

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 circle on the answer sheet. A choice may be used once, more than once, or not at all in each set.

Questions 1-3 refer to the following gaseous molecules.

- (A) BeCl_2
- (B) SO_2
- (C) N_2
- (D) O_2
- (E) F_2

1. Is a polar molecule
2. Is best represented by two or more resonance forms
3. Is the molecule in which the intramolecular forces are strongest

Questions 4-5

- (A) Alpha-particle emission
 - (B) Beta-particle emission
 - (C) Electron capture
 - (D) Gamma-ray emission
 - (E) Nuclear fission
4. Is the major process by which nuclei lose excess energy without a change in atomic number
5. Accounts for the transformation of $^{207}_{81}\text{Tl}$ into $^{207}_{82}\text{Pb}$

Questions 6-8 refer to the following types of chemical or physical changes.

- (A) Oxidation-reduction reaction
 - (B) Brønsted-Lowry acid-base reaction
 - (C) Sublimation
 - (D) Dehydration
 - (E) Precipitation
6. Occurs when aqueous solutions of ammonia and vinegar are mixed
7. Occurs when $\text{Al}(s)$ and $\text{CuCl}_2(aq)$ are mixed
8. Occurs when solid sodium acetate, $\text{NaC}_2\text{H}_3\text{O}_2(s)$, is added to water

Questions 9-10 refer to the following gas molecules at the conditions indicated.

- (A) $\text{H}_2(g)$ molecules at 10^{-3} atm and 200°C
- (B) $\text{O}_2(g)$ molecules at 20 atm and 200°C
- (C) $\text{SO}_2(g)$ molecules at 20 atm and 200°C
- (D) $\text{NH}_3(g)$ molecules at 20 atm and 200°C
- (E) $\text{NH}_3(g)$ molecules at 20 atm and 300°C

9. Behave most like an ideal gas

10. Have lowest root-mean-square speed

Questions 11-13

- (A) Cs
- (B) Ag
- (C) Pb
- (D) Br
- (E) Se

11. Has the highest electronegativity

12. Has the lowest first-ionization energy

13. Has the largest atomic radius

Questions 14-16 refer to the following compounds.

- (A) $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$
- (B) $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$
- (C) CH_3COCH_3
- (D) CH_3COOH
- (E) $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2$

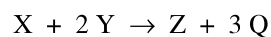
14. Is isomeric with $\text{CH}_3\text{CH}_2\text{CHO}$
15. Dissolves in water to form an acidic solution
16. Is the LEAST soluble in water

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 circle on the answer sheet.

17. A certain crystalline substance that has a low melting point does not conduct electricity in solution or when melted. This substance is likely to be
- (A) a covalent network solid
 - (B) a metallic solid
 - (C) a polymer
 - (D) an ionic solid
 - (E) a molecular solid
18. Solid $\text{Al}(\text{NO}_3)_3$ is added to distilled water to produce a solution in which the concentration of nitrate, $[\text{NO}_3^-]$, is 0.10 M . What is the concentration of aluminum ion, $[\text{Al}^{3+}]$, in this solution?
- (A) 0.010 M
 - (B) 0.033 M
 - (C) 0.066 M
 - (D) 0.10 M
 - (E) 0.30 M
19. Which of the following is a weak acid in aqueous solution?
- (A) HCl
 - (B) HClO_4
 - (C) HNO_3
 - (D) H_2S
 - (E) H_2SO_4

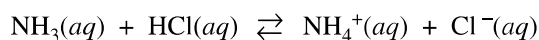
20. In 1.00 mol of potassium zirconium sulfate trihydrate, $\text{K}_4\text{Zr}(\text{SO}_4)_4 \cdot 3\text{H}_2\text{O}$, there are
- (A) $3 \times 6.02 \times 10^{23}$ hydrogen atoms
 - (B) 6.02×10^{23} sulfur atoms
 - (C) $4 \times 6.02 \times 10^{23}$ potassium atoms
 - (D) 4 moles of oxygen atoms
 - (E) 4 moles of zirconium atoms



21. For the reaction represented above, the initial rate of decrease in $[\text{X}]$ was $2.8 \times 10^{-3}\text{ mol L}^{-1}\text{ s}^{-1}$. What was the initial rate of decrease in $[\text{Y}]$?
- (A) $7.0 \times 10^{-4}\text{ mol L}^{-1}\text{ s}^{-1}$
 - (B) $1.4 \times 10^{-3}\text{ mol L}^{-1}\text{ s}^{-1}$
 - (C) $2.8 \times 10^{-3}\text{ mol L}^{-1}\text{ s}^{-1}$
 - (D) $5.6 \times 10^{-3}\text{ mol L}^{-1}\text{ s}^{-1}$
 - (E) $1.1 \times 10^{-2}\text{ mol L}^{-1}\text{ s}^{-1}$
22. To determine the percentage of water in a hydrated salt, a student heated a 1.2346 g sample of the salt for 30 minutes; when cooled to room temperature, the sample weighed 1.1857 g . After the sample was heated for an additional 10 minutes and again cooled to room temperature, the sample weighed 1.1632 g . Which of the following should the student do next?
- (A) Use the smallest mass value to calculate the percentage of water in the hydrated salt.
 - (B) Repeat the experiment with a new sample of the same mass and average the results.
 - (C) Repeat the experiment with a new sample that has a different mass.
 - (D) Reheat the sample until its mass is constant.
 - (E) Use the average of the mass values obtained after the two heatings to calculate the percentage of water in the hydrated salt.

23. Which of the following statements about atoms is NOT correct?

- (A) Atoms are electrically neutral because they have the same number of protons and electrons.
- (B) All atoms of a given element must have the same number of protons, neutrons, and electrons.
- (C) Most of the volume of an atom contains only electrons.
- (D) The nucleus is positively charged.
- (E) Almost all of the mass of an atom is in the nucleus.

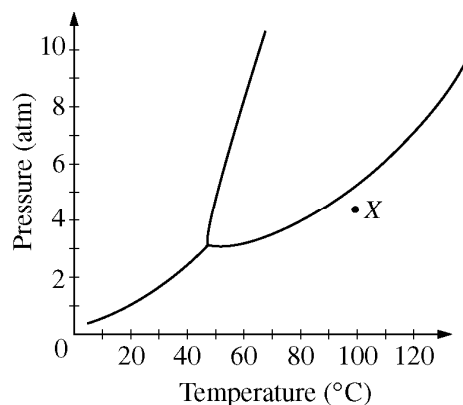


24. The Brønsted-Lowry bases in the reaction represented above are

- (A) $\text{NH}_3(aq)$ and $\text{NH}_4^+(aq)$
- (B) $\text{NH}_3(aq)$ and $\text{Cl}^-(aq)$
- (C) $\text{NH}_3(aq)$ and $\text{HCl}(aq)$
- (D) $\text{HCl}(aq)$ and $\text{NH}_4^+(aq)$
- (E) $\text{HCl}(aq)$ and $\text{Cl}^-(aq)$

25. When 6.0 L of $\text{He}(g)$ and 10. L of $\text{N}_2(g)$, both at 0°C and 1.0 atm, are pumped into an evacuated 4.0 L rigid container, the final pressure in the container at 0°C is

- (A) 2.0 atm
- (B) 4.0 atm
- (C) 6.4 atm
- (D) 8.8 atm
- (E) 16 atm



26. Shown above is the phase diagram of a pure substance. The substance under the conditions corresponding to point X on the diagram is cooled to 40°C while the pressure remains constant. As the substance cools, the phase of the substance changes from

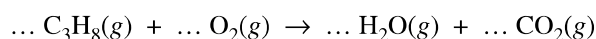
- (A) gas to liquid to solid
- (B) gas to solid to liquid
- (C) solid to liquid to gas
- (D) liquid to solid to gas
- (E) liquid to gas to solid

27. Oxygen is acting as an oxidizing agent in all of the following reactions EXCEPT

- (A) $2\text{C}(s) + \text{O}_2(g) \rightarrow 2\text{CO}(g)$
- (B) $\text{S}(s) + \text{O}_2(g) \rightarrow \text{SO}_2(g)$
- (C) $2\text{F}_2(g) + \text{O}_2(g) \rightarrow 2\text{OF}_2(g)$
- (D) $2\text{Na}(s) + \text{O}_2(g) \rightarrow \text{Na}_2\text{O}_2(s)$
- (E) $2\text{Mg}(s) + \text{O}_2(g) \rightarrow 2\text{MgO}(s)$

28. What is the maximum number of moles of Al_2O_3 that can be produced by the reaction of 0.40 mol of Al with 0.40 mol of O_2 ?

- (A) 0.10 mol
- (B) 0.20 mol
- (C) 0.27 mol
- (D) 0.33 mol
- (E) 0.40 mol



29. When the equation for the reaction represented above is balanced and all coefficients are reduced to the lowest whole-number terms, the coefficient for $\text{O}_2(g)$ is

(A) 1
(B) 2
(C) 3
(D) 5
(E) 6

30. A 0.1 M solution of which of the following is colorless?

(A) MgCl_2
(B) $\text{Ni}(\text{NO}_3)_2$
(C) Na_2CrO_4
(D) KMnO_4
(E) CuSO_4

31. Under which of the following conditions can an endothermic reaction be thermodynamically favorable?

(A) ΔG is positive
(B) ΔS is negative
(C) $T\Delta S > \Delta H$
(D) $T\Delta S = 0$

(E) There are no conditions under which an endothermic reaction can be thermodynamically favorable.

32. The vapor pressure of pure water at 25°C is 24.0 mm Hg. What is the expected vapor pressure at 25°C of an ideal solution of a nonvolatile nonelectrolyte in which the mole fraction of water is 0.900 ?

(A) 1.48 mm Hg
(B) 2.40 mm Hg
(C) 21.6 mm Hg
(D) 24.0 mm Hg
(E) 26.7 mm Hg

33. Which of the following salts is LEAST soluble in water?

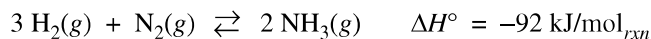
(A) NiS
(B) MgCl_2
(C) K_2CrO_4
(D) $\text{Al}_2(\text{SO}_4)_3$
(E) $\text{Pb}(\text{NO}_3)_2$

34. Which of the following is the best piece of laboratory glassware for preparing 500.0 mL of an aqueous solution of a solid?

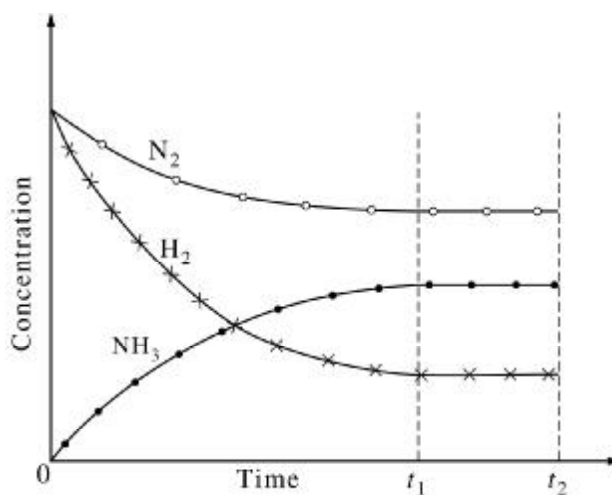
(A) Volumetric flask
(B) Erlenmeyer flask
(C) Test tube
(D) Graduated beaker
(E) Graduated cylinder

Questions 35-36 refer to the experiment described below.

H₂ gas and N₂ gas were placed in a rigid vessel and allowed to reach equilibrium in the presence of a catalyst according to the following equation.



The diagram below shows how the concentrations of H₂, N₂, and NH₃ in this system changed over time.



35. Which of the following was true for the system between time t_1 and time t_2 ?

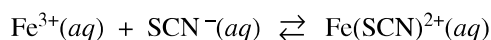
- (A) The concentration of N₂ decreased.
- (B) The temperature of the system decreased.
- (C) The number of effective collisions between H₂ and N₂ was zero.
- (D) The rates of the forward and reverse reactions were equal.
- (E) The rate of formation of NH₃ molecules was equal to the rate of disappearance of H₂ molecules.

36. More NH₃ gas is added to the system at time t_2 while the temperature is held constant. Which of the following will most likely occur?

- (A) The value of the equilibrium constant will increase.
- (B) The value of the equilibrium constant will decrease.
- (C) The total pressure in the container will decrease.
- (D) The amount of N₂ will increase.
- (E) The amount of H₂ will decrease.

37. When heated, metallic carbonates generally produce

- (A) metallic peroxide + CO
- (B) metal + CO + O₂
- (C) metallic hydroxide + CO₂
- (D) metallic oxalate + O₂
- (E) metallic oxide + CO₂



38. For the reaction represented above, the value of the equilibrium constant, K_{eq} , is 240 at 25°C.

From this information, correct deductions about the reaction at 25°C include which of the following?

- I. The reaction is quite rapid.
- II. The product is favored over the reactants at equilibrium.
- III. The reaction is endothermic.

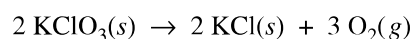
- (A) I only
- (B) II only
- (C) I and II only
- (D) II and III only
- (E) I, II, and III

39. The volume of water that must be added in order to dilute 40 mL of 9.0 M HCl to a concentration of 6.0 M is closest to

- (A) 10 mL
- (B) 20 mL
- (C) 30 mL
- (D) 40 mL
- (E) 60 mL

40. Which of the following statements best explains why an increase in temperature of 5-10 Celsius degrees can substantially increase the rate of a chemical reaction?

- (A) The activation energy for the reaction is lowered.
- (B) The number of effective collisions between reactant particles is increased.
- (C) The rate of the reverse reaction is increased.
- (D) ΔH for the reaction is lowered.
- (E) ΔG for the reaction becomes more positive.



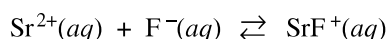
41. What is the percentage yield of O₂ if 12.3 g of KClO₃ (molar mass 123 g) is decomposed to produce 3.2 g of O₂ (molar mass 32 g) according to the equation above?

- (A) 100%
- (B) 67%
- (C) 50%
- (D) 33%
- (E) 10%

42. When a strong acid is titrated with a strong base using phenolphthalein as an indicator, the color changes abruptly at the endpoint of the titration and can be switched back and forth by the addition of only one drop of acid or base. The reason for the abruptness of this color change is that

- (A) a large change in pH occurs near the endpoint of the titration
- (B) a buffer solution exists at the endpoint of the titration
- (C) phenolphthalein is a strong proton donor
- (D) the pH of water is very resistant to change
- (E) phenolphthalein is much more sensitive to the pH of a solution than most other indicators

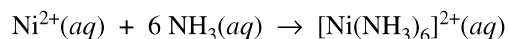
43. A 1 mol sample of zinc can reduce the greatest number of moles of which of the following ions?
- (A) Al^{3+}
 (B) Pb^{2+}
 (C) Ag^+
 (D) Cl^-
 (E) N^{3-}
44. At 298 K and 1 atm, bromine is a liquid with a high vapor pressure, whereas chlorine is a gas. This provides evidence that, under these conditions, the
- (A) forces among Br_2 molecules are greater than those among Cl_2 molecules
 (B) forces among Br_2 molecules are weaker than the $\text{Br}-\text{Br}$ bond
 (C) forces among Cl_2 molecules are stronger than the $\text{Cl}-\text{Cl}$ bond
 (D) $\text{Br}-\text{Br}$ bond is stronger than the $\text{Cl}-\text{Cl}$ bond
 (E) $\text{Br}-\text{Br}$ bond is weaker than the $\text{Cl}-\text{Cl}$ bond
45. The value of K_{sp} for PbCl_2 is 1.6×10^{-5} . What is the lowest concentration of $\text{Cl}^-(aq)$ that would be needed to begin precipitation of $\text{PbCl}_2(s)$ in $0.010\text{ M Pb(NO}_3)_2$?
- (A) $1.6 \times 10^{-7}\text{ M}$
 (B) $4.0 \times 10^{-4}\text{ M}$
 (C) $1.6 \times 10^{-3}\text{ M}$
 (D) $2.6 \times 10^{-3}\text{ M}$
 (E) $4.0 \times 10^{-2}\text{ M}$
46. Which of the following aqueous solutions has the lowest freezing point?
- (A) 0.2 m NaCl
 (B) 0.2 m CaCl_2
 (C) $0.2\text{ m H}_2\text{SO}_4$
 (D) 0.2 m NH_3
 (E) $0.2\text{ m Al(NO}_3)_3$
- Step 1: $\text{NO}(g) + \text{O}_3(g) \rightarrow \text{NO}_2(g) + \text{O}_2(g)$
 Step 2: $\text{NO}_2(g) + \text{O}(g) \rightarrow \text{NO}(g) + \text{O}_2(g)$
47. A reaction mechanism for the destruction of ozone, $\text{O}_3(g)$, is represented above. In the overall reaction, $\text{NO}(g)$ is best described as
- (A) an inhibitor
 (B) a catalyst
 (C) a reactant
 (D) an intermediate
 (E) a product
48. When a buret is rinsed before a titration, which of the techniques below is the best procedure?
- (A) Rinse the buret one time with some of the titrant solution.
 (B) Rinse the buret one time with some of the titrant solution and then dry the buret in an oven.
 (C) Rinse the buret two times: once with some of the titrant solution, then once with distilled water.
 (D) Rinse the buret two times: each time with some of the titrant solution.
 (E) Rinse the buret two times: each time with distilled water.



49. At 25°C, the equilibrium constant for the reaction represented above has a value of 1.3. At 50°C, the value of the equilibrium constant is less than 1.3.

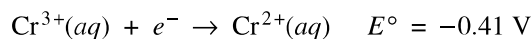
Based on this information, which of the following must be correct?

- (A) The reaction rate decreases as the temperature is increased.
- (B) The reaction is thermodynamically favorable only at temperatures above 25°C.
- (C) At 25°C, ΔG° for the reaction is positive.
- (D) At 25°C, ΔS° for the reaction is positive.
- (E) At 25°C, ΔH° for the reaction is negative.



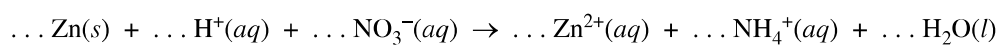
50. The reaction represented above is best classified as

- (A) a Lewis acid-base reaction
- (B) a Brønsted-Lowry acid-base reaction
- (C) an Arrhenius acid-base reaction
- (D) an oxidation-reduction reaction
- (E) a precipitation reaction



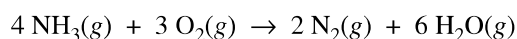
51. According to the half-reactions represented above, which of the following occurs in aqueous solutions under standard conditions?

- (A) $\text{Cu}^{2+}(\text{aq}) + \text{Cr}^{3+}(\text{aq}) \rightarrow \text{Cu}(\text{s}) + \text{Cr}^{2+}(\text{aq})$
- (B) $\text{Cu}^{2+}(\text{aq}) + 2 \text{Cr}^{2+}(\text{aq}) \rightarrow \text{Cu}(\text{s}) + 2 \text{Cr}^{3+}(\text{aq})$
- (C) $\text{Cu}(\text{s}) + 2 \text{Cr}^{3+}(\text{aq}) \rightarrow \text{Cu}^{2+}(\text{aq}) + 2 \text{Cr}^{2+}(\text{aq})$
- (D) $\text{Cu}(\text{s}) + \text{Cr}^{3+}(\text{aq}) \rightarrow \text{Cu}^{2+}(\text{aq}) + \text{Cr}^{2+}(\text{aq})$
- (E) $2 \text{Cu}^{2+}(\text{aq}) + \text{Cr}^{3+}(\text{aq}) \rightarrow 2 \text{Cu}(\text{s}) + \text{Cr}^{2+}(\text{aq})$



52. When the equation above is balanced and all coefficients are reduced to lowest whole number terms, the coefficient for $\text{Zn}(\text{s})$ is

- (A) 2
- (B) 4
- (C) 6
- (D) 10
- (E) 14



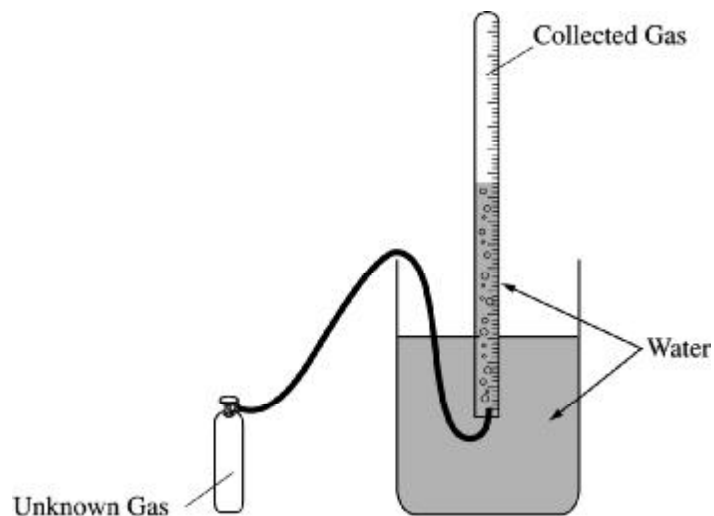
53. If the standard molar heats of formation of ammonia, $\text{NH}_3(g)$, and gaseous water, $\text{H}_2\text{O}(g)$, are -46 kJ/mol and -242 kJ/mol , respectively, what is the value of ΔH_{298}° for the reaction represented above?
- (A) $-190 \text{ kJ/mol}_{\text{rxn}}$
 (B) $-290 \text{ kJ/mol}_{\text{rxn}}$
 (C) $-580 \text{ kJ/mol}_{\text{rxn}}$
 (D) $-1,270 \text{ kJ/mol}_{\text{rxn}}$
 (E) $-1,640 \text{ kJ/mol}_{\text{rxn}}$
54. When a magnesium wire is dipped into a solution of lead(II) nitrate, a black deposit forms on the wire. Which of the following can be concluded from this observation?
- (A) The standard reduction potential, E° , for $\text{Pb}^{2+}(aq)$ is greater than that for $\text{Mg}^{2+}(aq)$.
 (B) $\text{Mg}(s)$ is less easily oxidized than $\text{Pb}(s)$.
 (C) An external source of potential must have been supplied.
 (D) The magnesium wire will be the cathode of a Mg/Pb cell.
 (E) $\text{Pb}(s)$ can spontaneously displace $\text{Mg}^{2+}(aq)$ from solution.
55. Which of the molecules represented below contains carbon with sp^2 hybridization?
- (A) CH_4
 (B) CH_2Cl_2
 (C) C_2H_6
 (D) $\text{C}_2\text{H}_2\text{Cl}_2$
 (E) $\text{C}_2\text{H}_4\text{Cl}_2$
56. A chemical supply company sells a concentrated solution of aqueous H_2SO_4 (molar mass 98 g mol^{-1}) that is 50. percent H_2SO_4 by mass. At 25°C , the density of the solution is 1.4 g mL^{-1} . What is the molarity of the H_2SO_4 solution at 25°C ?
- (A) 1.8 M
 (B) 3.6 M
 (C) 5.1 M
 (D) 7.1 M
 (E) 14 M
57. A reaction produces a colorless gas, which is collected by water displacement. A glowing splint inserted into a bottle full of the gas is extinguished. The gas could be
- (A) N_2
 (B) NO_2
 (C) O_2
 (D) Br_2
 (E) Cl_2
58. A solution of methanol, CH_3OH , in water is prepared by mixing together 128 g of methanol and 108 g of water. The mole fraction of methanol in the solution is closest to
- (A) 0.80
 (B) 0.60
 (C) 0.50
 (D) 0.40
 (E) 0.20
59. A sample of a compound contains 3.21 g of sulfur and 11.4 g of fluorine. Which of the following represents the empirical formula of the compound?
- (A) SF_2
 (B) SF_3
 (C) SF_4
 (D) SF_5
 (E) SF_6

60. Of the following, the best explanation for the fact that most gases are easily compressed is that the molecules in a gas

- (A) are in constant motion
- (B) are relatively far apart
- (C) have relatively small masses
- (D) have a real, nonzero volume
- (E) move slower as temperature decreases

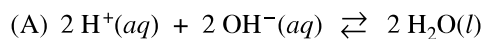
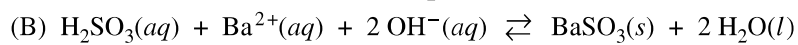
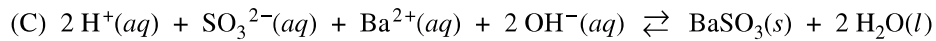
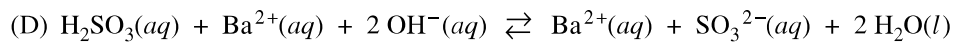
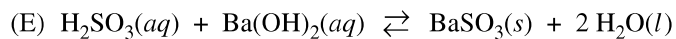
61. Given that the density of $\text{Hg}(l)$ at 0°C is about 14 g mL^{-1} , which of the following is closest to the volume of one mole of $\text{Hg}(l)$ at this temperature?

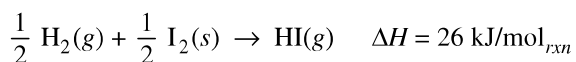
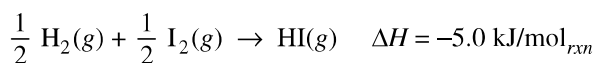
- (A) 0.070 mL
- (B) 0.14 mL
- (C) 1.4 mL
- (D) 14 mL
- (E) 28 mL



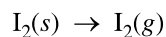
62. A sample of an unknown gas from a cylinder is collected over water in the apparatus shown above. After all the gas sample has been collected, the water levels inside and outside the gas collection tube are made the same. Measurements that must be made to calculate the molar mass of the gas include all of the following EXCEPT
- (A) atmospheric pressure
 - (B) temperature of the water
 - (C) volume of gas in the gas-collection tube
 - (D) initial and final mass of the gas cylinder
 - (E) mass of the water in the apparatus

63. Addition of sulfurous acid (a weak acid) to barium hydroxide (a strong base) results in the formation of a precipitate. The net ionic equation for this reaction is



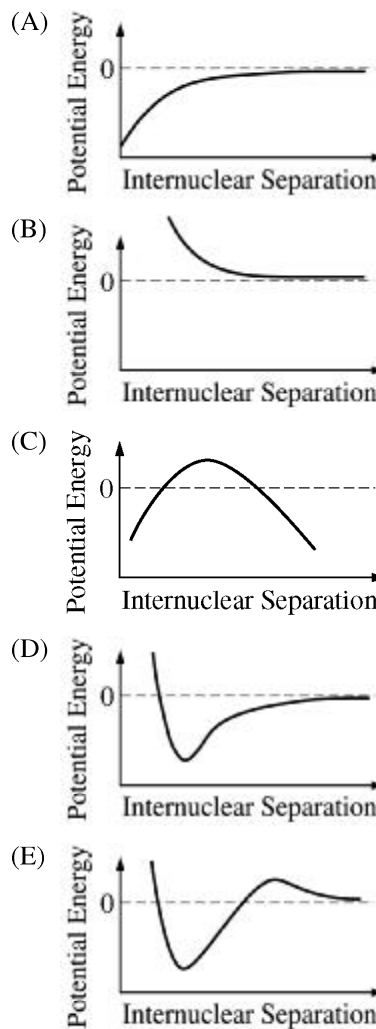


64. Based on the information above, what is the enthalpy change for the sublimation of iodine, represented below?



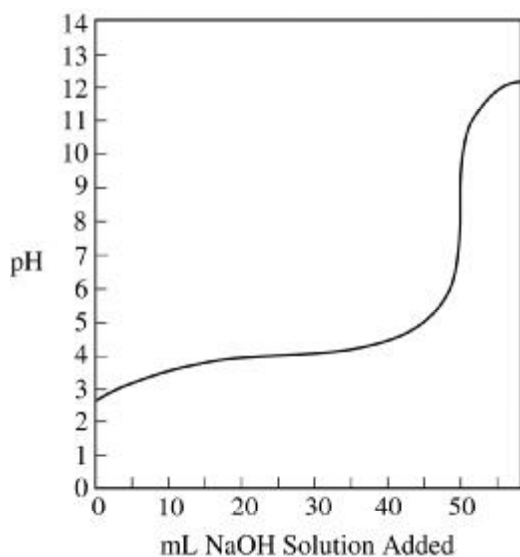
- (A) 15 kJ/mol_{rxn}
- (B) 21 kJ/mol_{rxn}
- (C) 31 kJ/mol_{rxn}
- (D) 42 kJ/mol_{rxn}
- (E) 62 kJ/mol_{rxn}

65. Which of the following graphs correctly shows the relationship between potential energy and internuclear separation for two hydrogen atoms?



66. Which of the following compounds is LEAST likely to exist?

- (A) PCl_5
- (B) PBr_3
- (C) NF_3
- (D) NI_5
- (E) SbF_5



67. The graph above shows the titration curve that resulted when a sample of 0.1 M monoprotic acid was titrated with a solution of NaOH . Based on the graph, the pK_a of the acid is closest to

- (A) 3.0
- (B) 4.0
- (C) 6.0
- (D) 8.0
- (E) 12.0

68. The rate law for the reaction of nitrogen dioxide and chlorine is found to be $\text{rate} = k [\text{NO}_2]^2 [\text{Cl}_2]$.

By what factor does the rate of the reaction change when the concentrations of both NO_2 and Cl_2 are doubled?

- (A) 2
- (B) 3
- (C) 4
- (D) 6
- (E) 8

69. When a student prepares an aqueous solution containing the five cations $\text{Ag}^+(aq)$, $\text{Hg}_2^{2+}(aq)$, $\text{Cu}^{2+}(aq)$, $\text{Mn}^{2+}(aq)$, and $\text{Ba}^{2+}(aq)$, the student observes that no precipitates form in the solution. Which of the following could be the identity of the anion in the solution?

- (A) $\text{Cl}^-(aq)$
- (B) $\text{CO}_3^{2-}(aq)$
- (C) $\text{CrO}_4^{2-}(aq)$
- (D) $\text{NO}_3^-(aq)$
- (E) $\text{SO}_4^{2-}(aq)$

70. What is the molarity of $\text{I}^-(aq)$ in a solution that contains 34 g of SrI_2 (molar mass 341 g) in 1.0 L of the solution?

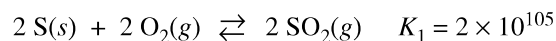
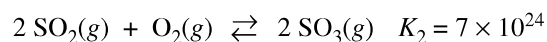
- (A) 0.034 M
- (B) 0.068 M
- (C) 0.10 M
- (D) 0.20 M
- (E) 0.68 M

71. Which of the following compounds contains both ionic and covalent bonds?

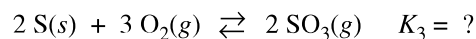
- (A) SO_3
- (B) $\text{C}_2\text{H}_5\text{OH}$
- (C) MgF_2
- (D) H_2S
- (E) NH_4Cl

72. Some pollutant gases in the atmosphere act as contributors to the formation of acid rain, a serious environmental problem. An example of such a gas is

- (A) N_2
- (B) O_2
- (C) H_2O
- (D) NO_2
- (E) CH_4



73. Given the value of the equilibrium constants K_1 and K_2 for the reactions represented above, what is the value of the equilibrium constant, K_3 , for the following reaction?



- (A) 1×10^{130}
- (B) 3×10^{80}
- (C) 1×10^{65}
- (D) 2×10^{40}
- (E) 7×10^{24}

74. Which of the following molecules is nonpolar but has polar covalent bonds?

- (A) N_2
- (B) H_2O_2
- (C) H_2O
- (D) CCl_4
- (E) CH_2Cl_2

75. A 0.10 *M* solution of which of the following salts is most basic?

- (A) LiNO_3
- (B) Na_2SO_4
- (C) CaCl_2
- (D) $\text{Al}(\text{NO}_3)_3$
- (E) K_2CO_3

END OF SECTION I

**IF YOU FINISH BEFORE TIME IS CALLED,
YOU MAY CHECK YOUR WORK ON THIS SECTION.**

DO NOT GO ON TO SECTION II UNTIL YOU ARE TOLD TO DO SO.

MAKE SURE YOU HAVE DONE THE FOLLOWING.

- **PLACED YOUR AP NUMBER LABEL ON YOUR ANSWER SHEET**
- **WRITTEN AND GRIDDED YOUR AP NUMBER CORRECTLY ON YOUR ANSWER SHEET**
- **TAKEN THE AP EXAM LABEL FROM THE FRONT OF THIS BOOKLET AND PLACED IT ON YOUR ANSWER SHEET**

CHEMISTRY

Section II

(Total time—95 minutes)

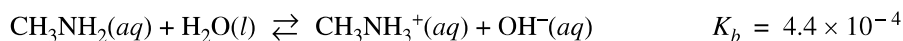
Part A

Time—55 minutes

YOU MAY USE YOUR CALCULATOR FOR PART A.

CLEARLY SHOW THE METHOD USED AND THE STEPS INVOLVED IN ARRIVING AT YOUR ANSWERS. It is to your advantage to do this, since you may obtain partial credit if you do and you will receive little or no credit if you do not. Attention should be paid to significant figures. Be sure to write all your answers to the questions on the lined pages following each question in this booklet.

Answer Questions 1, 2, and 3. The Section II score weighting for each question is 20 percent.



1. Methylamine, CH_3NH_2 , is a weak base that reacts with water according to the equation above. A student obtains a 50.0 mL sample of a methylamine solution and determines the pH of the solution to be 11.77.

- (a) Write the expression for the equilibrium constant, K_b , for methylamine.
- (b) Calculate the molar concentration of OH^- in the 50.0 mL sample of the methylamine solution.
- (c) Calculate the initial molar concentration of $\text{CH}_3\text{NH}_2(aq)$ in the solution before it reacted with water and equilibrium was established.

The 50.0 mL sample of the methylamine solution is titrated with an HCl solution of unknown concentration. The equivalence point of the titration is reached after a volume of 36.0 mL of the HCl solution is added. The pH of the solution at the equivalence point is 5.98.

- (d) Write the net-ionic equation that represents the reaction that takes place during the titration.
- (e) Calculate the concentration of the HCl solution used to titrate the methylamine.
- (f) Using the axes provided, sketch the titration curve that results from the titration described above. On the graph, clearly label the equivalence point of the titration.

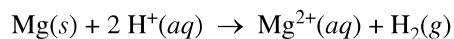


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-9-



2. A student performs an experiment to determine the volume of hydrogen gas produced when a given mass of magnesium reacts with excess $\text{HCl}(aq)$, as represented by the net ionic equation above. The student begins with a 0.0360 g sample of pure magnesium and a solution of 2.0 M $\text{HCl}(aq)$.

- Calculate the number of moles of magnesium in the 0.0360 g sample.
- Calculate the number of moles of $\text{HCl}(aq)$ needed to react completely with the sample of magnesium.

As the magnesium reacts, the hydrogen gas produced is collected by water displacement at 23.0°C. The pressure of the gas in the collection tube is measured to be 749 torr.

- (c) Given that the equilibrium vapor pressure of water is 21 torr at 23.0°C, calculate the pressure that the $\text{H}_2(\text{g})$ produced in the reaction would have if it were dry.
- (d) Calculate the volume, in liters measured at the conditions in the laboratory, that the $\text{H}_2(\text{g})$ produced in the reaction would have if it were dry.
- (e) The laboratory procedure specified that the concentration of the HCl solution be 2.0 M , but only 12.3 M HCl solution was available. Describe the steps for safely preparing 50.0 mL of 2.0 M $\text{HCl}(\text{aq})$ using 12.3 M HCl solution and materials selected from the list below. Show any necessary calculation(s).

10.0 mL graduated cylinder

Distilled water

250 mL beakers

Balance

50.00 mL volumetric flask

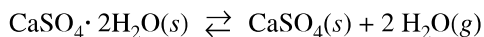
Dropper

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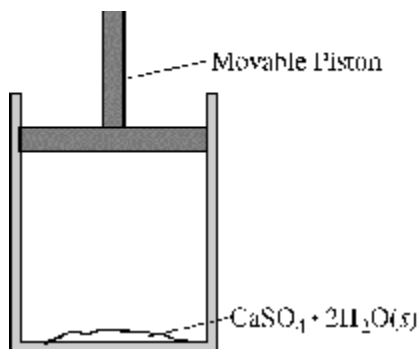
3. The hydrate $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}(s)$ can be heated to form the anhydrous salt, $\text{CaSO}_4(s)$, as shown by the reaction represented above.

(a) Using the data in the table below, calculate the value of ΔG° , in $\text{kJ/mol}_{\text{rxn}}$, for the reaction at 298 K.

Substance	ΔG_f° at 298 K (kJ/mol)
$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}(s)$	-1795.70
$\text{CaSO}_4(s)$	-1320.30
$\text{H}_2\text{O}(g)$	-228.59

(b) Given that the value of ΔH° for the reaction at 298 K is $+105 \text{ kJ/mol}_{\text{rxn}}$, calculate the value of ΔS° for the reaction at 298 K. Include units with your answer.

A sample of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}(s)$ is placed in a cylinder with a movable piston as shown in the diagram below. The air above the solid is at 1.00 atm and is initially dry (partial pressure of $\text{H}_2\text{O}(g) = 0 \text{ atm}$).



- (c) Write the expression for the equilibrium constant, K_p , for the reaction.
- (d) Given that the equilibrium constant, K_p , is 6.4×10^{-4} at 298 K, determine the partial pressure, in atm, of water vapor in the cylinder at equilibrium at 298 K.
- (e) If the volume of the system is reduced to one-half of its original volume and the system is allowed to reestablish equilibrium at 298 K, what will be the pressure, in atm, of the water vapor at the new volume? Justify your answer.

In the laboratory, the hydrate $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}(s)$ can be heated in a crucible to completely drive off the water of hydration to form the anhydrous salt, $\text{CaSO}_4(s)$.

- (f) A 2.49 g sample of pure $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}(s)$ is heated several times until the mass is constant. Calculate the mass, in grams, of the solid that remains after the dehydration reaction is complete.

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This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.

**If you finish before time is called, you may check your work on this part only.
Do not turn to the other part of the test until you are told to do so.**

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CHEMISTRY

Part B

Time—40 minutes

NO CALCULATORS MAY BE USED FOR PART B.

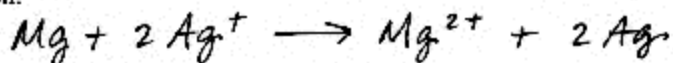
Answer Question 4 below. The Section II score weighting for this question is 10 percent.

4. For each of the following three reactions, in part (i) write a balanced equation for the reaction and in part (ii) answer the question about the reaction. In part (i), coefficients should be in terms of lowest whole numbers. Assume that solutions are aqueous unless otherwise indicated. Represent substances in solutions as ions if the substances are extensively ionized. Omit formulas for any ions or molecules that are unchanged by the reaction. You may use the empty space at the bottom of the next page for scratch work, but only equations that are written in the answer boxes provided will be scored.

EXAMPLE:

A strip of magnesium metal is added to a solution of silver(I) nitrate.

(i) Balanced equation:



(ii) Which substance is oxidized in the reaction?

Mg is oxidized.

- (a) Solutions of ethanoic (acetic) acid and lithium hydroxide are combined.

(i) Balanced equation:

- (ii) If the ethanoic acid is titrated with the lithium hydroxide, is the pH at the equivalence point equal to 7, less than 7, or greater than 7? Explain.

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(b) Solutions of iron(III) chloride and tin(II) chloride are combined.

(i) Balanced equation:

(ii) Identify the species that is reduced in the reaction.

(c) Solutions of silver(I) nitrate and sodium phosphate are combined, forming a precipitate.

(i) Balanced equation:

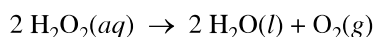
(ii) If 5 mol of silver(I) nitrate and 3 mol of sodium phosphate react as completely as possible, which reactant, if any, is present in excess? Justify your answer.

**YOU MAY USE THE SPACE BELOW FOR SCRATCH WORK, BUT ONLY EQUATIONS
THAT ARE WRITTEN IN THE ANSWER BOXES PROVIDED WILL BE SCORED.**

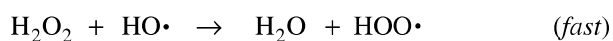
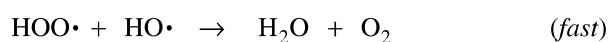
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Answer Question 5 and Question 6. The Section II score weighting for these questions is 15 percent each.

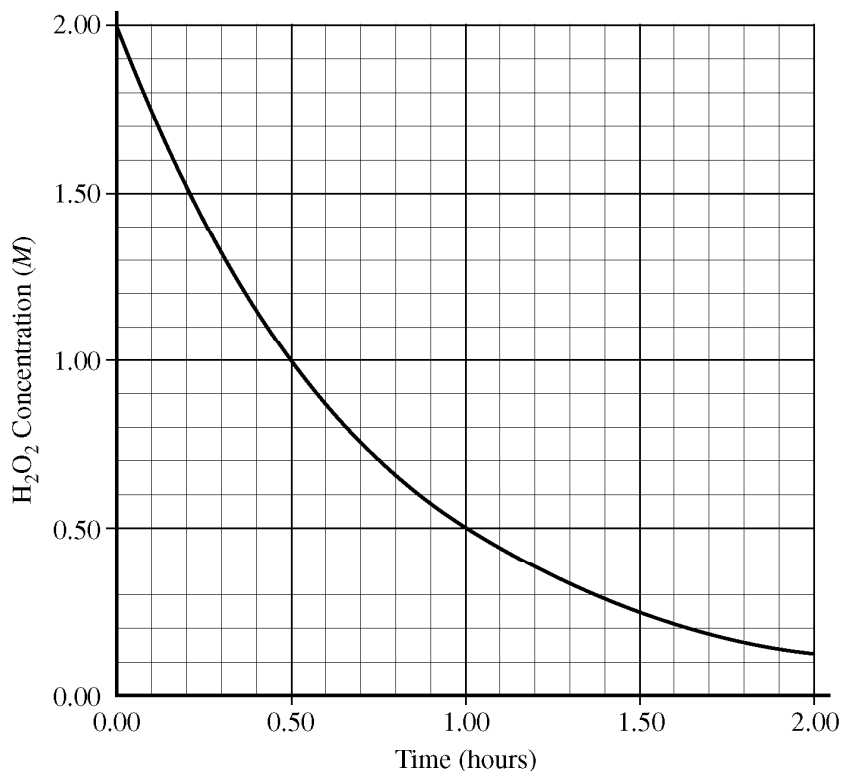
Your responses to these questions will be scored on the basis of the accuracy and relevance of the information cited. Explanations should be clear and well organized. Examples and equations may be included in your responses where appropriate. Specific answers are preferable to broad, diffuse responses.



5. The decomposition of hydrogen peroxide to form water and oxygen gas is represented by the equation above. A proposed mechanism for the reaction, which involves the free radicals $\text{HO}\cdot$ and $\text{HOO}\cdot$, is represented by the three equations below.



- (a) Write the rate law consistent with the proposed mechanism above.
- (b) The rate of the decomposition reaction was studied in an experiment, and the resulting data were plotted in the graph below.



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ADDITIONAL PAGE FOR ANSWERING QUESTION 5

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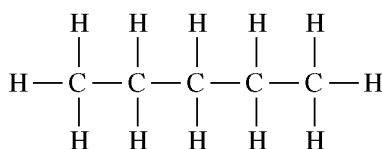
ADDITIONAL PAGE FOR ANSWERING QUESTION 5

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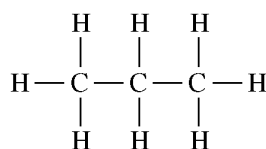
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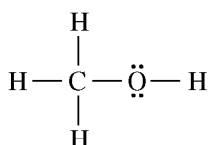
6. Answer the following questions in terms of principles of chemical bonding and intermolecular forces. In each explanation where a comparison is to be made, a complete answer must include a discussion of both substances. The following complete Lewis electron-dot diagrams may be useful in answering parts of this question.



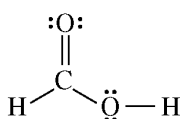
Pentane



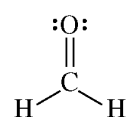
Propane



Methanol



Methanoic (formic) acid



Methanal (formaldehyde)

- (a) At 1 atm and 298 K, pentane is a liquid whereas propane is a gas. Explain.
- (b) At 1 atm and 298 K, methanol is a liquid whereas propane is a gas. Explain.
- (c) Indicate the hybridization of the carbon atom in each of the following:
- Methanol
 - Methanoic (formic) acid
- (d) Draw the complete Lewis electron-dot diagram for a molecule of propanoic acid, $\text{HC}_3\text{H}_5\text{O}_2$.
- (e) Explain the following observations about the two carbon-oxygen bonds in the methanoate (formate) anion, HCO_2^- . You may draw a Lewis electron-dot diagram (or diagrams) of the methanoate ion as part of your explanations.
- The two carbon-oxygen bonds in the methanoate (formate) anion, HCO_2^- , have the same length.
 - The length of the carbon-oxygen bonds in the methanoate (formate) anion, HCO_2^- , is intermediate between the length of the carbon-oxygen bond in methanol and the length of the carbon-oxygen bond in methanal.

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ADDITIONAL PAGE FOR ANSWERING QUESTION 6

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ADDITIONAL PAGE FOR ANSWERING QUESTION 6

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ADDITIONAL PAGE FOR ANSWERING QUESTION 6

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MATERIAL IN THE FOLLOWING TABLE MAY BE USEFUL IN ANSWERING THE QUESTIONS IN THIS SECTION OF THE EXAMINATION.

DO NOT DETACH FROM BOOK.

PERIODIC TABLE OF THE ELEMENTS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	485	486	487	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	630	631	632	633	634	635	636	637	638	639	640	641	642	643	644	645	646	647	648	649	650	651	652	653	654	655	656	657	658	659	660	661	662	663	664	665	666	667	668	669	670	671	672	673	674	675	676	677	678	679	680	681	682	683	684	685	686	687	688	689	690	691	692	693	694	695	696	697	698	699	700	701	702	703	704	705	706	707	708	709	710	711	712	713	714	715	716	717	718	719	720	721	722	723	724	725	726	727	728	729	730	731	732	733	734	735	736	737	738	739	740	741	742	743	744	745	746	747	748	749	750	751	752	753	754	755	756	757	758	759	760	761	762	763	764	765	766	767	768	769	770	771	772	773	774	775	776	777	778	779	780	781	782	783	784	785	786	787	788	789	790	791	792	793	794	795	796	797	798	799	800	801	802	803	804	805	806	807	808	809	810	811	812	813	814	815	816	817	818	819	820	821	822	823	824	825	826	827	828	829	830	831	832	833	834	835	836	837	838	839	840	841	842	843	844	845	846	847	848	849	850	851	852	853	854	855	856	857	858	859	860	861	862	863	864	865	866	867	868	869	870	871	872	873	874	875	876	877	878	879	880	881	882	883	884	885	886	887	888	889	890	891	892	893	894	895	896	897	898	899	900	901	902	903	904	905	906	907	908	909	910	911	912	913	914	915	916	917	918	919	920	921	922	923	924	925	926	927	928	929	930	931	932	933	934	935	936	937	938	939	940	941	942	943	944	945	946	947	948	949	950	951	952	953	954	955	956	957	958	959	960	961	962	963	964	965	966	967	968	969	970	971	972	973	974	975	976	977	978	979	980	981	982	983	984	985	986	987	988	989	990	991	992	993	994	995	996	997	998	999	1000	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012	1013	1014	1015	1016	1017	1018	1019	1020	1021	1022	1023	1024	1025	1026	1027	1028	1029	1030	1031	1032	1033	1034	1035	1036	1037	1038	1039	1040	1041	1042	1043	1044	1045	1046	1047	1048	1049	1050	1051	1052	1053	1054	1055	1056	1057	1058	1059	1060	1061	1062	1063	1064	1065	1066	1067	1068	1069	1070	1071	1072	1073	1074	1075	1076	1077	1078	1079	1080	1081	1082	1083	1084	1085	1086	1087	1088	1089	1090	1091	1092	1093	1094	1095	1096	1097	1098	1099	1100	1101	1102	1103	1104	1105	1106	1107	1108	1109	1110	1111	1112	1113	1114	1115	1116	1117	1118	1119	1120	1121	1122	1123	1124	1125	1126	1127	1128	1129	1130	1131	1132	1133	1134	1135	1136	1137	1138	1139	1140	1141	1142	1143	1144	1145	1146	1147	1148	1149	1150	1151	1152	1153	1154	1155	1156	1157	1158	1159	1160	1161	1162	1163	1164	1165	1166	1167	1168	1169	1170	1171	1172	1173	1174	1175	1176	1177	1178	1179	1180	1181	1182	1183	1184	1185	1186	1187	1188	1189	1190	1191	1192	1193	1194	1195	1196	1197	1198	1199	1200	1201	1202	1203	1204	1205	1206	1207	1208	1209	1210	1211	1212	1213	1214	1215	1216	1217	1218	1219	1220	1221	12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STANDARD REDUCTION POTENTIALS IN AQUEOUS SOLUTION AT 25°C

Half-reaction			$E^\circ(\text{V})$
$\text{F}_2(\text{g}) + 2\text{e}^-$	$\rightarrow$	2F^-	2.87
$\text{Co}^{3+} + \text{e}^-$	$\rightarrow$	Co^{2+}	1.82
$\text{Au}^{3+} + 3\text{e}^-$	$\rightarrow$	$\text{Au}(\text{s})$	1.50
$\text{Cl}_2(\text{g}) + 2\text{e}^-$	$\rightarrow$	2Cl^-	1.36
$\text{O}_2(\text{g}) + 4\text{H}^+ + 4\text{e}^-$	$\rightarrow$	$2\text{H}_2\text{O}(\text{l})$	1.23
$\text{Br}_2(\text{l}) + 2\text{e}^-$	$\rightarrow$	2Br^-	1.07
$2\text{Hg}^{2+} + 2\text{e}^-$	$\rightarrow$	Hg_2^{2+}	0.92
$\text{Hg}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Hg}(\text{l})$	0.85
$\text{Ag}^+ + \text{e}^-$	$\rightarrow$	$\text{Ag}(\text{s})$	0.80
$\text{Hg}_2^{2+} + 2\text{e}^-$	$\rightarrow$	$2\text{Hg}(\text{l})$	0.79
$\text{Fe}^{3+} + \text{e}^-$	$\rightarrow$	Fe^{2+}	0.77
$\text{I}_2(\text{s}) + 2\text{e}^-$	$\rightarrow$	2I^-	0.53
$\text{Cu}^+ + \text{e}^-$	$\rightarrow$	$\text{Cu}(\text{s})$	0.52
$\text{Cu}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Cu}(\text{s})$	0.34
$\text{Cu}^{2+} + \text{e}^-$	$\rightarrow$	Cu^+	0.15
$\text{Sn}^{4+} + 2\text{e}^-$	$\rightarrow$	Sn^{2+}	0.15
$\text{S}(\text{s}) + 2\text{H}^+ + 2\text{e}^-$	$\rightarrow$	$\text{H}_2\text{S}(\text{g})$	0.14
$2\text{H}^+ + 2\text{e}^-$	$\rightarrow$	$\text{H}_2(\text{g})$	0.00
$\text{Pb}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Pb}(\text{s})$	-0.13
$\text{Sn}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Sn}(\text{s})$	-0.14
$\text{Ni}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Ni}(\text{s})$	-0.25
$\text{Co}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Co}(\text{s})$	-0.28
$\text{Cd}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Cd}(\text{s})$	-0.40
$\text{Cr}^{3+} + \text{e}^-$	$\rightarrow$	Cr^{2+}	-0.41
$\text{Fe}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Fe}(\text{s})$	-0.44
$\text{Cr}^{3+} + 3\text{e}^-$	$\rightarrow$	$\text{Cr}(\text{s})$	-0.74
$\text{Zn}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Zn}(\text{s})$	-0.76
$2\text{H}_2\text{O}(\text{l}) + 2\text{e}^-$	$\rightarrow$	$\text{H}_2(\text{g}) + 2\text{OH}^-$	-0.83
$\text{Mn}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Mn}(\text{s})$	-1.18
$\text{Al}^{3+} + 3\text{e}^-$	$\rightarrow$	$\text{Al}(\text{s})$	-1.66
$\text{Be}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Be}(\text{s})$	-1.70
$\text{Mg}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Mg}(\text{s})$	-2.37
$\text{Na}^+ + \text{e}^-$	$\rightarrow$	$\text{Na}(\text{s})$	-2.71
$\text{Ca}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Ca}(\text{s})$	-2.87
$\text{Sr}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Sr}(\text{s})$	-2.89
$\text{Ba}^{2+} + 2\text{e}^-$	$\rightarrow$	$\text{Ba}(\text{s})$	-2.90
$\text{Rb}^+ + \text{e}^-$	$\rightarrow$	$\text{Rb}(\text{s})$	-2.92
$\text{K}^+ + \text{e}^-$	$\rightarrow$	$\text{K}(\text{s})$	-2.92
$\text{Cs}^+ + \text{e}^-$	$\rightarrow$	$\text{Cs}(\text{s})$	-2.92
$\text{Li}^+ + \text{e}^-$	$\rightarrow$	$\text{Li}(\text{s})$	-3.05

ADVANCED PLACEMENT CHEMISTRY EQUATIONS AND CONSTANTS

ATOMIC STRUCTURE

$$E = h\nu \quad c = \lambda\nu$$

$$\lambda = \frac{h}{mv} \quad p = mv$$

$$E_n = \frac{-2.178 \times 10^{-18}}{n^2} \text{ joule}$$

EQUILIBRIUM

$$K_a = \frac{[\text{H}^+][\text{A}^-]}{[\text{HA}]}$$

$$K_b = \frac{[\text{OH}^-][\text{HB}^+]}{[\text{B}]}$$

$$K_w = [\text{OH}^-][\text{H}^+] = 1.0 \times 10^{-14} \text{ @ } 25^\circ\text{C}$$

$$= K_a \times K_b$$

$$\text{pH} = -\log[\text{H}^+], \text{pOH} = -\log[\text{OH}^-]$$

$$14 = \text{pH} + \text{pOH}$$

$$\text{pH} = \text{p}K_a + \log \frac{[\text{A}^-]}{[\text{HA}]}$$

$$\text{pOH} = \text{p}K_b + \log \frac{[\text{HB}^+]}{[\text{B}]}$$

$$\text{p}K_a = -\log K_a, \text{p}K_b = -\log K_b$$

$$K_p = K_c(RT)^{\Delta n},$$

where Δn = moles product gas – moles reactant gas

THERMOCHEMISTRY/KINETICS

$$\Delta S^\circ = \sum S^\circ \text{ products} - \sum S^\circ \text{ reactants}$$

$$\Delta H^\circ = \sum \Delta H_f^\circ \text{ products} - \sum \Delta H_f^\circ \text{ reactants}$$

$$\Delta G^\circ = \sum \Delta G_f^\circ \text{ products} - \sum \Delta G_f^\circ \text{ reactants}$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

$$= -RT \ln K = -2.303 RT \log K$$

$$= -n\mathcal{F}E^\circ$$

$$\Delta G = \Delta G^\circ + RT \ln Q = \Delta G^\circ + 2.303 RT \log Q$$

$$q = mc\Delta T$$

$$C_p = \frac{\Delta H}{\Delta T}$$

$$\ln[A]_t - \ln[A]_0 = -kt$$

$$\frac{1}{[A]_t} - \frac{1}{[A]_0} = kt$$

$$\ln k = \frac{-E_a}{R} \left(\frac{1}{T} \right) + \ln A$$

E = energy

v = velocity

ν = frequency

n = principal quantum number

λ = wavelength

m = mass

p = momentum

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

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

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

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

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

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

Equilibrium Constants

K_a (weak acid)

K_b (weak base)

K_w (water)

K_p (gas pressure)

K_c (molar concentrations)

S° = standard entropy

H° = standard enthalpy

G° = standard free energy

E° = standard reduction potential

T = temperature

n = moles

m = mass

q = heat

c = specific heat capacity

C_p = molar heat capacity at constant pressure

E_a = activation energy

k = rate constant

A = frequency factor

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

Gas constant, $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$
 $= 0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1}$
 $= 62.4 \text{ L torr mol}^{-1} \text{ K}^{-1}$
 $= 8.31 \text{ volt coulomb mol}^{-1} \text{ K}^{-1}$

GO ON TO THE NEXT PAGE.

GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

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

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

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

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

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

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

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

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

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

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

$$\frac{r_1}{r_2} = \sqrt{\frac{M_2}{M_1}}$$

molarity, M = moles solute per liter solution

molality = moles solute per kilogram solvent

$$\Delta T_f = iK_f \times \text{molality}$$

$$\Delta T_b = iK_b \times \text{molality}$$

$$\pi = iMRT$$

$$A = abc$$

P = pressure

V = volume

T = temperature

n = number of moles

D = density

m = mass

v = velocity

u_{rms} = root-mean-square speed

KE = kinetic energy

r = rate of effusion

M = molar mass

π = osmotic pressure

i = van't Hoff factor

K_f = molal freezing-point depression constant

K_b = molal boiling-point elevation constant

A = absorbance

a = molar absorptivity

b = path length

c = concentration

Q = reaction quotient

I = current (amperes)

q = charge (coulombs)

t = time (seconds)

E° = standard reduction potential

K = equilibrium constant

OXIDATION-REDUCTION; ELECTROCHEMISTRY

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

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

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

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

Gas constant, $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$

$= 0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1}$

$= 62.4 \text{ L torr mol}^{-1} \text{ K}^{-1}$

$= 8.31 \text{ volt coulomb mol}^{-1} \text{ K}^{-1}$

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

K_f for $\text{H}_2\text{O} = 1.86 \text{ K kg mol}^{-1}$

K_b for $\text{H}_2\text{O} = 0.512 \text{ K kg mol}^{-1}$

1 atm = 760 mm Hg

= 760 torr

STP = 0.00°C and 1.0 atm

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

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APPENDIX - ANSWERS

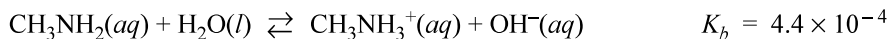
AP CHEMISTRY 2012

Multiple-choice key transcribed from the matching supplied source.

Question	Answer	Question	Answer	Question	Answer
1	B	26	A	51	B
2	B	27	C	52	B
3	C	28	B	53	D
4	D	29	D	54	A
5	B	30	A	55	D
6	B	31	C	56	D
7	A	32	C	57	A
8	B	33	A	58	D
9	A	34	A	59	E
10	C	35	D	60	B
11	D	36	D	61	D
12	A	37	E	62	E
13	A	38	B	63	B
14	C	39	B	64	E
15	D	40	B	65	D
16	A	41	B	66	D
17	E	42	A	67	B
18	B	43	C	68	E
19	D	44	A	69	D
20	C	45	E	70	D
21	D	46	E	71	E
22	D	47	B	72	D
23	B	48	D	73	A
24	B	49	E	74	D
25	B	50	A	75	E

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Question 1



Methylamine, CH_3NH_2 , is a weak base that reacts with water according to the equation above. A student obtains a 50.0 mL sample of a methylamine solution and determines the pH of the solution to be 11.77.

- (a) Write the expression for the equilibrium constant, K_b , for methylamine.

$K_b = \frac{[\text{CH}_3\text{NH}_3^+][\text{OH}^-]}{[\text{CH}_3\text{NH}_2]}$	One point is earned for the correct expression.
--	---

- (b) Calculate the molar concentration of OH^- in the 50.0 mL sample of the methylamine solution.

<p>pH = 11.77</p> <p>$[\text{H}^+] = 10^{-11.77} = 1.7 \times 10^{-12}$</p> <p>$[\text{OH}^-] = \frac{K_w}{[\text{H}^+]} = \frac{1.0 \times 10^{-14}}{1.7 \times 10^{-12}} = 5.9 \times 10^{-3}$</p> <p>OR</p> <p>pOH = 14 – pH = 2.23</p> <p>$[\text{OH}^-] = 10^{-2.23} = 5.9 \times 10^{-3}$</p>	One point is earned for correct $[\text{OH}^-]$.
---	---

- (c) Calculate the initial molar concentration of $\text{CH}_3\text{NH}_2(aq)$ in the solution before it reacted with water and equilibrium was established.

$K_b = \frac{[\text{CH}_3\text{NH}_3^+][\text{OH}^-]}{[\text{CH}_3\text{NH}_2]}$ $4.4 \times 10^{-4} = \frac{(5.9 \times 10^{-3})(5.9 \times 10^{-3})}{(x - 5.9 \times 10^{-3})}$ <p>$x = \mathbf{0.085\ M}$</p>	<p>One point is earned for $[\text{CH}_3\text{NH}_3^+] = [\text{OH}^-]$.</p> <p>One point is earned for the correct initial molar concentration.</p> <p><u>Note:</u> An approximated molar concentration does <i>not</i> earn the second point.</p>
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Question 1 (continued)

The 50.0 mL sample of the methylamine solution is titrated with an HCl solution of unknown concentration. The equivalence point of the titration is reached after a volume of 36.0 mL of the HCl solution is added. The pH of the solution at the equivalence point is 5.98.

(d) Write the net-ionic equation that represents the reaction that takes place during the titration.

$\text{CH}_3\text{NH}_2 + \text{H}_3\text{O}^+ \rightarrow \text{CH}_3\text{NH}_3^+ + \text{H}_2\text{O}$ <p style="text-align: center;">OR</p> $\text{CH}_3\text{NH}_2 + \text{H}^+ \rightarrow \text{CH}_3\text{NH}_3^+$	One point is earned for a correct equation.
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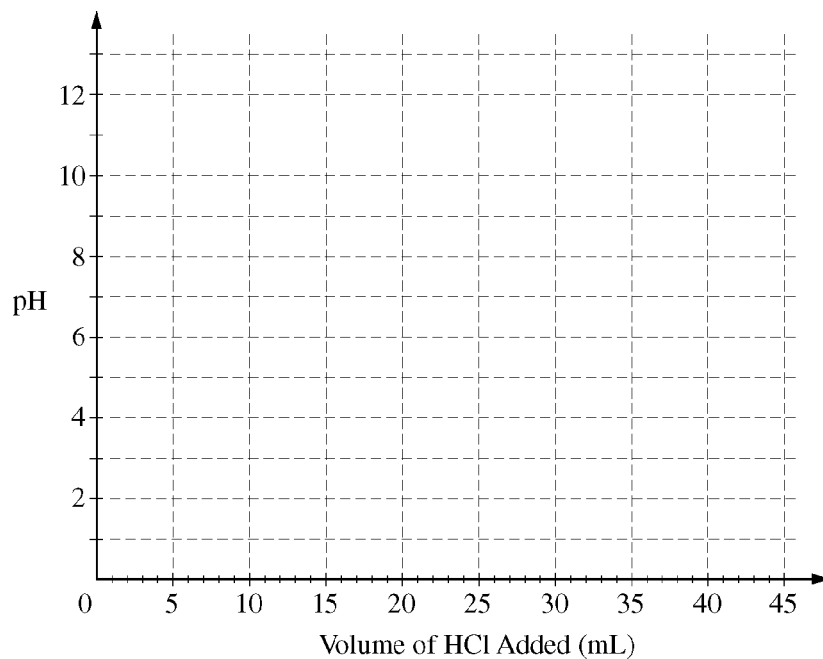
(e) Calculate the concentration of the HCl solution used to titrate the methylamine.

$\frac{0.085 \text{ mol}}{1000. \text{ mL}} \times 50.0 \text{ mL} = 0.00425 \text{ mol CH}_3\text{NH}_2$	One point is earned for equal moles of acid and base.
$\frac{0.00425 \text{ mol HCl}}{36.0 \text{ mL}} \times \frac{1000. \text{ mL}}{1.000 \text{ L}} = \mathbf{0.12 \text{ M}}$	One point is earned for the correct concentration.

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Question 1 (continued)

- (f) Using the axes provided, sketch the titration curve that results from the titration described above. On the graph, clearly label the equivalence point of the titration.



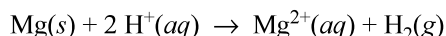
One point is earned for a curve starting at a pH between 11 and 12.

One point is earned for labeling the equivalence point at $V = \sim 36.0$ mL HCl and a pH of ~ 5.98 .

One point is earned for general shape of the curve for a weak acid/strong base titration.

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Question 2



A student performs an experiment to determine the volume of hydrogen gas produced when a given mass of magnesium reacts with excess $\text{HCl}(aq)$, as represented by the net ionic equation above. The student begins with a 0.0360 g sample of pure magnesium and a solution of 2.0 M $\text{HCl}(aq)$.

- (a) Calculate the number of moles of magnesium in the 0.0360 g sample.

$\frac{1 \text{ mol Mg}}{24.30 \text{ g Mg}} \times 0.0360 \text{ g} = 0.00148 \text{ mol Mg}$	<p>One point is earned for the correct number of moles of Mg.</p> <p><u>Note:</u> For errors in significant figures or mathematics, there is a 1 point deduction; For the entire question, only 1 point total can be deducted for each type of error.</p>
--	---

- (b) Calculate the number of moles of $\text{HCl}(aq)$ needed to react completely with the sample of magnesium.

$0.00148 \text{ mol Mg} \times \frac{2 \text{ mol H}^+}{1 \text{ mol Mg}} = 0.00296 \text{ mol HCl}$	<p>One point is earned for the correct number of moles of HCl.</p>
--	--

As the magnesium reacts, the hydrogen gas produced is collected by water displacement at 23.0°C. The barometric pressure in the lab is measured to be 749 torr.

- (c) Given that the equilibrium vapor pressure of water is 21 torr at 23.0°C, calculate the pressure that the $\text{H}_2(g)$ produced in the reaction would have if it were dry.

$P = 749 \text{ torr} - 21 \text{ torr} = 728 \text{ torr}$	<p>One point is earned for the correct pressure.</p>
---	--

- (d) Calculate the volume, in liters measured at the conditions in the laboratory, that the $\text{H}_2(g)$ produced in the reaction would have if it were dry.

$PV = nRT \Rightarrow V = \frac{nRT}{P}$ $728 \text{ torr} \times \frac{1 \text{ atm}}{760 \text{ torr}} = 0.958 \text{ atm}$ $V = \frac{(0.00148 \text{ mol H}_2)(0.0821 \text{ L atm mol}^{-1} \text{ K}^{-1})(296 \text{ K})}{0.958 \text{ atm}}$ $= 0.0375 \text{ L}$	<p>One point is earned for the correct moles of $\text{H}_2(g)$.</p> <p>One point is earned for agreement of units of P (from part(c)) and R.</p> <p>One point is earned for the correct temperature substitution and calculated volume.</p>
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AP[®] CHEMISTRY 2012 SCORING GUIDELINES (INTERNATIONAL)**Question 2 (continued)**

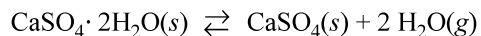
- (e) The laboratory procedure specified that the concentration of the HCl solution be 2.0 *M*, but only 12.3 *M* HCl solution was available. Describe the steps for safely preparing 50.0 mL of 2.0 *M* HCl(aq) using 12.3 *M* HCl solution and materials selected from the list below. Show any necessary calculation(s).

10.0 mL graduated cylinder	Distilled water
250 mL beakers	Balance
50.00 mL volumetric flask	Dropper

$\frac{2.0 \text{ mol HCl}}{1000. \text{ mL}} \times 50.0 \text{ mL} = 0.10 \text{ mol HCl}$ $\frac{1000. \text{ mL}}{12.3 \text{ mol HCl}} \times 0.10 \text{ mol HCl} = 8.1 \text{ mL}$ <p>Pour some distilled water into the volumetric flask so it is about half full. Use the graduated cylinder to measure 8.1 mL of 12.3 <i>M</i> HCl and pour it into the volumetric flask. Add a few mL of distilled water to the graduated cylinder, swirl, and add the liquid to the volumetric flask. Swirl the flask to mix. Carefully add more distilled water to the flask, using the dropper for the last few mL to fill the flask to the mark with distilled water.</p>	<p>One point is earned for calculating the correct volume of 12.3 <i>M</i> HCl.</p> <p>One point is earned for adding acid to water in the dilution process.</p> <p>One point is earned for filling the volumetric to the 50.00 mL mark with distilled water.</p>
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Question 3



The hydrate $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}(s)$ can be heated to form the anhydrous salt, $\text{CaSO}_4(s)$, as shown by the reaction represented above.

- (a) Using the data in the table below, calculate the value of ΔG° , in kJ mol^{-1} , for the reaction at 298 K.

Substance	ΔG_f° at 298 K (kJ mol^{-1})
$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}(s)$	-1795.70
$\text{CaSO}_4(s)$	-1320.30
$\text{H}_2\text{O}(g)$	-228.59

$\Delta G^\circ = \Sigma \Delta G_f^\circ \text{ products} - \Sigma \Delta G_f^\circ \text{ reactants}$ $= -1320.30 + (2 \times -228.59) - (-1795.70 \text{ kJ mol}^{-1})$ $= \mathbf{18.22 \text{ kJ mol}^{-1}}$	<p>One point is earned for the mole factor for water.</p> <p>One point is earned for answer (units are optional)</p>
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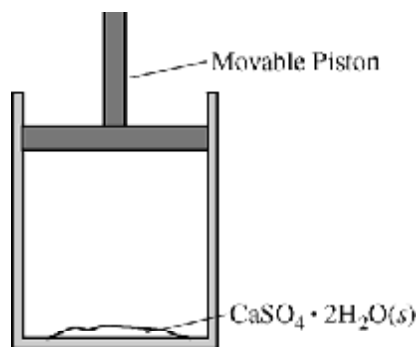
- (b) Given that the value of ΔH° for the reaction at 298 K is $+105 \text{ kJ mol}^{-1}$, calculate the value of ΔS° for the reaction at 298 K. Include units with your answer.

$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$ $\Delta S^\circ = \frac{\Delta H^\circ - \Delta G^\circ}{T} = \frac{(105 - 18.22) \text{ kJ mol}^{-1}}{298 \text{ K}}$ $= \mathbf{0.29 \text{ kJ K}^{-1} \text{ mol}^{-1} \text{ OR } 290 \text{ J K}^{-1} \text{ mol}^{-1}}$	<p>One point is earned for the correct substitution of ΔG°, ΔH°, and T.</p> <p>One point is earned for the correct answer <i>with correct units</i>.</p>
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Question 3 (continued)

A sample of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}(s)$ is placed in a cylinder with a movable piston as shown in the diagram below. The air above the solid is at 1.00 atm and is initially dry (partial pressure of $\text{H}_2\text{O}(g) = 0$ atm).



- (c) Write the expression for the equilibrium constant, K_p , for the reaction.

$K_p = (p_{\text{H}_2\text{O}})^2$	One point is earned for the correct expression (use of partial pressure only).
------------------------------------	--

- (d) Given that the equilibrium constant, K_p , is 6.4×10^{-4} at 298 K, determine the partial pressure, in atm, of water vapor in the cylinder at equilibrium at 298 K.

$K_p = (p_{\text{H}_2\text{O}})^2 \Rightarrow 6.4 \times 10^{-4}$ $p_{\text{H}_2\text{O}} = \sqrt{6.4 \times 10^{-4}} = \mathbf{0.025 \text{ atm}}$	One point is earned for the correct partial pressure (units are not required).
---	--

- (e) If the volume of the system is reduced to one-half of its original volume and the system is allowed to reestablish equilibrium at 298 K, what will be the pressure, in atm, of the water vapor at the new volume? Justify your answer.

<p>The $p_{\text{H}_2\text{O}}$ at equilibrium at the new volume will be 0.025 atm.</p> <p>Equilibrium vapor pressure is dependent on K_p, which in turn is a function of temperature, not volume. Because the temperature is still 298 K, the vapor pressure of H_2O remains 0.025 atm in the new volume.</p>	One point is earned for the correct answer with justification.
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Question 3 (continued)

In the laboratory, the hydrate $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}(s)$ can be heated in a crucible to completely drive off the water of hydration to form the anhydrous salt, $\text{CaSO}_4(s)$.

- (f) A 2.49 g sample of pure $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}(s)$ is heated several times until the mass is constant. Calculate the mass, in grams, of the solid that remains after the dehydration reaction is complete.

$\begin{aligned}\text{molar mass of } \text{CaSO}_4 \cdot 2\text{H}_2\text{O}(s) &= 172.172 \text{ g mol}^{-1} \\ \text{molar mass of } \text{CaSO}_4(s) &= 136.14 \text{ g mol}^{-1} \\ 2.49 \text{ g } \text{CaSO}_4 \cdot 2\text{H}_2\text{O} \times \frac{136.14 \text{ g } \text{CaSO}_4}{172.172 \text{ g } \text{CaSO}_4 \cdot 2\text{H}_2\text{O}} &= 1.97 \text{ g } \text{CaSO}_4\end{aligned}$	<p>One point is earned for the (rounded) correct molar masses.</p> <p>One point is earned for an answer consistent with the molar masses.</p>
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Question 4

For each of the following three reactions, in part (i) write a balanced equation for the reaction and in part (ii) answer the question about the reaction. In part (i), coefficients should be in terms of lowest whole numbers. Assume that solutions are aqueous unless otherwise indicated. Represent substances in solutions as ions if the substances are extensively ionized. Omit formulas for any ions or molecules that are unchanged by the reaction. You may use the empty space at the bottom of the next page for scratch work, but only equations that are written in the answer boxes provided will be graded.

(a) Solutions of ethanoic (acetic) acid and lithium hydroxide are combined.

<p>(i) Balanced equation:</p> $\text{HC}_2\text{H}_3\text{O}_2 + \text{OH}^- \rightarrow \text{C}_2\text{H}_3\text{O}_2^- + \text{H}_2\text{O}$	<p>One point is earned for the correct reactants.</p> <p>Two points are earned for the correct products.</p> <p>One point is earned for balancing the equation for mass and charge.</p>
---	---

(ii) If the ethanoic acid is titrated with the lithium hydroxide, is the pH at the equivalence point equal to 7, less than 7, or greater than 7? Explain.

<p>The pH will be greater than 7. $\text{HC}_2\text{H}_3\text{O}_2$ is a weak acid and LiOH is a strong base. At the equivalence point, the $\text{C}_2\text{H}_3\text{O}_2^-$ is the pH-determining species because of the reaction, $\text{C}_2\text{H}_3\text{O}_2^- + \text{H}_2\text{O} \rightleftharpoons \text{HC}_2\text{H}_3\text{O}_2 + \text{OH}^-$.</p>	<p>One point is earned for the correct answer with an explanation.</p>
--	--

(b) Solutions of iron(III) chloride and tin(II) chloride are combined.

<p>(i) Balanced equation:</p> $2 \text{Fe}^{3+} + \text{Sn}^{2+} \rightarrow 2 \text{Fe}^{2+} + \text{Sn}^{4+}$ <p style="text-align: center;">OR</p> $2 \text{Fe}^{3+} + 3 \text{Sn}^{2+} \rightarrow 2 \text{Fe} + 3 \text{Sn}^{4+}$	<p>One point is earned for the correct reactants.</p> <p>Two points are earned for the correct products.</p> <p>One point is earned for balancing the equation for both mass and charge.</p>
---	--

(ii) Identify the species that is reduced in the reaction.

<p>Fe^{3+} is reduced.</p>	<p>One point is earned for correct answer.</p>
--	--

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Question 4 (continued)

(c) Solutions of silver(I) nitrate and sodium phosphate are combined, forming a precipitate.

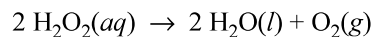
<p>(i) Balanced equation:</p> $3 \text{Ag}^+ + \text{PO}_4^{3-} \rightarrow \text{Ag}_3\text{PO}_4$	<p>Two points are earned for the correct reactants.</p> <p>One point is earned for the correct product.</p> <p>One point is earned for balancing the equation for both mass and charge.</p>
---	---

(ii) If 5 mol of silver(I) nitrate and 3 mol of sodium phosphate react as completely as possible, which reactant, if any, is present in excess? Justify your answer.

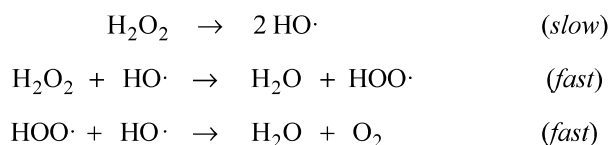
<p>Nine moles of Ag^+ would be needed to react completely with the three moles of PO_4^{3-}, so sodium phosphate is present in excess.</p>	<p>One point is earned for a correct answer with reference to reactant data.</p>
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Question 5



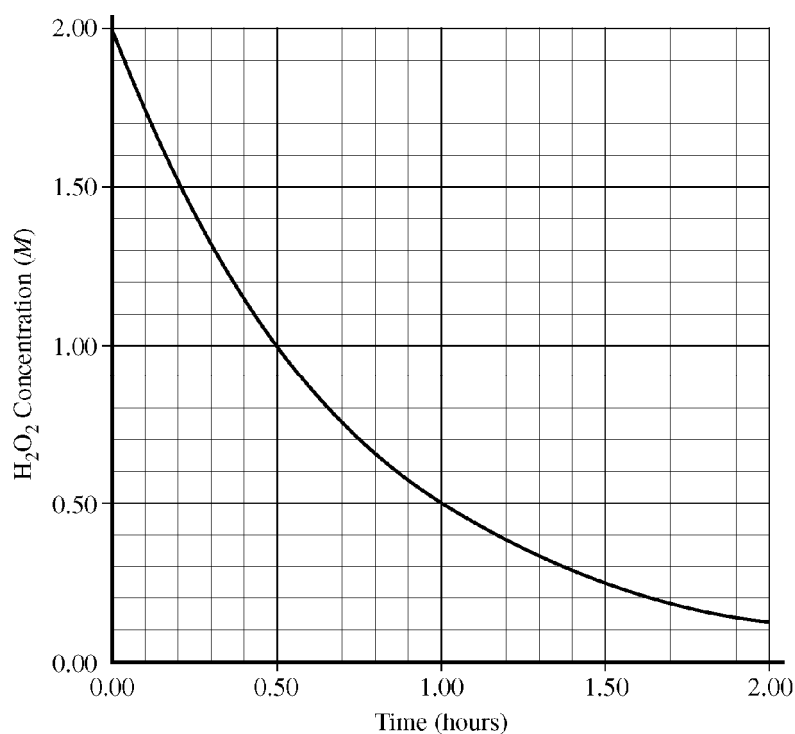
The decomposition of hydrogen peroxide to form water and oxygen gas is represented by the equation above. A proposed mechanism for the reaction, which involves the free radicals $\text{HO}\cdot$ and $\text{HOO}\cdot$, is represented by the three equations below.



- (a) Write the rate law consistent with the proposed mechanism above.

$\text{rate} = k [\text{H}_2\text{O}_2]$	One point is earned for the correct rate law.
--	---

- (b) The rate of the decomposition reaction was studied in an experiment, and the resulting data were plotted in the graph below.



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Question 5 (continued)

Using the graph, determine the time, in hours, needed for the concentration of H_2O_2 to change from

(i) 1.50 *M* to 0.75 *M*

Time = $0.71 - 0.21 = 0.50 \pm 0.05$ hour	One point is earned for the correct time.
---	---

(ii) 0.80 *M* to 0.40 *M*

Time = $1.17 - 0.66 = 0.51 \pm 0.05$ hour	One point is earned for the correct time.
---	---

(c) The experimental data are consistent with the proposed mechanism. Explain.

<p>The data show that the time remains constant when the concentration of the reactant decreases by one-half, indicating that the reaction is first order.</p> <p>The rate law for the proposed mechanism has $[\text{H}_2\text{O}_2]$ to the first power, indicating a first-order reaction.</p>	One point is earned for a correct explanation.
--	--

An electrochemical cell based on the decomposition of H_2O_2 can be constructed based on the half-reactions in the table below.

Half-Reaction	Standard Reduction Potential, E°
$\text{H}_2\text{O}_2 + 2 e^- \rightarrow 2 \text{OH}^-$	0.88 V
$\text{O}_2 + 2 \text{H}_2\text{O} + 2 e^- \rightarrow \text{H}_2\text{O}_2 + 2 \text{OH}^-$	-0.15 V

(d) Calculate the value of the standard cell potential, E° , for the cell.

$\text{H}_2\text{O}_2 + 2 \text{OH}^- \rightarrow \text{O}_2 + 2 \text{H}_2\text{O} + 2 e^-$ 0.15 V $\text{H}_2\text{O}_2 + 2 e^- \rightarrow 2 \text{OH}^-$ 0.88 V <hr/> $2 \text{H}_2\text{O}_2 \rightarrow 2 \text{H}_2\text{O} + \text{O}_2$ 1.03 V	One point is earned for the correct value of E° .
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Question 5 (continued)

- (e) Indicate whether ΔG° for the decomposition reaction is greater than 0, less than 0, or equal to 0. Justify your answer.

ΔG° is less than 0. $\Delta G^\circ = -nFE^\circ$. Because E° is positive, ΔG° must be negative. OR E° is positive, thus the reaction is spontaneous. For spontaneous reactions, ΔG° is always negative.	One point is earned for the correct answer with justification.
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- (f) The decomposition of $\text{H}_2\text{O}_2(aq)$ is slow at 298 K, but a suitable catalyst greatly increases the rate of the decomposition reaction.

- (i) Draw a circle around each of the quantities below that has a different value for the catalyzed reaction than for the uncatalyzed reaction.

K_{eq}

ΔG°

ΔH°

E_a

Only E_a should be circled.	One point is earned for circling E_a and none of the other quantities.
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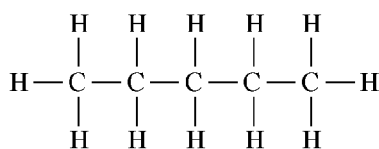
- (ii) For any quantity that you circled above, indicate whether its value is greater or less for the catalyzed reaction than for the uncatalyzed reaction. Explain why.

E_a , the activation energy, is less for the catalyzed reaction than for the uncatalyzed reaction. A catalyst provides a new reaction mechanism that requires a lower minimum required potential energy for the reaction to occur. Thus the activation energy is lowered. <u>Note:</u> reference to other circled quantities is ignored.	One point is earned for a correct answer with reference to an altered mechanism.
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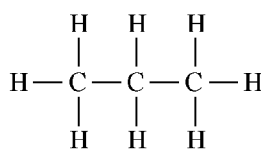
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Question 6

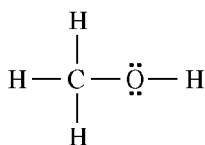
Answer the following questions in terms of principles of chemical bonding and intermolecular forces. In each explanation where a comparison is to be made, a complete answer must include a discussion of both substances. The following complete Lewis electron-dot diagrams may be useful in answering parts of this question.



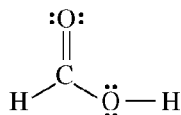
Pentane



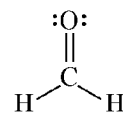
Propane



Methanol



Methanoic (formic) acid



Methanal (formaldehyde)

(a) At 1 atm and 298 K, pentane is a liquid whereas propane is a gas. Explain.

Both molecules are nonpolar, and the only intermolecular forces in each are London dispersion forces. However, pentane is larger than propane and has a more extensive electron cloud that can be involved in a greater number of London interactions, leading to stronger intermolecular attractions overall. Thus it takes a higher temperature for pentane molecules to have enough kinetic energy (on average) to overcome their stronger intermolecular attractions, thus pentane has the higher boiling point.

One point is earned for recognizing that pentane and propane *both* have only LDF's.
One point is earned for recognizing that pentane has a larger electron cloud with greater IMF's and higher BP (reference to state of matter).

(b) At 1 atm and 298 K, methanol is a liquid whereas propane is a gas. Explain.

Propane molecules are nonpolar and only interact with one another via London dispersion forces. Methanol molecules are polar and hydrogen bonds (as well as London forces) can form among them. Because hydrogen bonds are stronger than London forces, methanol has greater intermolecular attractions. Thus it takes a higher temperature for methanol molecules to have enough kinetic energy (on average) to overcome their stronger intermolecular attractions, thus methanol has the higher boiling point.

One point is earned for recognizing that methanol has hydrogen-bonding IMF's and propane has LDF's.

One point is earned for recognizing that hydrogen-bonding results in a greater IMF causing methanol to be a liquid.

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Question 6 (continued)

(c) Indicate the hybridization of the carbon atom in each of the following:

(i) Methanol

sp^3	One point is earned for the correct hybridization.
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(ii) Methanoic (formic) acid

sp^2	One point is earned for the correct hybridization.
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(d) Draw the complete Lewis electron-dot diagram for a molecule of propanoic acid, $\text{HC}_3\text{H}_5\text{O}_2$.

<pre> H H :O: H — C — C — C — O — H H H </pre>	One point is earned for the correct diagram (all electron pairs must be included).
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(e) Explain the following observations about the two carbon-oxygen bonds in the methanoate (formate) anion, HCO_2^- . You may draw a Lewis electron-dot diagram (or diagrams) of the methanoate ion as part of your explanations.

(i) The two carbon-oxygen bonds in the methanoate (formate) anion, HCO_2^- , have the same length.

Resonance structures can be drawn for the methanoate anion, with one carbon-oxygen bond as a single bond and the other as a double bond (and the opposite in the other structure). The electrons are shared equally between the two carbon-oxygen bonds in the methanoate anion, resulting in two bonds with the same length.	One point is earned for the correct explanation.
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(ii) The length of the carbon-oxygen bonds in the methanoate (formate) anion, HCO_2^- , is intermediate between the length of the carbon-oxygen bond in methanol and the length of the carbon-oxygen bond in methanal.

The two identical carbon-oxygen bonds in the methanoate anion each have a bond order of 1.5. The carbon-oxygen bond in methanol is a single bond, and the carbon-oxygen bond in methanal is a double bond. Single bonds between atoms of the same two elements are longer than double bonds, and a bond with a bond order of 1.5 would have a bond length between that of a single bond and that of a double bond.	One point is earned for the correct explanation comparing the single, double <i>and</i> resonating bonds of the respective molecules.
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