

## CHEMISTRY

## Section I

Time—1 hour and 30 minutes

NO CALCULATOR MAY BE USED WITH SECTION I.

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

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

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

## Part A

**Directions:** Each set of lettered choices below refers to the numbered statements immediately following it. Select the one lettered choice that best fits each statement and then fill in the corresponding oval on the answer sheet. A choice may be used once, more than once, or not at all in each set.

## Questions 1-2

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

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

1. The atom that contains exactly two unpaired electrons
2. The atom that contains only one electron in the highest occupied energy sublevel

## Questions 3-5 refer to the following molecules.

- (A)  $\text{CO}_2$
- (B)  $\text{H}_2\text{O}$
- (C)  $\text{CH}_4$
- (D)  $\text{C}_2\text{H}_4$
- (E)  $\text{PH}_3$

3. The molecule with only one double bond
4. The molecule with the largest dipole moment
5. The molecule that has trigonal pyramidal geometry

**Section I****Part A**

Questions 6-7 refer to the following solid compounds.

- (A)  $\text{PbSO}_4$
- (B)  $\text{CuO}$
- (C)  $\text{KMnO}_4$
- (D)  $\text{KCl}$
- (E)  $\text{FeCl}_3$

- 6. Is purple in aqueous solution
- 7. Is white and very soluble in water

Questions 8-10 refer to the following gases at  $0^\circ\text{C}$  and 1 atm.

- (A) Ne
- (B) Xe
- (C)  $\text{O}_2$
- (D) CO
- (E) NO

- 8. Has an average atomic or molecular speed close to that of  $\text{N}_2$  molecules at  $0^\circ\text{C}$  and 1 atm
- 9. Has the greatest density
- 10. Has the greatest rate of effusion through a pinhole

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Questions 11-14 refer to the reactions represented below.

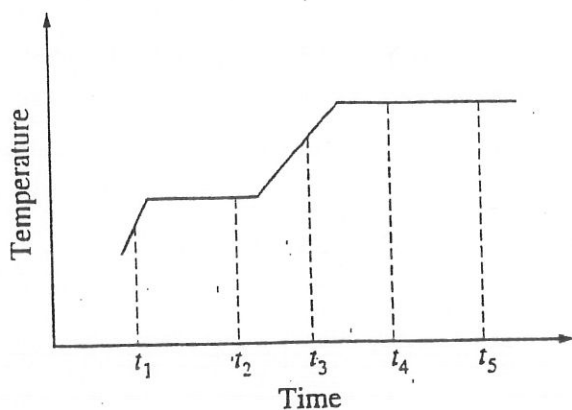
- (A)  $\text{H}_2\text{SeO}_4(\text{aq}) + 2 \text{Cl}^-(\text{aq}) + 2 \text{H}^+(\text{aq}) \rightarrow \text{H}_2\text{SeO}_3(\text{aq}) + \text{Cl}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$
- (B)  $\text{S}_8(\text{s}) + 8 \text{O}_2(\text{g}) \rightarrow 8 \text{SO}_2(\text{g})$
- (C)  $3 \text{Br}_2(\text{aq}) + 6 \text{OH}^-(\text{aq}) \rightarrow 5 \text{Br}^-(\text{aq}) + \text{BrO}_3^-(\text{aq}) + 3 \text{H}_2\text{O}(\text{l})$
- (D)  $\text{Ca}^{2+}(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) \rightarrow \text{CaSO}_4(\text{s})$
- (E)  $\text{PtCl}_4(\text{s}) + 2 \text{Cl}^-(\text{aq}) \rightarrow \text{PtCl}_6^{2-}(\text{aq})$

- 11. A precipitation reaction
- 12. A reaction that produces a coordination complex
- 13. A reaction in which the same reactant undergoes both oxidation and reduction
- 14. A combustion reaction

## Part B

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

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



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

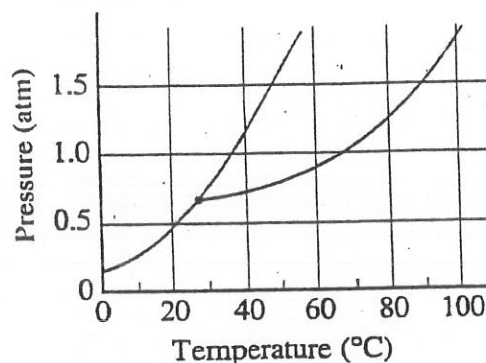
- (A)  $t_1$
- (B)  $t_2$
- (C)  $t_3$
- (D)  $t_4$
- (E)  $t_5$

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

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

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

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



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

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

## Section I

## Part B

19. In which of the following species does sulfur have the same oxidation number as it does in  $\text{H}_2\text{SO}_4$ ?

- (A)  $\text{H}_2\text{SO}_3$   
 (B)  $\text{S}_2\text{O}_3^{2-}$   
 (C)  $\text{S}^{2-}$   
 (D)  $\text{S}_8$   
 (E)  $\text{SO}_2\text{Cl}_2$

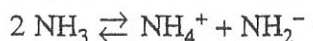
20. A flask contains 0.25 mole of  $\text{SO}_2(g)$ , 0.50 mole of  $\text{CH}_4(g)$ , and 0.50 mole of  $\text{O}_2(g)$ . The total pressure of the gases in the flask is 800 mm Hg. What is the partial pressure of the  $\text{SO}_2(g)$  in the flask?

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

21. In the laboratory,  $\text{H}_2(g)$  can be produced by adding which of the following to 1 M  $\text{HCl}(aq)$ ?

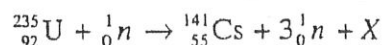
- I. 1 M  $\text{NH}_3(aq)$   
 II.  $\text{Zn}(s)$   
 III.  $\text{NaHCO}_3(s)$

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



22. In liquid ammonia, the reaction represented above occurs. In the reaction  $\text{NH}_4^+$  acts as

- (A) a catalyst  
 (B) both an acid and a base  
 (C) the conjugate acid of  $\text{NH}_3$   
 (D) the reducing agent  
 (E) the oxidizing agent

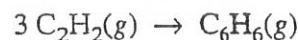


23. Neutron bombardment of uranium can induce the reaction represented above. Nuclide X is which of the following?

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

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

- (A)  $\text{KTeO}$   
 (B)  $\text{KTe}_2\text{O}$   
 (C)  $\text{K}_2\text{TeO}_3$   
 (D)  $\text{K}_2\text{TeO}_6$   
 (E)  $\text{K}_4\text{TeO}_6$



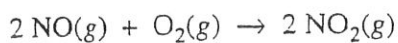
25. What is the standard enthalpy change,  $\Delta H^\circ$ , for the reaction represented above?

( $\Delta H_f^\circ$  of  $\text{C}_2\text{H}_2(g)$  is  $230 \text{ kJ mol}^{-1}$ ;  
 $\Delta H_f^\circ$  of  $\text{C}_6\text{H}_6(g)$  is  $83 \text{ kJ mol}^{-1}$ .)

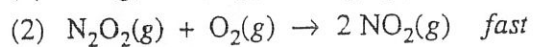
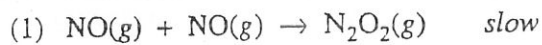
- (A)  $-607 \text{ kJ}$   
 (B)  $-147 \text{ kJ}$   
 (C)  $-19 \text{ kJ}$   
 (D)  $+19 \text{ kJ}$   
 (E)  $+773 \text{ kJ}$

26. Approximately what mass of  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$  ( $250 \text{ g mol}^{-1}$ ) is required to prepare 250 mL of 0.10 M copper(II) sulfate solution?

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



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



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

(A) Rate =  $k[\text{NO}]^2$

(B) Rate =  $k \frac{[\text{NO}]}{[\text{O}_2]}$

(C) Rate =  $k \frac{[\text{NO}]^2}{[\text{O}_2]}$

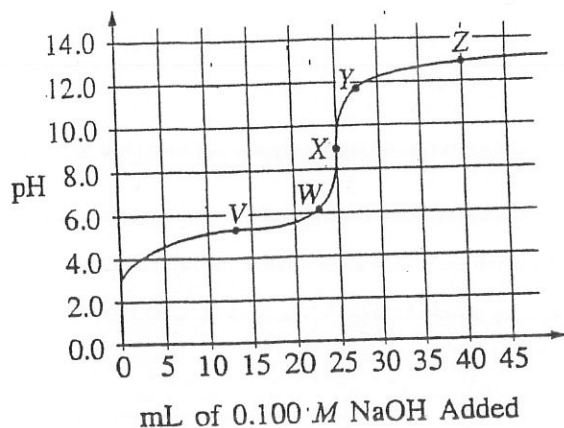
(D) Rate =  $k[\text{NO}]^2[\text{O}_2]$

(E) Rate =  $k[\text{N}_2\text{O}_2][\text{O}_2]$

28. Of the following compounds, which is the most ionic?
- (A)  $\text{SiCl}_4$   
 (B)  $\text{BrCl}$   
 (C)  $\text{PCl}_3$   
 (D)  $\text{Cl}_2\text{O}$   
 (E)  $\text{CaCl}_2$
29. The best explanation for the fact that diamond is extremely hard is that diamond crystals
- (A) are made up of atoms that are intrinsically hard because of their electronic structures  
 (B) consist of positive and negative ions that are strongly attracted to each other  
 (C) are giant molecules in which each atom forms strong covalent bonds with all of its neighboring atoms  
 (D) are formed under extreme conditions of temperature and pressure  
 (E) contain orbitals or bands of delocalized electrons that belong not to single atoms but to each crystal as a whole
30. At  $25^\circ\text{C}$ , aqueous solutions with a pH of 8 have a hydroxide ion concentration,  $[\text{OH}^-]$ , of
- (A)  $1 \times 10^{-14} \text{ M}$   
 (B)  $1 \times 10^{-8} \text{ M}$   
 (C)  $1 \times 10^{-6} \text{ M}$   
 (D)  $1 \text{ M}$   
 (E)  $8 \text{ M}$
- $\text{CS}_2(l) + 3 \text{O}_2(g) \rightarrow \text{CO}_2(g) + 2 \text{SO}_2(g)$
31. What volume of  $\text{O}_2(g)$  is required to react with excess  $\text{CS}_2(l)$  to produce 4.0 L of  $\text{CO}_2(g)$ ? (Assume all gases are measured at  $0^\circ\text{C}$  and 1 atm)
- (A) 12 L  
 (B) 22.4 L  
 (C)  $\frac{1}{3} \times 22.4 \text{ L}$   
 (D)  $2 \times 22.4 \text{ L}$   
 (E)  $3 \times 22.4 \text{ L}$
32. Which of the following oxides is a gas at  $25^\circ\text{C}$  and 1 atm?
- (A)  $\text{Rb}_2\text{O}$   
 (B)  $\text{N}_2\text{O}$   
 (C)  $\text{Na}_2\text{O}_2$   
 (D)  $\text{SiO}_2$   
 (E)  $\text{La}_2\text{O}_3$

## Questions 33-34

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



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

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

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

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

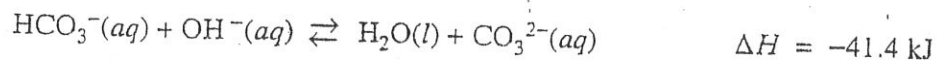
35. A solution is made by dissolving a nonvolatile solute in a pure solvent. Compared to the pure solvent, the solution

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

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

- (A)  $\text{Ag}^+(aq)$  and  $\text{Hg}_2^{2+}(aq)$   
 (B)  $\text{Ag}^+(aq)$  and  $\text{Pb}^{2+}(aq)$   
 (C)  $\text{Ba}^{2+}(aq)$  and  $\text{Ag}^+(aq)$   
 (D)  $\text{Ba}^{2+}(aq)$  and  $\text{Hg}_2^{2+}(aq)$   
 (E)  $\text{Ba}^{2+}(aq)$  and  $\text{Pb}^{2+}(aq)$

Part B



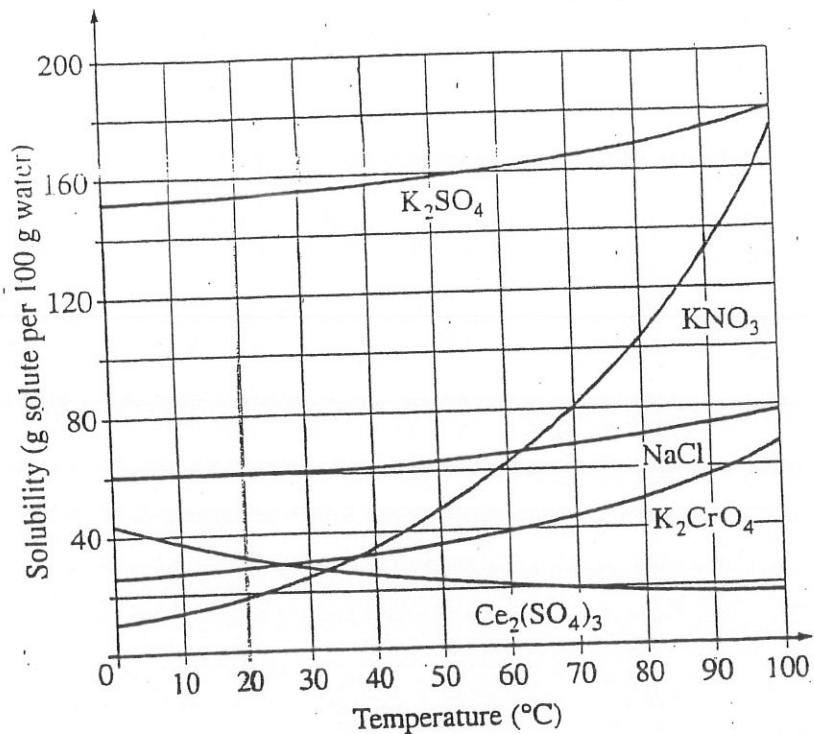
37. When the reaction represented by the equation above is at equilibrium at 1 atm and 25°C, the ratio  $\frac{[\text{CO}_3^{2-}]}{[\text{HCO}_3^-]}$  can be increased by doing which of the following?

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

38. A 0.10 M aqueous solution of sodium sulfate,  $\text{Na}_2\text{SO}_4$ , is a better conductor of electricity than a 0.10 M aqueous solution of sodium chloride,  $\text{NaCl}$ . Which of the following best explains this observation?

- (A)  $\text{Na}_2\text{SO}_4$  is more soluble in water than  $\text{NaCl}$  is.
- (B)  $\text{Na}_2\text{SO}_4$  has a higher molar mass than  $\text{NaCl}$  has.
- (C) To prepare a given volume of 0.10 M solution, the mass of  $\text{Na}_2\text{SO}_4$  needed is more than twice the mass of  $\text{NaCl}$  needed.
- (D) More moles of ions are present in a given volume of 0.10 M  $\text{Na}_2\text{SO}_4$  than in the same volume of 0.10 M  $\text{NaCl}$ .
- (E) The degree of dissociation of  $\text{Na}_2\text{SO}_4$  in solution is significantly greater than that of  $\text{NaCl}$ .





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

- (A) NaCl
- (B) KNO<sub>3</sub>
- (C) K<sub>2</sub>CrO<sub>4</sub>
- (D) K<sub>2</sub>SO<sub>4</sub>
- (E) Ce<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>