response Total Time – 90 Minutes
(Multiple-Choice Questions are found in Section I.)

Part A: Question 76
and
Question 77 or Question 78
Time: 40 minutes

Access to calculators, Periodic Table, lists of standard reduction potentials, and *Equations and Constants*

(2004 Examination directions) Clearly show the method used and the steps involved in arriving at your answers. It is to your advantage to do this, because 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 76 below. The Section II score weighting for this question is 20 percent.

76. Answer all four questions below related to the dissolving of calcium hydroxide in water. The solubility of $Ca(OH)_2$ is 0.51 grams/liter at 298 K.

(a) Write the balanced equation for the solubility equilibrium of $Ca(OH)_2$ in water and the corresponding mass action expression for the solubility product constant, K_{sp}.

(b) Calculate the value for the solubility product constant, K_{sp}, at 298 K.

(c) Calculate the pH of a saturated solution of $Ca(OH)_2$ at 298 K.

(d) A mixture is prepared by adding 40.0 mL of 0.020 *M* $CaCl_{2(aq)}$ to 60.0 mL of 0.015 *M* $KOH_{(aq)}$. Does precipitation of $Ca(OH)_{2(s)}$ occur at 298 K? Show calculations to support your answer. (Assume the volumes of the two solutions are additive.)

Answer either question 77 or question 78 below.

(2004 examination directions) 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 that you choose is 20 percent.

77. Answer all four questions below about the combustion (burning) of butane. Butane is a hydrocarbon fuel gas used for many camp stoves and lanterns.

(a) Write the balanced equation for the complete combustion of butane, $C_4H_{10(g)}$, in oxygen at 298 K. Include the phase for each reactant and product in its standard state.

(b) What volume of $O_{2(g)}$, measured at 0.965 atm and 20.0°C, is consumed when 10.0 g $C_4H_{10(g)}$ is burned?

(c) Some standard heats of formation, ΔH_f°, at 298 K are given below

$H_2O_{(\ell)}$	-285.83 kJ mol^{-1}
$C_4H_{10(g)}$	..?.. kJ mol^{-1}
$CO_{2(g)}$	-393.5 kJ mol^{-1}

The standard heat of combustion, ΔH_{comb}°, of butane at 298 K is $-2{,}874.5$ kJ mol^{-1}. Determine the standard heat of formation, ΔH_f°, of butane.

(d) Energy from the burning of butane can be used to heat water. Assuming all the energy produced is transferred to the water, what mass of water can be heated from 15.0°C to 70.0°C when 1.00 mole of $C_4H_{10(g)}$ is burned? (The specific heat capacity of water is 4.18 J g^{-1} °C^{-1}.)

78. Answer all four questions below about the chemical reaction for which rate information is given.

The reaction between $NO_{(g)} + Br_{2(g)}$ to form $NOBr_{(g)}$ is studied in the four trials described below:

$$2NO_{(g)} + Br_{2(g)} \rightarrow 2NOBr_{(g)}$$

Trial	Initial [NO] (mol L^{-1})	Initial $[Br_2]$ (mol L^{-1})	Initial rate of formation of NOBr $(\text{mol L}^{-1}\ \text{sec}^{-1})$
I	0.100	0.100	1.20×10^{-3}
II	0.100	0.200	2.40×10^{-3}
III	0.200	0.100	4.80×10^{-3}
IV	0.300	0.100	1.08×10^{-2}

(a) Write the rate law for the reaction above in the form Rate $= k[NO]^x[Br_2]^y$. Explain how you determined the values for exponents x and y.

(b) On the basis of the rate law determined in part (A), calculate the specific rate constant. Specify the units.

(c) Calculate the initial rate in trial III if the volume of the container for the reaction mixture is decreased to half its original volume.

(d) Calculate the rate in trial IV after [NO] has decreased to 0.150 M.

Part B: Questions 79, 80, 81 and
Question 82 or Question 83
Time: 50 minutes

Access to Periodic Table, lists of standard reduction potentials
and *Equations and Constants*
No access to calculators

Answer question 79 below: The Section II score weighting for this question is 15 percent.

79. (2004 Examination directions) 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 the 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.

(a) Diethyl ether is ignited in air.

(b) A dilute solution of hydrofluoric acid is added to excess potassium hydroxide solution.

(c) Solutions of sodium sulfide and manganese(II) nitrate are mixed.

(d) Solid calcium oxide is sprinkled onto water.

(e) An electric current is passed through molten potassium iodide.

(f) Solid potassium chlorate is mixed with solid manganese(IV) oxide and heated in a test tube.

(g) Fine iron wire is heated in oxygen.

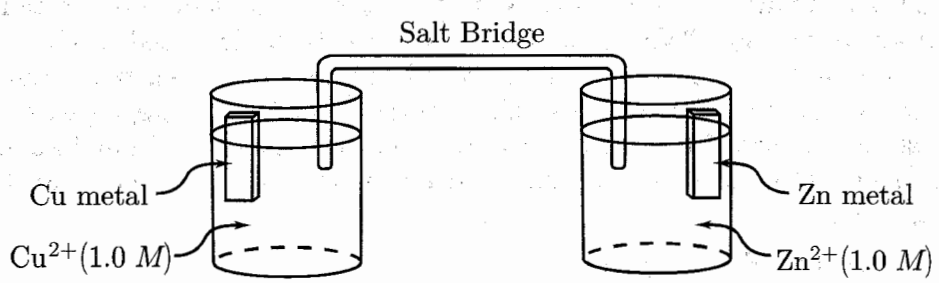
(h) A bar of aluminum is placed in a solution of copper(II) nitrate.

(2004 Examination directions) 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.

(2004 examination directions) **Answer both Question 80 and Question 81 below.** Both questions will be graded.

The Section II score weighting for these questions is 30 percent (15 percent each).

80.



Answer the following questions about the setup and operation of a galvanic cell.

(a) One item is missing from this electrochemical cell that prevents it from functioning. Identify that item by drawing it onto the diagram. Label the missing item.

(b) Once this cell is operating, a redox reaction occurs.

(i) Which electrode, Cu or Zn, is the cathode? Explain.

(ii) Write the reaction for the half-cell containing zinc.

(iii) Calculate the voltage E° for this cell.

(c) Set up the equation to calculate E in volts for the cell when the molarity of Cu^{2+} in the left half-cell is reduced to 0.10 M. Label each factor in the equation with proper units.

(d) Suppose that the temperature of the original galvanic cell is decreased to 273 K. Would the voltage decrease, stay the same, or increase? Explain.

(e) What would be the effect on the voltage if the metal electrodes were doubled in mass? Explain.

(f) What would be the effect on the voltage if a solution of NaOH were poured into the Zn/Zn^{2+} half-cell? Explain.

(g) What would be the effect on the voltage if a solution of 10.0 M $Zn(NO_3)_2$ were poured into the Zn/Zn^{2+} half-cell? Explain.

81. Answer the four questions below about a buffer solution

$$H_2O + CO_2 \rightleftharpoons HCO_3^- + H^+ \qquad K_I = 4.4 \times 10^{-7}$$
$$HCO_3^- \rightleftharpoons CO_3^{2-} + H^+ \qquad K_{II} = 4.7 \times 10^{-11}$$

A buffer solution is prepared by placing 0.30 mol CO_3^{2-} and 0.50 mol HCO_3^- in sufficient water to prepare 1.00 liter of solution. Half of this solution is poured into a flask labeled #1; the other half is placed in flask #2.

(a) What is a buffer solution? What characteristics of the dissolved species give this solution its buffering properties?

(b) Draw Lewis dot structures for hydrogen carbonate ion and hydroxide ion.

(c) What is the effect on $[CO_3^{2-}]$ and $[HCO_3^-]$ when 0.10 mol $KHSO_{4(s)}$ is added to the solution in flask #1? Account for your answer in terms of moles of protons transferred. Has the capacity of the buffer been exceeded?

(d) In another experiment 0.10 mol $NaOH_{(s)}$ is added to the solution in flask #2. What are the new equilibrium values for $[CO_3^{2-}]$ and $[HCO_3^-]$?

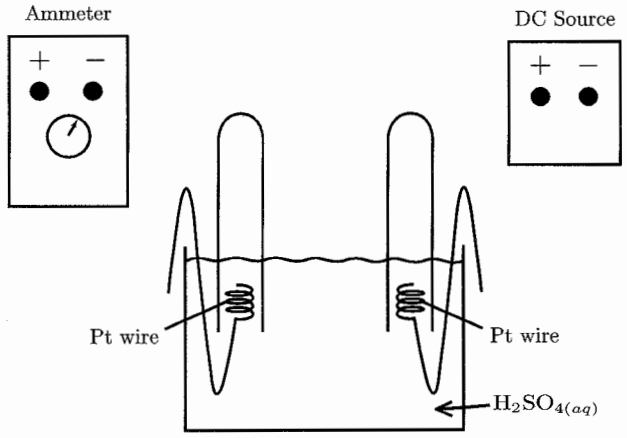
(2004 examination directions) **Answer either question 82 or question 83 below.** Only one of these two questions will be graded. If you start both questions, be sure to cross out the question you do not want graded. The Section II score weighting for the question that you choose is 15 percent.

82. Answer all four questions below about the setup and operation of an electrolytic device.

The term, faraday, refers to the quantity of charge on one mole of electrons. That value can be determined experimentally by the electrolysis of a dilute solution of sulfuric acid and collecting the gases produced. The materials and apparatus available are listed below:

apparatus to be assembled	other apparatus
ammeter	barometer
dilute sulfuric acid in a large vessel	clock
platinum wires	thermometer
source of direct current	
two graduated measuring tubes	

(a) Sketch a diagram to show how to assemble the apparatus listed above to conduct the experiment that will provide a value of the faraday. You may choose to connect the apparatus in the diagram below.



Sulfuric acid solution with two gas measuring tubes and two platinum wires

(b) When the volume of hydrogen collected is 90.0 mL, what is the expected volume of oxygen? Explain.

(c) What measurements are necessary to determine the number of coulombs of electricity that are transferred during the experiment? Explain.

(d) How would the experiment be affected if copper metal were used in place of platinum? Explain.

83. Provide the information specified in the three questions below about the classification of solids.

Most crystalline solids can be classified into one of the four categories specified in columns 1 through 4 listed below. This classification is based upon differences in force of attraction between the particles found at the lattice points.

Answer each of the following for the four categories of solid listed according to the directions below. For each category, one piece of information is given. Complete the table by writing your answer in each space provided.

(a) Identify a substance that corresponds to the given information in columns 2 and 4.

(b) For columns 1, 3 and 4, specify the chemical symbol or formula for the particle(s) found at each lattice point for the example given on line (a) in the table.

(c) For columns 1, 2 and 3, identify or describe the force of attraction between the particles specified on line (b) the table.

	Categories of Solids			
	1	**2**	**3**	**4**
	ionic solid	**metallic solid**	**molecular solid**	**network (covalent solid)**
(i) example	CaS (calcium sulfide)		CO_2	
(ii) particles at lattice point		Mg^{2+} ion		
(iii) force between particles				covalent bond (shared pair of electrons)

SAMPLE EXAMINATION IV

Section I – Multiple Choice

Questions 1-5. The set of lettered choices, a list of oxides, below refers to the numbered phrases immediately following it. Select the one lettered choice that is most closely associated with each numbered phrase. Each lettered choice can be used once, more than once or not at all.

(A) SO_2

(B) BaO_2

(C) CO_2

(D) GeO_2

(E) NO_2

1. an odd electron molecule

2. an ionic compound

3. at STP the gas that illustrates greatest deviation from ideal behavior

4. source of a semiconductor

5. includes a element with oxidation number of +2

---

6. Which event is most likely to occur in an experiment to measure ionization energy?

   (A) A positive ion is converted to a negative ion.

   (B) A neutral atom is converted to a positive ion.

   (C) A neutral atom is converted to a negative ion.

   (D) A negative ion is converted to a neutral atom.

   (E) A negative ion is converted to a positive ion.

7. All of these sets of quantum numbers apply to an electron in the p-sublevel EXCEPT

(A) $2,\ 1,\ 1, +\frac{1}{2}$

(B) $3,\ 1,\ 0, +\frac{1}{2}$

(C) $3,\ 1,\ 0, -\frac{1}{2}$

(D) $2,\ 0,\ 0, +\frac{1}{2}$

(E) $2,\ 1,\ 0, +\frac{1}{2}$

8. Which is a correct comparison of a sulfide ion to a sulfur atom?

I. The radius of the sulfur atom is greater.

II. The sulfide ion contains more electrons.

III. The number of energy levels occupied by electrons is the same.

(A) I only

(B) II only

(C) I and II only

(D) I and III only

(E) II and III only

Questions 9-11: The set of lettered choices below is a list of molecular formulas for certain gases. Select the one lettered choice that best fits each numbered description of the bonds within the molecules of the gas.

(A) H_2

(B) N_2

(C) O_2

(D) F_2

(E) Cl_2

9. contains bond with greatest multiplicity

10. has the strongest bond

11. has the shortest bond length

Questions 12-14: The set of lettered choices below is a list of molecular geometries. For each numbered species, select the one lettered choice that describes its molecular geometry.

(A) linear

(B) seesaw

(C) square planar

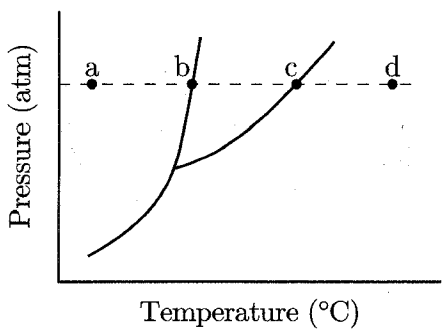
(D) square pyramidal

(E) T-shaped

12. $XeCl_4$

13. I_3^-

14. IF_3



15. The dashed line, *ad*, in the phase diagram above represents properties of a closed system as energy is added to that system at a constant rate. The properties are observed at points *a*, *b*, *c*, and *d*. Which is associated with the longest time period?

(A) change in temperature from *a* to *b*

(B) equilibrium with constant temperature at *b*

(C) change in temperature from *b* to *c*

(D) equilibrium with constant temperature at *c*

(E) change in temperature from *c* to *d*

16. Which gives a reason why, compared to CO_2, SO_2 exhibits greater deviation from ideal gas behavior?

I. The O-S-O bond angle is greater than the O-C-O bond angle.

II. A molecule of SO_2 contains more electrons than a molecule of CO_2.

III. The bond order of the S-O bond is less than the bond order of the C-O bond.

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

17. When these five water solution systems are listed in order of increasing vapor pressure, which position is occupied by 0.1 m $C_6H_{12}O_6$, glucose? (Assume ideal behavior.)

0.2 m KNO_3
0.2 m $(NH_2)_2CO$, urea
0.1 m $CaCl_2$
0.1 m C_2H_5OH
0.1 m $C_6H_{12}O_6$, glucose

(A) first
(B) second
(C) third
(D) fourth
(E) fifth

18. A solution is prepared by dissolving 8.01 g of ammonium nitrate, NH_4NO_3 (molar mass: 80.1 g), in enough water to yield 250.0 mL of solution. What is the molarity of ammonium nitrate in this solution?

(A) 32.0 M
(B) 4.00 M
(C) 0.400 M
(D) 0.100 M
(E) 0.0400 M

19. Which aqueous solution has the highest boiling point?

(A) 0.1 m $SrBr_2$

(B) 0.1 m KBr

(C) 0.1 m $MgSO_4$

(D) 0.1 m CH_3COOH

(E) 0.1 m C_2H_5OH

20. Which of these chlorine-containing compounds is most soluble in water?

(A) AgCl

(B) CCl_3OH

(C) CCl_4

(D) $PbCl_2$

(E) $HClO_4$

21. Which conditions of pressure and temperature favor greatest solubility of a gas into a liquid?

	P	**T**
(A)	low	low
(B)	low	high
(C)	high	low
(D)	high	high
(E)	moderate	moderate

22. A solution is prepared by dissolving 1.0 mol of acetic acid, CH_3COOH (molar mass: 60.0 g), in 5.0 mol water (molar mass: 18 g). Which expression gives the molality of this solution.

(A) $\frac{1}{0.090}$

(B) $\frac{1}{5}$

(C) $\frac{1}{6}$

(D) $\frac{60}{5 \times 18}$

(E) $\frac{60}{0.090}$

23. Consider a solution that is 0.50 X (mole fraction) of ethanol (molar mass: 46 g) in water (molar mass: 18 g). Which value gives the best approximation for percent by mass ethanol in that solution?

(A) 10%

(B) 25%

(C) 50%

(D) 75%

(E) 90%

24. The mass percent of one oxide of manganese is determined to be 69.6% Mn and 30.4% O. Which expression is the best representation of the empirical formula of this compound?

(A) $\mathrm{Mn}_{\frac{69.6}{6.02}}\ \mathrm{O}_{\frac{30.4}{6.02}}$

(B) $\mathrm{Mn}_{\frac{69.6}{30.4}}\ \mathrm{O}_{\frac{30.4}{30.4}}$

(C) $\mathrm{Mn}_{\frac{69.6}{30.4}}\ \mathrm{O}_{\frac{30.4}{69.6}}$

(D) $\mathrm{Mn}_{\frac{69.6}{55.0}}\ \mathrm{O}_{\frac{30.4}{16.0}}$

(E) $\mathrm{Mn}_{\frac{55.0}{69.6}}\ \mathrm{O}_{\frac{16.0}{30.4}}$

25. When zinc reacts with nitric acid, one product is ammonium nitrate. When the corresponding half-reaction as shown below is balanced using the lowest integers, what is the sum of the coefficients?

$$..?..\ NO_3^- + ..?..\ H^+ + ..?..\ e^- \rightarrow ..?..\ NH_4^+ + ..?..\ H_2O$$

(A) 13

(B) 15

(C) 19

(D) 21

(E) 23

26. Consider a mixture of gases that contains 0.10 mol of $N_2O_{5(g)}$ and 0.10 mol of $NO_{2(g)}$ at STP. Which gives a correct description of a quantity of material present?

I. The number of atoms is greater than 5×10^{23}.

II. The number of molecules is greater than 1×10^{23}.

III. The volume of the sample is greater than 2.24 liters.

(A) I and II only

(B) II and III only

(C) III only

(D) I and III only

(E) I, II and III only

27. Consider the reaction of powdered zinc metal with hydrochloric acid to form hydrogen gas. Each of the following causes the reaction rate to decrease EXCEPT

(A) substituting a zinc bar of the same mass as the powdered zinc

(B) cooling the reaction mixture

(C) diluting the acid solution

(D) stirring the reaction mixture

(E) substituting HF solution of equal molarity for the HCl solution

28. Ordinarily the rate of any reaction in a closed system at constant temperature decreases over time. Which corresponding change over time accounts for this phenomenon?

(A) The concentrations of the products increase.

(B) The concentrations of the reactants decrease.

(C) The number of effective collisions between reacting particles increases.

(D) The energy of activation decreases.

(E) The effective concentration of the catalyst decreases.

29. Strontium-90 has a half-life of 28.8 years. Approximately what mass from a 50.0 gram sample of pure ^{90}Sr would remain after the passage of 90 years?

(A) 33.3 g

(B) 25.0 g

(C) 16.7 g

(D) 12.5 g

(E) 6.25 g

30. Carbon-14 has a half-life of approximately 6000 years. What fraction of an original sample would remain after 24,000 years?

(A) 1/64

(B) 1/32

(C) 1/16

(D) 1/8

(E) 1/4

31. Each of the following is a reasonable label for the rate of a reaction EXCEPT

(A) mol L^{-1}

(B) mol L^{-1} sec^{-1}

(C) molecules sec^{-1}

(D) g sec^{-1}

(E) mol L^{-1} sec^{-1}

32. When the rate law for a reaction is second order in terms of a certain reactant, how will the reaction rate be affected when the concentration of that reactant is doubled?

(A) halved
(B) remains the same
(C) doubles
(D) triples
(E) quadruples

33. Excess 0.1 M $NaCl_{(aq)}$ is added to 100 mL of 0.1 M $AgNO_{3(aq)}$. A white precipitate forms. Which is a correct description of the quantities present?

	liquid phase	**solid phase**
(A)	$[Ag^+] = [Cl^-]$	mol Ag^+ = mol Cl^-
(B)	$[Ag^+] < [Cl^-]$	mol Ag^+ = mol Cl^-
(C)	$[Ag^+] = [Cl^-]$	mol Ag^+ < mol Cl^-
(D)	$[Ag^+] < [Cl^-]$	mol Ag^+ < mol Cl^-
(E)	$[Ag^+] > [Cl^-]$	mol Ag^+ < mol Cl^-

34. Which statement of equality applies to the equilibrium established when excess 0.1 M $NaCl_{(aq)}$ is added to 100 mL of 0.1 M $AgNO_{3(aq)}$?

(A) $[Na^+] = [NO_3^-]$
(B) $[Ag^+] = [Cl^-]$
(C) $[Na^+] = [Cl^-]$
(D) The rate of formation of $AgCl_{(s)}$ = rate of dissolution of $AgCl_{(s)}$
(E) The rate of formation of $NaCl_{(s)}$ = rate of formation of $AgCl_{(s)}$

35. A sealed metal tank contains the equilibrium system represented by the equation below.

$$2NO_{(g)} + \tfrac{1}{2}O_{2(g)} \rightleftharpoons N_2O_{3(g)} + 90 \text{ kJ}$$

Some additional oxygen is added to the equilibrium system and the tank resealed. A new equilibrium is achieved after 10 minutes. Conditions of pressure and temperature are represented by the symbols in the table below.

	pressure	**temperature**
at the original equilibrium	P_1	T_1
at the time oxygen added	P_2	T_2
at the final equilibrium	P_3	T_3

Which is a correct statement of the relationship between these values?

(A) P_1 is the greatest of the three pressures; T_1 is the greatest of the three temperatures.

(B) P_3 is the greatest of the three pressures; T_1 is the greatest of the three temperatures.

(C) P_2 is the greatest of the three pressures; T_1 is the greatest of the three temperatures.

(D) P_2 is the greatest of the three pressures; T_3 is the greatest of the three temperatures.

(E) P_3 is the greatest of the three pressures; T_3 is the greatest of the three temperatures.

36. For which ranges of values for enthalpy change, ΔH, and entropy change, ΔS, is a reaction always spontaneous?

	ΔH	**ΔS**
(A)	>0	>0
(B)	>0	<0
(C)	<0	>0
(D)	0	<0
(E)	>0	0

37. $$C_5H_{12(\ell)} + 8O_{2(g)} \rightarrow 5CO_{2(g)} + 6H_2O_{(g)}$$

For the combustion of pentane as shown in the equation above, what are the signs of ΔG, ΔH, and ΔS?

	ΔG	**ΔH**	**ΔS**
(A)	$-$	$-$	$-$
(B)	$-$	$-$	$+$
(C)	$-$	$+$	$-$
(D)	$+$	$-$	$+$
(E)	$+$	$+$	$+$

38. Which terms describe the quantity of energy in the universe and the measure of entropy in the universe, respectively?

(A) constant, increasing

(B) constant, constant

(C) constant, decreasing

(D) increasing, constant

(E) decreasing, decreasing

39. Which applies to a reaction system for which $\Delta G = 0$?

(A) The reaction system has gone to completion.

(B) The reaction system has reached equilibrium.

(C) The reaction system has reached the temperature of 0 kelvins.

(D) The entropy of the reaction system has reached zero.

(E) The limiting reactant has been consumed.

40. Which properties must be known in order to use a constant-pressure ("coffee cup") calorimeter to investigate heats of reaction?

I. Heat capacity of the calorimeter, c_{cal}

II. Heat capacity of the solution, $c_{sol'n}$

III. Mass of solution

(A) I only

(B) II only

(C) III only

(D) I and III only

(E) I, II, and III

41. Which 0.1 *M* solution has the lowest pH?

(A) $NaNO_3$

(B) NaH_2PO_4

(C) NaOH

(D) Na_2CO_3

(E) $NaHCO_3$

42. Which pair of equations illustrates the amphiprotic properties of some aluminum-containing species?

1. $Al^{3+}_{(aq)} + S^{2-}_{(aq)} \rightarrow Al_2S_{3(s)}$
2. $4Al_{(s)} + 3O_{2(g)} \rightarrow 2Al_2O_{3(s)}$
3. $2Al_{(s)} + Fe_2O_{3(s)} \rightarrow Al_2O_{3(s)} + 2Fe_{(s)}$
4. $AlCl_{3(s)} + NaCl_{(aq)} \rightarrow AlCl_4^-{}_{(aq)} + Na^+_{(aq)}$
5. $Al(OH)_{3(s)} + 3H^+_{(aq)} \rightarrow Al^{3+}_{(aq)} + 3H_2O$
6. $Al(OH)_{3(s)} + OH^-_{(aq)} \rightarrow AlO_2^-{}_{(aq)} + 2H_2O$

(A) equations 1 & 4
(B) equations 2 & 3
(C) equations 2 & 6
(D) equations 4 & 5
(E) equations 5 & 6

43. Which accounts for the chemical change that occurs when $NH_{3(aq)}$ is added to $HCl_{(aq)}$?

(A) The Cl^- ion gives up excess electrons.
(B) When dissolved in water, the Cl^- ion takes on eight valence electrons.
(C) The NH_3 molecule has a greater dipole moment than the HCl molecule.
(D) The H-N-H bond angle is less than 109°47' (the regular tetrahedral bond angle).
(E) The unshared electron pair on NH_3 provides a bond site for the transferred proton.

44. Which applies to the process of the electrolysis of a dilute H_2SO_4 solution?

I. The pH of the solution around the anode becomes lower.
II. Reduction occurs at the cathode.
III. Bubbles appear at each electrode.

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

45. Which description applies to any galvanic (voltaic) cell?

(A) Oxidation occurs at the anode.

(B) Electrons move from the cathode to the anode through an external circuit.

(C) Electrons move from the anode to the cathode through the salt bridge.

(D) The anode gains mass.

(E) The cathode attracts anions.

46. Which describes the behavior of the galvanic (voltaic) cell $Zn/Zn^{2+}(1\ M)//Cu^{2+}(1\ M)/Cu$ during the discharge reaction?

(A) Oxidation occurs at the copper electrode.

(B) The mass of the zinc electrode decreases.

(C) The concentration of Cu^{2+} ion increases.

(D) Bubbling of gas occurs at each electrode.

(E) The concentration of Zn^{2+} ion decreases.

47. For which reduction does the transfer of one mole of electrons produce the greatest mass of metal?

(A) aluminum: $Al^{3+} \rightarrow Al$

(B) chromium: $Cr^{3+} \rightarrow Cr$

(C) copper: $Cu^{2+} \rightarrow Cu$

(D) silver: $Ag^{+} \rightarrow Ag$

(E) zinc: $Zn^{2+} \rightarrow Zn$

48. Which mathematical expression identifies the number of coulombs necessary to produce one mole of iron metal from an aqueous solution of iron(III) sulfate, $Fe_2(SO_4)_3$?

(A) $\dfrac{96{,}500}{(2 \times 3)}$

(B) $\dfrac{96{,}500}{3}$

(C) $96{,}500$

(D) $96{,}500 \times 3$

(E) $96{,}500 \times (2 \times 3)$

49. Which describes a dead battery?

I. $\Delta G = 0$

II. All chemical reactions have stopped.

III. The cell can no longer do work.

(A) I only

(B) II only

(C) I and III only

(D) II and III only

(E) I, II, and III

50. Which gives the number of isomers by category for the hydrocarbon pentene, C_5H_{10}?

	straight chain isomers	**branched chain isomers**
(A)	1	2
(B)	1	3
(C)	2	2
(D)	2	3
(E)	2	4

51. Which set of hybrid orbitals accounts for the O–C–C bond angle in propanone, CH_3COCH_3?

(A) sp^2

(B) sp^3

(C) sp^4

(D) dsp^3

(E) d^2sp^3

52. Which six-carbon compound reacts most readily with $Br_{2(\ell)}$?

(A) glucose, $C_6H_{12}O_6$

(B) benzene, C_6H_6

(C) cyclohexene, C_6H_{10}

(D) cyclohexane, C_6H_{12}

(E) hexane, C_6H_{14}

Questions 53-56: The list of lettered choices below gives the symbols for five of the noble gases. For each numbered phrase, choose the symbol of the noble gas with which that phrase is most closely associated. A choice may be used once, more than once or not at all.

(A) He
(B) Ne
(C) Ar
(D) Xe
(E) Rn

53. first discovered in spectroscopy of the Sun

54. most abundant noble gas in the atmosphere

55. name means "the stranger"

56. prolonged exposure causes lung cancer

---

57. Which oxide, when added to water, can produce a solution that is a strong acid?

(A) Na_2O
(B) CaO
(C) Fe_2O_3
(D) N_2O_5
(E) P_4O_{10}

58. Which oxide has the highest melting point?

(A) CO_2
(B) Al_2O_3
(C) Na_2O
(D) MgO
(E) SO_2

59. Which is the best description of the chemical change that occurs when magnesium metal dissolves in dilute hydrochloric acid?

(A) reduction of Mg

(B) oxidation of Mg

(C) proton donation by HCl

(D) proton acceptance by Cl^-

(E) proton donation by Cl^-

60. These isoelectronic species are listed in order of increasing atomic mass. When the list is rearranged according to increasing positive charge-to-mass ratio, what position is occupied by $^{39}K^+$?

$$^{31}P^{3-} \quad ^{35}Cl^- \quad ^{39}K^+ \quad ^{40}Ar^0 \quad ^{45}Sc^{3+}$$

(A) first

(B) second

(C) third

(D) fourth

(E) fifth

61. Which applies to the formation of solid water (ice) crystals on the surface of a package of frozen food stored in a home freezer?

I. Hydrogen bonds form between water molecules.

II. Energy is absorbed from the food package by the water molecules

III. The entropy of the system decreases

(A) I only

(B) III only

(C) I and III only

(D) II and III only

(E) I, II and III

62. The heat of solution for $LiBr_{(s)}$, a crystalline solid, is -48.8 kJ mol^{-1}. Which describes the changes that are predicted to occur when $LiBr_{(s)}$ dissolves in water?

(A) The temperature of the system remains the same as the entropy increases.

(B) The temperature of the system increases as the entropy increases.

(C) The temperature of the system decreases as the entropy increases.

(D) The temperature of the system increases as the entropy decreases.

(E) The temperature of the system decreases as the entropy decreases.

63. Which is the best description of the chemical change that occurs when excess $OH^-_{(aq)}$ is added to a solution of KHC_2O_4?

(A) A proton is transferred from each $HC_2O_4^-$ ion to form H_2O molecules.

(B) A proton is transferred from each $HC_2O_4^-$ ion to form H_3O^+ ions.

(C) A proton is transferred from each $HC_2O_4^-$ ion to release CO_2 molecules.

(D) A proton is transferred to each $HC_2O_4^-$ ion to form $H_2C_2O_4$ molecules.

(E) Two protons are transferred to each $HC_2O_4^-$ ion to form $H_3C_2O_4^+$ ions.

64. The heat of solution for $NH_4NO_{3(s)}$ is +25.7 kJ mol^{-1}. Its solubility is 120 g per 100 g H_2O at 298 K. Which gives the best description of the thermodynamic parameters ΔH, ΔG and ΔS, for the dissolving process at 298 K?

	ΔH	**ΔG**	**ΔS**
(A)	>0	<0	>0
(B)	<0	<0	<0
(C)	>0	>0	>0
(D)	>0	0	>0
(E)	>0	0	<0

65. What is the best description of the distribution of bonding electrons at the carbon atom in a molecule of formic acid, HCOOH?

(A) one *pi* bond and two *sigma* bonds with *sp* hybridization

(B) one *pi* bond and three *sigma* bonds with sp^2 hybridization

(C) one *pi* bond and three *sigma* bonds with sp^3 hybridization

(D) four *sigma* bonds with sp^3 hybridization

(E) three *sigma* bonds with sp^2 hybridization

66. All of these properties are the same for both isotopes of chlorine, $^{35}_{17}Cl$ and $^{37}_{17}Cl$, EXCEPT

(A) nuclear mass

(B) nuclear charge

(C) extra-nuclear charge

(D) number of occupied orbitals in the outer energy level

(E) number of vacant orbitals in the outer energy level

67. When 100 mL of 0.100 M $Ba(NO_3)_2$ solution is added to 100 mL of 0.100 M NaF solution, a white precipitate forms. Which ratio of concentrations of ions in the resulting solution is closest to 2:1?

(A) $\frac{[F^-]}{[NO_3{}^-]}$

(B) $\frac{[F^-]}{[Ba^{2+}]}$

(C) $\frac{[NO_3{}^-]}{[Na^+]}$

(D) $\frac{[Ba^{2+}]}{[Na^+]}$

(E) $\frac{[NO_3{}^-]}{[Ba^{2+}]}$

68. Magnesium sulfate, $MgSO_4$ (molar mass: 120 g) occurs as a hydrated salt, $MgSO_4\ 7H_2O$ (molar mass: 246 g). Which expression gives the gain in mass of the solid phase expected when 10.0 grams of anhydrous magnesium sulfate is dissolved in water and the solution allowed to evaporate?

(A) $10.0 \times \frac{246}{120}$

(B) $10.0 \times \frac{126}{246}$

(C) $10.0 \times \frac{246}{126}$

(D) $10.0 \times \frac{126}{120}$

(E) $10.0 \times \frac{120}{126}$

69. Which describes the concentrations of K^+ and Cl^- ions in the reaction mixture produced when $KOH_{(aq)}$ is added to $HCl_{(aq)}$?

	$[K^+]$	$[Cl^-]$
(A)	decreases	decreases
(B)	remains the same	decreases
(C)	increases	remains the same
(D)	remains the same	decreases
(E)	increases	decreases

70. Which cation, when added to a solution of KOH, produces a colored precipitate?

(A) Ca^{2+}

(B) K^{+}

(C) Mg^{2+}

(D) Ni^{2+}

(E) Zn^{2+}

71. In a dilute aqueous solution of H_3PO_4, which proton donor has the highest concentration?

(A) H_3O^{+}

(B) $HPO_4{}^{2-}$

(C) H_3PO_4

(D) $H_2PO_4{}^{-}$

(E) $H_4PO_4{}^{+}$

72. When $BaSO_4$ dissolves to form a saturated solution, $[Ba^{2+}] = 1.05 \times 10^{-5}$. When the solubility product constant, K_{sp}, for $BaSO_4$ is expressed in scientific notation, what is the value of its exponential term?

(A) -30

(B) -25

(C) -15

(D) -10

(E) -5

73. Two Lewis structures can be used to represent the resonance features of the bonding in the sulfur dioxide, SO_2, molecule. Which Lewis structure below is one of those resonance structures?

(A) :O=S=O:

(B) :Ö—S̈=Ö:

(C) :Ö—S̈—Ö:

(D) :Ö=S=Ö:

(E) :Ö—S̈—Ö:

74. What is the sum of all coefficients when the following equation is balanced using smallest possible integers?

$$\ldots C_{12}H_{22}O_{11(s)} + \ldots O_{2(g)} \rightarrow \ldots CO_{2(g)} + \ldots H_2O_{(g)}$$

(A) 4
(B) 12
(C) 13
(D) 35
(E) 36

75. Spontaneous dissolving processes for ionic compounds in water can be exothermic or endothermic. Which component of the dissolving process supplies most of the energy that is produced in an exothermic process?

(A) dissociation of the solvent
(B) increase in entropy
(C) hydration of ions
(D) ionization energy of the cation
(E) loss of energy of activation