(iii) Make ethyl methanoate using molecular model kits.

A complete Lewis electron-dot diagram of a molecule of ethyl methanoate is given below.

\[
\begin{array}{c}
\text{O} \\
\text{H} \\
\text{H} \\
\end{array} \quad \begin{array}{c}
\text{H} \\
\text{C}_2 \quad \text{H} \\
\text{H} \\
\end{array} \quad \begin{array}{c}
\text{C} \quad \text{O} \\
\text{H} \\
\end{array}
\]

(i) Identify the hybridization of the valence electrons of the carbon atom labeled \( \text{C}_2 \).

(ii) Estimate the numerical value of the \( \text{H} - \text{C}_2 - \text{O} \) bond angle in an ethyl methanoate molecule. Explain the basis of your estimate.

(iii) Make ethyl methanoate using molecular model kits.

Oct 29-7:55 AM

Ethyl methanoate, \( \text{CH}_3\text{CHOCH}_3 \), is synthesized in the laboratory from ethanol, \( \text{C}_2\text{H}_5\text{OH} \), and methanoic acid, \( \text{HCOOH} \), as represented by the following equation.

\[ \text{C}_2\text{H}_5\text{OH}(l) + \text{HCOOH}(l) \rightarrow \text{CH}_3\text{CHOCH}_3(l) + \text{H}_2\text{O}(l) \]

(i) In the box below, draw the complete Lewis electron-dot diagram of a methanoic acid molecule.

(ii) Make methanoic acid using molecular model kits.
(iv) Using molecular model kits, show how hydrogen bonding.

At standard temperature and pressure, carbon dioxide is a gas and sodium chloride is a solid.

(i) Explain this difference in state of matter.
(ii) Draw what both carbon dioxide and sodium chloride look like in their standard states in containers.
(iii) Draw what both look like when dissolved in water.

(i) What are two conditions that would make CO$_2$ more soluble in water?
(ii) What are four conditions that would make NaCl more soluble in water?
Which of the following pairs will be the most soluble in water?

- \( \text{C}_6\text{H}_5\text{O}_6 \text{ or CH}_4 \)
- \( \text{HCl or CH}_3\text{COOH} \)
- \( \text{CH}_4\text{Cl}_2 \text{ or CaCl}_2 \)
- \( \text{CH}_3\text{COCH}_3 \text{ or CH}_3\text{CH}_2\text{COOH} \)
- \( \text{CCl}_4 \text{ or KClO}_3 \text{ (s) at high temps or KClO}_3 \text{ (s) at low temps} \)
- \( \text{O}_2 \text{ (g) at high temps or O}_2 \text{ (g) at low temps} \)
- \( \text{CO}_2 \text{ (g) at high pressure or CO}_2 \text{ (g) at low pressure} \)

**Draw (in particles) what sodium sulfate, \( \text{Na}_2\text{SO}_4 \), and calcium phosphate, \( \text{Ca}_3(\text{PO}_4)_2 \), would look like when dissolved in water.**

(i) If these substances were equimolar, which would boil faster and which would boil slower?

**Benzene (\( \text{C}_6\text{H}_6 \)) is a circular molecule that is an excellent solvent.**

(i) Draw the Lewis Structure of benzene.
(ii) Explain why the carbon-to-carbon bond lengths are all the same in benzene.
(iii) Identify the intermolecular forces that benzene contains.
(iv) Identify one other compound that could readily be soluble in benzene.
Separation Techniques

Chromatography (Paper & Column)
Distillation
Filtration
Separate by?
Vapor Pressure
Solids/Solutions
Intermolecular Attractions

---

Draw (in particles) what sugar, C₆H₁₂O₆, and potassium chloride, KCl, would look like when dissolved in water.

(i) If a conductivity meter was placed in the water before each substance was dissolved, describe the change, if any.

---

Oct 31-1:54 PM

---

Oct 29-8:09 AM

---

Oct 17-7:59 AM
For each of the following, use appropriate chemical principles to explain the observation. Include chemical equations as appropriate.

(a) In areas affected by acid rain, statues and structures made of limestone (calcium carbonate) often show signs of considerable deterioration.

(b) When table salt (NaCl) and sugar (C\textsubscript{12}H\textsubscript{22}O\textsubscript{11}) are dissolved in water, it is observed that:
   (i) both solutions have higher boiling points than pure water, and
   (ii) the boiling point of 0.1 M NaCl(aq) is higher than that of 0.1 M C\textsubscript{12}H\textsubscript{22}O\textsubscript{11}(aq).

For each of the following, use appropriate chemical principles to explain the observation. Include chemical equations as appropriate.

(c) Methane gas does not behave as an ideal gas at low temperatures and high pressures.

(d) Water droplets form on the outside of a beaker containing an ice bath.

---

**Draw a particle diagram of before and after from a reaction of hydrogen gas and oxygen gas producing water.**

![Particle Diagram]

---

**A student mixes dilute AgNO\textsubscript{3} (aq) with *excess* NaCl (aq) to form AgCl (s). Which diagram best represents the ions that are present in the resulting solution?**

![Diagrams]
A student mixes dilute AgNO$_3$ (aq) with excess NaBr (aq) to form a precipitate. Draw a particle diagram to show the resulting precipitate and ions? (Do not show the water molecules in this diagram!)
2.0 \text{ Pb(NO}_3\text{)}_2 \text{ (aq)} + 2.0 \text{ M KI (aq)} \rightarrow \text{ PbI}_2 \text{ (s)} + ____ \text{ M KNO}_3 \text{ (aq)}

Oct 23-8:32 AM

SMART Document Camera

Ensure that a SMART Document Camera is connected and isn’t in use in another application.

Oct 24-12:24 PM

Oct 24-8:57 AM
A student performs an experiment in which the conductance of a solution of Ba(OH)_2 is monitored as the solution is titrated with H_2SO_4. The original volume of the Ba(OH)_2 solution is 25.0 mL. A precipitate of BaSO_4 (K_sp = 1.0 x 10^{-5}) forms during the titration. The data collected from the experiment are plotted in the graph above.

(i) The conductance of the Ba(OH)_2 solution decreases as the volume of added 0.10 M H_2SO_4 changes from 0.0 mL to 30.0 mL.
(ii) Identify the chemical species that enable the solution to conduct electricity as the first 30.0 mL of 0.10 M H_2SO_4 are added.
(iii) On the basis of the equations you wrote in (a), explain why the conductance decreases.
(iv) Using the information in the graph, calculate the molarity of the original Ba(OH)_2 solution.

(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:
   (i) Methanol
   (ii) Methanoic (formic) acid
(a) Draw the Lewis electron dot diagram for a molecule of propionic acid, HCHO₂.

(b) Explain the following observations about the two carbon-oxygen bonds in the methanoate (formate) anion, HCOO⁻. You may draw a Lewis electron dot diagram (or diagrams) of the methanoate ion as part of your explanation:
   (i) The two carbon-oxygen bonds in the methanoate (formate) anion, HCOO⁻, have the same length.
   (ii) The length of the carbon-oxygen bonds in the methanoate (formate) anion, HCOO⁻, is intermediate between the length of the carbon-oxygen bond in methanol and the length of the carbon-oxygen bond in methane.

Mg(s) + 2HCl(aq) → MgCl₂(aq) + H₂(g)

- A student performs an experiment to determine the volume of hydrogen gas produced when a given mass of magnesium reacts with excess HCl(aq), as represented by the net ionic equation above. The student begins with 0.0050 g of pure magnesium and a solution of 2.0 M HCl(aq).
- Calculate the number of moles of magnesium in the 0.0050 g sample.
- Calculate the number of moles of HCl(aq) needed to react completely with the sample of magnesium.
- The magnesium reacts with the hydrogen gas produced. If collected by water displacement at 23.0°C, the pressure of the gas in the collection tube is measured to be 740 torr.
- Given that the equilibrium vapor pressure of water is 21 torr at 23.0°C, calculate the pressure that the H₂(g) produced in the reaction would have if it were dry.
- Calculate the volume, in liters, measured at the conditions in the laboratory, that the H₂(g) produced in the reaction would have if it were dry.

The laboratory procedure specified that the concentration of the HCl solution be 2.0 M, but only 2.3 M HCl solution was available. Describe the steps for safely preparing 500 mL of 2.0 M HCl(aq) using 2.3 M HCl solution and materials selected from the list below. Show any necessary calculations:

- 10.0 mL graduated cylinder
- Distilled water
- 250 mL beakers
- Balance
- 50.0 mL volumetric flask
- Dropper
An experiment is performed to compare the solubilities of I$_2$(s) in different solvents, water and hexane (C$_6$H$_{14}$).

A student adds 2 ml of H$_2$O and 2 ml of C$_6$H$_{14}$ to a test tube. Because H$_2$O and C$_6$H$_{14}$ are immiscible, two layers are observed in the test tube. The student drops a small, purple crystal of I$_2$(s) into the test tube, which is then corked and inverted several times. The C$_6$H$_{14}$ layer becomes light purple, while the H$_2$O layer remains virtually colorless.

(b) Explain why the hexane layer is light purple while the water layer is virtually colorless. Your explanation should reference the relative strengths of interactions between molecules of I$_2$ and the solvents H$_2$O and C$_6$H$_{14}$, and the reason for the difference.

d) The student then adds a small crystal of KI(s) to the test tube. The test tube is corked and inverted several times. The I$^-$ ion reacts with I$_2$ to form the I$_2$,$^-$ ion, a linear species.

(i) In the box below, draw the complete Lewis electron-dot diagram for the I$_2$,$^-$ ion.

(ii) In which layer, water or hexane, would the concentration of I$^-$ be higher? Explain.

Oct 31-8:29 AM

(a) In the boxes provided, draw the complete Lewis structure (electron-dot diagram) for each of the three molecules represented below.

CF$_4$  PF$_3$  SF$_3$

(b) On the basis of the Lewis structures drawn above, answer the following questions about the particular molecule indicated.

(i) What is the F–F bond angle in CF$_4$?

(ii) What is the hybridization of the valence orbitals of P in PF$_3$?

(iii) What is the geometric shape formed by the atoms in SF$_3$?
Name 5 ways to increase the solubility of a solid in a liquid.

Like Dissolves Like   Add more solvent
Increased KE          Add a catalyst
Greater # of          Surface Areas
Name 2 ways to increase the solubility of a gas in a liquid.
High Pressure         Low Temperature

Nov 7-8:50 AM

Calculate without a calculator:
1) The Molar concentration (Molarity) of 40g of CuSO₄ (MM = 160) in 500mL of H₂O.
2) How many grams of NaOH (MW = 40) is needed to make 250 mL of a 0.5 M solution?
3) If a 50 mL of a 2M solution of HCl is added to 150 mL of water, what is the concentration of H⁺ of the resulting soln?

Nov 7-8:48 AM

Which is more soluble in water?
Give a quick explanation.
1) CH₄ or HF
2) CH₃COCH₃ or CH₃CH₂CH₂
3) CH₃(CH₂)₄CH₃ or CH₃(CH₂)₄OH
4) Cl₂ or KCl
5) F₂ at high temperatures or F₂ at low temperatures

Nov 7-9:00 AM
Calculate without a calculator

1) How many grams of KBr (119 g mol\(^{-1}\)) are needed to make a 250mL solution of 2.0M?

2) A 1.5M solution was made by placing 54g of solute into 2L of solvent. What is the molar mass of the solute?

3) A solution contains 0.04 mol of X, 0.05 mol of Y, and 0.01 mol of Z. The vapor pressure of pure X is 40 mmHg. What is the new vapor pressure of the X solution?

5. Suppose you have saturated solutions at 50°C for each of the compounds in the above graph. Which solution will precipitate the greatest mass of solute when the solutions are cooled to 20°C?
   (A) KI
   (B) KCl
   (C) Pb(NO\(_3\))\(_2\)
   (D) Cu(NO\(_3\))\(_2\)
   (E) NaCl

1. How many grams of (NH\(_4\))\(_2\)SO\(_4\) (MM=132g/mol) are needed to create 750 mL of 0.1 M ammonium sulfate?
   (A) 8.9 g
   (B) 9.9 g
   (C) 7.5 g
   (D) 8.99 g
   (E) 75 g

10. Suppose 250 mL of 0.90 M Ca(NO\(_3\))\(_2\) is poured into 500 mL of distilled water. What is the concentration of the final solution?
   (A) 0.25 M
   (B) 0.60 M
   (C) 0.30 M
   (D) 0.50 M
   (E) 0.20 M
What is the mole fraction of ethanol, \( C_6H_5OH \), in an aqueous solution that is 46% ethanol by mass? (Molar mass of ethanol is 46, the molar mass of water is 18)

(a) 0.25  
(b) 0.46  
(c) 0.54  
(d) 0.67  
(e) 0.75

If 200mL of 0.60M \( MgCl_2 \) is added to 400mL of water, what is the concentration of \( Mg^{2+} \) in the resulting solution? (assume the volumes are additive)

(a) 0.20 M  
(b) 0.30 M  
(c) 0.40 M  
(d) 0.60 M  
(e) 1.2 M

2. How many grams of \( KNO_2 \) (MM=101 g/mol) are needed to make 250 mL of 0.20 M potassium nitrite?

(A) 2.5 g  
(B) 5.1 g  
(C) 7.5 g  
(D) 25 g  
(E) 0.25 g

3. Which of the following compounds has the greatest solubility in water?

(A) \( CH_3CH_2CH_2CH_3 \)  
(B) \( CH_3CH_2CH_2OH \)  
(C) \( CH_3CH_2CH_2OH \)  
(D) \( CH_3CH(=O)H \)  
(E) \( CH_3CH_2OH \)

6. When the temperature of an unsaturated solution of potassium nitrite, \( KNO_2 \), decreases from 90°C to 0°C, which of the following statements holds true.

I. The solubility remains the same.  
II. The mole fraction of \( KNO_2 \) remains the same.  
III. The mobility of the solution remains the same.  

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

4. Which of the following pairs of compounds is most likely to behave like an ideal solution?

(A) \( C_2H_5OH \) (l) and \( H_2O \) (l)  
(B) \( H_2O \) (l) and \( AlCl_3 \) (aq)  
(C) \( C_2H_5OH \) (l) and \( CH_3OH \) (l)  
(D) \( C_2H_2 \) (g) and \( C_2H_2 \) (l)  
(E) \( C_2H_5OH \) (l) and \( CH_3CH_2OH \) (l)
Colligative Properties

Boiling Point
Vapor Pressure
Freezing Point

Explain what happens to each property when a material is made into a solution and why.

Elevate
Lower

Van't Hoff Factor
Many people use 18g of sugar (sucrose = C\textsubscript{12}H\textsubscript{22}O\textsubscript{11}) in each cup (250mL or 250g of water) of coffee. The vapor pressure of pure water at 80°C is 355mmHg.

What is the vapor pressure of sugared coffee at this same temperature?
Pure Lauric Acid freezes at a specific temperature. A solution made by dissolving BHT into Lauric Acid changes the freezing point. To determine the molar mass of BHT...

(1) Determine 4 measurements you would need to make.
(2) Determine 1 thing you would need from me.
(3) Determine the 4 calculations you need to make.

Equations for Colligative Properties Problems

\[ \Delta T = iK_m \]

\[ m = \frac{\text{mol}}{\text{kg}} \]

\[ \text{mol} = \frac{\text{mass}}{M_m} \]

When 10.0g of nicotine, \(\text{C}_{10}\text{H}_{14}\text{N}_2\), is dissolved in 50.0 g of naphthalene, determine the new freezing point of naphthalene. The freezing point of pure naphthalene is 80.29°C and the Kf for naphthalene is 6.94°C/m.
A 2.00 g sample of a large biomolecule was dissolved in 15.0 g of CCl₄. The boiling point of this solution was determined to be 77.85°C. The $K_b$ for CCl₄ is 5.03°C·kg/mol and the BP of pure CCl₄ is 76.50°C. Calculate the molar mass of the biomolecule.

A solution was prepared by dissolving 18.00 g of an organic solute in 150.0 g of water. The resulting solution is found to have a boiling point of 100.34°C. The $K_b$ for water is 0.51°C/m. 

(A) Calculate the molar mass of the organic solute. 
(B) If the organic solute has an empirical formula of CH₂O, what is the molecular formula?

A chemist is trying to identify an organic molecule by determining its molar mass. A sample weighing 0.546g was dissolved in 150g of benzene. The freezing point depression is found to be 0.240°C. The $K_f$ for benzene is 5.12°C·kg·mol⁻¹.
A hydrocarbon is found to be 86% carbon by mass. An experiment is performed where 3.72g of the unknown hydrocarbon is placed in 50.0g of benzene. The freezing point of the solution was found to be 0.06°C. The normal freezing point of benzene is 5.50°C and the Kf for benzene is 5.12°C m⁻¹.

(a) What is the empirical formula of the hydrocarbon?
(b) What is the molar mass of the hydrocarbon?
(c) What is the molecular formula of the hydrocarbon?

Multiple Choice
1) An excess of Mg (s) is added to 100mL of 0.400 M HCl. At 0°C and 1 atm pressure, what volume of H₂ can be obtained? (Hint: make a balanced reaction first)
   (a) 22.4 mL
   (b) 44.8 mL
   (c) 224 mL
   (d) 448 mL
   (e) 896 mL

Explain each of the following:
(a) The atomic radius of Li is larger than that of Be.
(b) The second ionization energy of K is greater than the second ionization energy of Ca.
(c) The carbon-to-carbon bond energy in C₂H₄ is greater than it is in C₂H₆.
(d) The boiling point of Cl₂ is lower than the boiling point of Br₂.
Multiple Choice
1) What mass of KBr (molar mass 119 g mol⁻¹) is required to make 250 mL of a 0.400 M KBr solution?
   (a) 0.595 g  
   (b) 1.19 g  
   (c) 2.50 g  
   (d) 11.9 g  
   (e) 47.6 g

2) Three gases - Ar (0.35 mol), CH₄ (0.90 mol), N₂ (0.25 mol) are added to a rigid container. If the total pressure in the tank is 3.0 atm at 25°C, the partial pressure of N₂ (g) is closest to:
   (a) 0.75 atm  
   (b) 0.50 atm  
   (c) 0.33 atm  
   (d) 0.25 atm  
   (e) 0.17 atm

Multiple Choice
1) Which of the following aqueous solutions has the highest boiling point at 1.0 atm?
   (A) 0.20 M CaCl₂  
   (B) 0.25 M Na₂SO₄  
   (C) 0.30 M NaCl  
   (D) 0.30 M KBr  
   (E) 0.40 M C₆H₁₂O₆

2) A sample of a solution of RbCl (molar mass 121 g mol⁻¹) contains 11.0% RbCl by mass. From the information above, what is needed to determine the molarity of RbCl in solution?
   I. Mass of the sample  
   II. Volume of the sample  
   III. Temperature of the sample

Multiple Choice
1) Which of the following properties is (are) colligative properties?
   I. Freezing point elevation  
   II. Vapor pressure elevation  
   III. Boiling point elevation
   (A) 0.5 M NaCl  
   (B) 0.5 M KBr  
   (C) 0.5 M CaCl₂  
   (D) 0.5 M C₆H₁₂O₆  
   (E) 0.5 M NaNO₃

2) Which of the following aqueous solutions has the highest boiling point?
Multiple Choice
1) Which of the following substance is LEAST soluble in water?
(A) (NH₄)₂SO₄
(B) KMnO₄
(C) BaCO₃
(D) Zn(NO₃)₂
(E) Na₃PO₄

2) Which of the following pure substances has the highest melting point?
(A) S₈
(B) I₂
(C) SiO₂
(D) SO₂
(E) C₆H₆

Multiple Choice
1) A pure, white crystalline solid dissolves in water to yield a basic solution that liberates a gas when excess acid is added to it. On the basis of this information, the solid could be
(A) KNO₃
(B) K₂CO₃
(C) KOH
(D) KHSO₄
(E) KCl

2) 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

Multiple Choice
1) Sodium chloride is LEAST soluble in which of the following liquids?
(A) H₂O
(B) CCl₄
(C) HF
(D) CH₃OH
(E) CH₃COOH

2) According to the VSEPR model, the progressive decrease in bond angles in the series of molecule CH₄, NH₃, and H₂O is best accounted for by the
(A) increasing strength of the bonds
(B) decreasing size of the central atom
(C) increasing electronegativity of the central atom
(D) increasing number of unshared pairs of electrons
(E) decreasing repulsion between hydrogen atoms
Multiple Choice

1) A flask contains 0.25 mole of SO\(_2\) (g), 0.50 mole of CH\(_4\) (g), and 0.50 mole of O\(_2\) (g). The total pressure of the gases in the flask is 800 mmHg. What is the partial pressure of SO\(_2\) (g) in the flask?
   (A) 800 mmHg  
   (B) 600 mmHg  
   (C) 250 mmHg  
   (D) 200 mmHg  
   (E) 160 mmHg

2) A compound contains 1.10 mol of K, 0.55 mol of Te, and 1.65 mol of O. What is the simplest formula of this compound?
   (A) KTeO  
   (B) KTe\(_2\)O  
   (C) K\(_2\)TeO\(_3\)  
   (D) K\(_2\)TeO\(_6\)  
   (E) K\(_4\)TeO\(_6\)
Answer EITHER Question 7 below OR Question 8 below. Only one of these two questions will be graded. If you start both questions, be sure to cross out the question you do not want graded. The Section II score weighting for the question you choose is 15 percent.

7. Answer the following questions, which refer to the 100 mL samples of aqueous solutions at 25°C in the stoppered flasks shown above.

(a) Which solution has the lowest electrical conductivity? Explain.

(b) Which solution has the lowest freezing point? Explain.

(c) Above which solution is the pressure of water vapor greatest? Explain.

(d) Which solution has the highest pH? Explain.

8. Answer the following questions using principles of chemical bonding and molecular structure.

(a) Consider the carbon dioxide molecule, \( \text{CO}_2 \), and the carbonate ion, \( \text{CO}_3^{2-} \).

   (i) Draw the complete Lewis electron-dot structure for each species.

   (ii) Account for the fact that the carbon-oxygen bond length in \( \text{CO}_3^{2-} \) is greater than the carbon-oxygen bond length in \( \text{CO}_2 \).

(b) Consider the molecules \( \text{CF}_4 \) and \( \text{SF}_4 \).

   (i) Draw the complete Lewis electron-dot structure for each molecule.

   (ii) In terms of molecular geometry, account for the fact that the \( \text{CF}_4 \) molecule is nonpolar, whereas the \( \text{SF}_4 \) molecule is polar.

END OF EXAMINATION
AP® CHEMISTRY
1999 SCORING GUIDELINES

Question 7

8 points:

a. **1 point**

C₂H₅OH (Flask #3)

**1 point**

Ethanol, a nonelectrolyte, does not break up or dissociate in solution.

- One point earned for identifying C₂H₅OH
- One point earned for the correct explanation.
- Explanation point earned for a description of a nonelectrolyte (e.g., something that does not break up or does not dissociate.)
- No point earned for describing C₂H₅OH as organic, or as the compound that contains the most hydrogens.

b. **1 point**

MgCl₂ (Flask #2)

**1 point**

The freezing-point depression is proportional to the concentration of solute particles. All solutes are at the same concentration, but the van't Hoff factor (i) is largest for MgCl₂.

- One point earned for identifying MgCl₂.
- One point earned for the correct explanation.

c. **1 point**
C\textsubscript{2}H\textsubscript{5}OH (Flask #3)

1 point

The lowering of vapor pressure of water is directly proportional to the concentration of solute particles in solution. C\textsubscript{2}H\textsubscript{5}OH is the only nonelectrolyte, so it will have the fewest solute particles in solution.

- One point earned for identifying C\textsubscript{2}H\textsubscript{5}OH.
- One point earned for the correct explanation.

d. 1 point

NaF (Flask #1)

1 point

The F\textsuperscript{-} ion, generated upon dissolution of NaF, is a weak base. It is the only solution with pH > 7.

- One point earned for identifying NaF.
- One point earned for the correct explanation.
2001 AP® CHEMISTRY FREE-RESPONSE QUESTIONS

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

Answer BOTH Question 5 below AND Question 6 printed on page 11. Both of these questions will be graded. The Section II score weighting for these questions is 30 percent (15 percent each).

![Solution 1](image1) ![Solution 2](image2) ![Solution 3](image3) ![Solution 4](image4) ![Solution 5](image5)

0.10 M Pb(NO₃)₂ 0.10 M NaCl 0.10 M KMnO₄ 0.10 M C₂H₅OH 0.10 M KC₂H₃O₂

5. Answer the questions below that relate to the five aqueous solutions at 25°C shown above.

(a) Which solution has the highest boiling point? Explain.

(b) Which solution has the highest pH? Explain.

(c) Identify a pair of the solutions that would produce a precipitate when mixed together. Write the formula of the precipitate.

(d) Which solution could be used to oxidize the Cl⁻(aq) ion? Identify the product of the oxidation.

(e) Which solution would be the least effective conductor of electricity? Explain.
Question 5

(10 points)

In each part, one point is earned for the correct solution or solutions, and one point is earned for the correct explanation (in parts a, b, and e), precipitate (in part c), or product (in part d).

(a) Pb(NO$_3$)$_2$ (Solution 1)  

Pb(NO$_3$)$_2$ has the largest value of $i$, the van’t Hoff factor, so the solution has the highest number of solute particles (it dissociates into the most particles).  

- Student must address the relative number of particles.

(b) KC$_2$H$_3$O$_2$ (Solution 5)  

The acetate ion is the conjugate base of a weak acid, so it is a weak base  

(or KC$_2$H$_3$O$_2$ is the salt of a strong base and a weak acid, so the solution is basic).

(c) Pb(NO$_3$)$_2$ and NaCl (Solutions 1 and 2)  

PbCl$_2$ would precipitate  

- Points can also be earned for KMnO$_4$ plus one of the other solutions (with the precipitation of MnO$_2$).  
- Points can also be earned for KMnO$_4$ plus Pb(NO$_3$)$_2$ (with the precipitation of PbO$_2$, or MnO$_2$).

(d) KMnO$_4$ (Solution 3)  

The product of the oxidation is Cl$_2$  

(e) C$_2$H$_5$OH (Solution 4)  

Ethanol is the only nonelectrolyte given. It does not readily dissociate into ions, so it would not produce charged species that would conduct a current.  

- One point can also be earned for explanations using $i$, the van’t Hoff factor.
8. The graph below shows the result of the titration of a 25 mL sample of a 0.10 \( M \) solution of a weak acid, \( \text{HA} \), with a strong base, 0.10 \( M \) \( \text{NaOH} \).

![Graph showing titration curve]

(a) Describe two features of the graph above that identify \( \text{HA} \) as a weak acid.

(b) Describe one method by which the value of the acid-dissociation constant for \( \text{HA} \) can be determined using the graph above.

(c) On the graph above, sketch the titration curve that would result if 25 mL of 0.10 \( M \) \( \text{HCl} \) were used instead of 0.10 \( M \) \( \text{HA} \).

(d) A 25 mL sample of 0.10 \( M \) \( \text{HA} \) is titrated with 0.20 \( M \) \( \text{NaOH} \).
   (i) What volume of base must be added to reach the equivalence point?
   (ii) The pH at the equivalence point for this titration is slightly higher than the pH at the equivalence point in the titration using 0.10 \( M \) \( \text{NaOH} \). Explain.
8 points

The graph below shows the result of the titration of a 25 mL sample of a 0.10 \( M \) solution of a weak acid, HA, with a strong base, 0.10 \( M \) NaOH.

(a) Describe two features of the graph above that identify HA as a weak acid.

<table>
<thead>
<tr>
<th>Feature Description</th>
<th>Points Earned</th>
</tr>
</thead>
<tbody>
<tr>
<td>The initial pH of the solution before base has been added is greater than 1 (the pH expected for a 0.1 ( M ) strong acid).</td>
<td>1 point earned for initial pH &gt; 1</td>
</tr>
<tr>
<td>The pH at the equivalence point is greater than 7.</td>
<td>1 point earned for pH &gt; 7 at equivalence point</td>
</tr>
<tr>
<td>There is a rapid increase in the pH after adding a small amount of base at the beginning of the titration. The increase quickly diminishes on continued addition of base (buffer region).</td>
<td></td>
</tr>
</tbody>
</table>
(b) Describe one method by which the value of the acid-dissociation constant for \( HA \) can be determined using the graph above.

<table>
<thead>
<tr>
<th>The ( K_a ) for the weak acid can be obtained by determining the pH at the:</th>
<th>1 point earned for indicating any one of the first three points (at left) identified on the titration curve.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. half-equivalence point in the titration where ( K_a = 10^{-pH} )</td>
<td>1 point earned for describing the determination of ( K_a ) from that point.</td>
</tr>
<tr>
<td>2. zero volume of base</td>
<td>(For any other point on the curve, 2 points for correct justification.)</td>
</tr>
<tr>
<td>3. equivalence point</td>
<td></td>
</tr>
<tr>
<td>(Any point on the titration curve is acceptable with justification.)</td>
<td></td>
</tr>
</tbody>
</table>

(c) On the graph above, sketch the titration curve that would result if 25 mL of 0.10 \( M \) HCl were used instead of 0.10 \( M \) HA.

![Titration Curve Graph](image)

The graph should have the following features:

1. pH before adding any base is 1
2. the equivalence point pH is 7 at 25 mL
3. the titration curve beyond the equivalence point is nearly identical to the original curve

1 point earned for any two features and 2 points for all three.

Beginning the pH at 1, the equivalence point at pH = 7 (when the volume is equal to the volume of the base required to neutralize the strong acid), and the ending pH of the solution is nearly the same as the original curve.
(d) A 25 mL sample of 0.10 M HA is titrated with 0.20 M NaOH.

(i) What volume of base must be added to reach the equivalence point?

\[
\frac{2.5 \text{ mmol HA}}{2.5 \text{ mmol OH}^-} = \frac{2.5 \text{ mmol OH}^-}{0.20 \text{ mmol/mL}} = 13 \text{ mL}
\]

1 point earned for the correct volume

(ii) The pH at the equivalence point for this titration is slightly higher than the pH at the equivalence point in the titration using 0.10 M NaOH. Explain.

In the titration with 0.1 M NaOH, the total volume at the equivalence point is 50 mL. In the titration with 0.20 M NaOH the total volume at the equivalence point is 37.5 mL.

The smaller volume in the titration with 0.2 M NaOH means the [A⁻], the molar concentration of the conjugate base of HA, is larger compared to the [A⁻] at the equivalence point with 0.1 M NaOH.

Therefore, the pH is slightly higher.

1 point earned for correct explanation
5. In a laboratory class, a student is given three flasks that are labeled $Q$, $R$, and $S$. Each flask contains one of the following solutions: $1.0 \ M \ \text{Pb(NO}_3\text{)}_2$, $1.0 \ M \ \text{NaCl}$, or $1.0 \ M \ \text{K}_2\text{CO}_3$. The student is also given two flasks that are labeled $X$ and $Y$. One of these flasks contains $1.0 \ M \ \text{AgNO}_3$, and the other contains $1.0 \ M \ \text{BaCl}_2$. This information is summarized in the diagram below.

Each flask contains one of the following solutions:
- $\text{Pb(NO}_3\text{)}_2$
- $\text{NaCl}$
- $\text{K}_2\text{CO}_3$

Each flask contains one of the following solutions:
- $\text{AgNO}_3$
- $\text{BaCl}_2$

(a) When the student combined a sample of solution $Q$ with a sample of solution $X$, a precipitate formed. A precipitate also formed when samples of solutions $Q$ and $Y$ were combined.
   (i) Identify solution $Q$.
   (ii) Write the chemical formulas for each of the two precipitates.

(b) When solution $Q$ is mixed with solution $R$, a precipitate forms. However, no precipitate forms when solution $Q$ is mixed with solution $S$.
   (i) Identify solution $R$ and solution $S$.
   (ii) Write the chemical formula of the precipitate that forms when solution $Q$ is mixed with solution $R$.

(c) The identity of solution $X$ and solution $Y$ are to be determined using only the following solutions: $1.0 \ M \ \text{Pb(NO}_3\text{)}_2$, $1.0 \ M \ \text{NaCl}$, and $1.0 \ M \ \text{K}_2\text{CO}_3$.
   (i) Describe a procedure to identify solution $X$ and solution $Y$.
   (ii) Describe the observations that would allow you to distinguish between solution $X$ and solution $Y$.
   (iii) Explain how the observations would enable you to distinguish between solution $X$ and solution $Y$. 
Question 5

In a laboratory class, a student is given three flasks that are labeled Q, R, and S. Each flask contains one of the following solutions: 1.0 M Pb(NO$_3$)$_2$, 1.0 M NaCl, or 1.0 M K$_2$CO$_3$. The student is also given two flasks that are labeled X and Y. One of these flasks contains 1.0 M AgNO$_3$, and the other contains 1.0 M BaCl$_2$. This information is summarized in the diagram below.

(a) When the student combined a sample of solution Q with a sample of solution X, a precipitate formed. A precipitate also formed when samples of solutions Q and Y were combined.

(i) Identify solution Q.

Solution Q is K$_2$CO$_3$ 1 point for correct identification of solution Q

(ii) Write the chemical formulas for each of the two precipitates.

Ag$_2$CO$_3$ and BaCO$_3$ 1 point each for correct formulas of carbonate precipitates

(b) When solution Q is mixed with solution R, a precipitate forms. However, no precipitate forms when solution Q is mixed with solution S.

(i) Identify solution R and solution S.

Solution R is Pb(NO$_3$)$_2$ and solution S is NaCl. 1 point each for identification of solutions R and S

(ii) Write the chemical formula of the precipitate that forms when solution Q is mixed with solution R.

PbCO$_3$ 1 point for correct formula of the precipitate
(c) The identity of solution \( X \) and solution \( Y \) are to be determined using only the following solutions: 1.0 \( M \) Pb(NO\(_3\))\(_2\), 1.0 \( M \) NaCl, and 1.0 \( M \) K\(_2\)CO\(_3\).

(i) Describe a procedure to identify solution \( X \) and solution \( Y \).

<table>
<thead>
<tr>
<th>The identities of solutions ( X ) and ( Y ) can be determined by adding a sample of NaCl to each solution.</th>
<th>1 point for a correct identification of a reagent that will differentiate between the two solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR</td>
<td>The identities of solutions ( X ) and ( Y ) can be determined by adding a sample of Pb(NO(_3))(_2) to solution ( X ) and solution ( Y ).</td>
</tr>
</tbody>
</table>

(ii) Describe the observations that would allow you to distinguish between solution \( X \) and solution \( Y \).

<table>
<thead>
<tr>
<th>NaCl will form a white precipitate when added to a solution of AgNO(_3), but will not form a precipitate when added to a solution of BaCl(_2).</th>
<th>1 point for correct observation that a precipitate is formed in one solution but not the other</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR</td>
<td>Pb(NO(_3))(_2) will form a white precipitate when added to a solution of BaCl(_2), but will not form a precipitate when added to a solution of AgNO(_3).</td>
</tr>
</tbody>
</table>

(iii) Explain how the observations would enable you to distinguish between solution \( X \) and solution \( Y \).

<table>
<thead>
<tr>
<th>When NaCl is added to solution ( X ), a precipitate of AgCl forms if solution ( X ) is AgNO(_3). If no precipitate forms, solution ( X ) must be BaCl(_2). The same logic can be used to identify solution ( Y ).</th>
<th>1 point for correct identification of the solution that forms a precipitate</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR</td>
<td>When Pb(NO(_3))(_2) is added to solution ( X ), a precipitate of PbCl(_2) forms if solution ( X ) is BaCl(_2). If no precipitate forms, solution ( X ) must be AgNO(_3). The same logic can be used to identify solution ( Y ).</td>
</tr>
</tbody>
</table>
2004 AP® CHEMISTRY FREE-RESPONSE QUESTIONS (Form B)

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

Answer BOTH Question 5 below AND Question 6 printed on page 11. Both of these questions will be graded. The Section II score weighting for these questions is 30 percent (15 percent each).

5. An experiment is performed to determine the molar mass of an unknown solid monoprotic acid, HA, by titration with a standardized NaOH solution.

(a) What measurement(s) must be made to determine the number of moles of NaOH used in the titration?

(b) Write a mathematical expression that can be used to determine the number of moles of NaOH used to reach the endpoint of the titration.

(c) How can the number of moles of HA consumed in the titration be determined?

(d) In addition to the measurement(s) made in part (a), what other measurement(s) must be made to determine the molar mass of the acid, HA?

(e) Write the mathematical expression that is used to determine the molar mass of HA.

(f) The following diagram represents the setup for the titration. In the appropriate boxes below, list the chemical(s) needed to perform the titration.

(g) Explain what effect each of the following would have on the calculated molar mass of HA. Justify your answers.

(i) The original solid acid, HA, was not completely dry at the beginning of the experiment.

(ii) The procedure called for 25 mL of H₂O in the Erlenmeyer flask, but a student used 35 mL of H₂O.
5. An experiment is performed to determine the molar mass of an unknown solid monoprotic acid, HA, by titration with a standardized NaOH solution.

(a) What measurement(s) must be made to determine the number of moles of NaOH used in the titration?

| Initial volume of standardized NaOH solution and final volume of standardized NaOH solution (volume at the endpoint of the titration) | 1 point for identifying both initial and final volume of base |

(b) Write a mathematical expression that can be used to determine the number of moles of NaOH used to reach the endpoint of the titration.

\[ M_{\text{NaOH}} \times V_{\text{NaOH}} \]

(Molarity of NaOH solution) times (volume (in L) of NaOH added) 1 point for mathematical expression

(c) How can the number of moles of HA consumed in the titration be determined?

\[
\begin{align*}
\text{HA} + \text{NaOH} & \rightarrow \text{NaA} + \text{H}_2\text{O} \\
\text{moles HA} &= \text{moles NaOH} \\
\text{moles monoprotic acid} &= \text{moles NaOH} \\
n_{\text{HA}} &= \text{moles NaOH} \left( \frac{1 \text{ mol HA}}{1 \text{ mol NaOH}} \right) \\
\end{align*}
\]

1 point for showing conversion based on stoichiometry of the neutralization reaction

(d) In addition to the measurement(s) made in part (a), what other measurement(s) must be made to determine the molar mass of the acid, HA?

| mass of HA | 1 point for measurement |

(e) Write the mathematical expression that is used to determine the molar mass of HA.

\[
\text{mass HA} \quad \text{mol HA} \\
\text{mass of HA} \quad \text{measured in part (d)} \quad \text{divided by the moles of HA determined in part (c)}
\]

1 point for quotient
Question 5 (cont'd.)

(f) The following diagram represents the setup for the titration. In the appropriate boxes below, list the chemical(s) needed to perform the titration.

Chemicals needed in flask: solid weak monoprotic acid (HA) and an indicator to detect endpoint of titration

Chemical in buret: standardized NaOH solution

1 point for either one of two chemicals in flask, 2 points for both
1 point for NaOH in the buret

(g) Explain what effect each of the following would have on the calculated molar mass of HA. Justify your answers.

(i) The original solid acid, HA, was not completely dry at the beginning of the experiment.

Measured mass of HA is larger; so, according to expression in part (e), calculated molar mass will be higher than it should.

1 point for the effect on molar mass and explanation.

(ii) The procedure called for 25 mL of H₂O in the Erlenmeyer flask, but a student used 35 mL of H₂O.

No effect on calculated molar mass, because mathematical expression for molar mass does not include amount of water used to dissolve solid HA. Both mass and number of moles of HA are unaffected by the addition of water.

1 point for effect on molar mass and explanation.
2005 AP® CHEMISTRY FREE-RESPONSE QUESTIONS

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

Answer BOTH Question 5 below AND Question 6 printed on page 12. Both of these questions will be graded. The Section II score weighting for these questions is 30 percent (15 percent each).

5. Answer the following questions that relate to laboratory observations and procedures.

(a) An unknown gas is one of three possible gases: nitrogen, hydrogen, or oxygen. For each of the three possibilities, describe the result expected when the gas is tested using a glowing splint (a wooden stick with one end that has been ignited and extinguished, but still contains hot, glowing, partially burned wood).

(b) The following three mixtures have been prepared: CaO plus water, SiO₂ plus water, and CO₂ plus water. For each mixture, predict whether the pH is less than 7, equal to 7, or greater than 7. Justify your answers.

(c) Each of three beakers contains a 0.1 M solution of one of the following solutes: potassium chloride, silver nitrate, or sodium sulfide. The three beakers are labeled randomly as solution 1, solution 2, and solution 3. Shown below is a partially completed table of observations made of the results of combining small amounts of different pairs of the solutions.

<table>
<thead>
<tr>
<th></th>
<th>Solution 1</th>
<th>Solution 2</th>
<th>Solution 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution 1</td>
<td></td>
<td>black precipitate</td>
<td></td>
</tr>
<tr>
<td>Solution 2</td>
<td></td>
<td></td>
<td>no reaction</td>
</tr>
<tr>
<td>Solution 3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(i) Write the chemical formula of the black precipitate.
(ii) Describe the expected results of mixing solution 1 with solution 3.
(iii) Identify each of the solutions 1, 2, and 3.
Answer the following questions that relate to laboratory observations and procedures.

(a) An unknown gas is one of three possible gases: nitrogen, hydrogen, or oxygen. For each of the three possibilities, describe the result expected when the gas is tested using a glowing splint (a wooden stick with one end that has been ignited and extinguished, but still contains hot, glowing, partially burned wood).

| Nitrogen: When the glowing splint is inserted into the gas sample, the glowing splint will be extinguished. |
| Hydrogen: When the glowing splint is inserted into the gas sample, a popping sound (explosion) can be heard. |
| Oxygen: When the glowing splint is inserted into the gas sample, the splint will glow brighter or reignite. |

One point is earned for each description.

(b) The following three mixtures have been prepared: CaO plus water, SiO\(_2\) plus water, and CO\(_2\) plus water. For each mixture, predict whether the pH is less than 7, equal to 7, or greater than 7. Justify your answers.

| CaO plus water: The pH of the solution will be greater than 7. CaO in water forms the base Ca(OH)\(_2\) (or metal oxides are basic, or basic anhydrides). |
| SiO\(_2\) plus water: The pH of the solution will be equal to 7. SiO\(_2\) is insoluble in water, so there would not be a change in the pH of the mixture. |
| CO\(_2\) plus water: The pH of the solution will be less than 7. CO\(_2\) in water forms the acid H\(_2\)CO\(_3\) (or nonmetal oxides are acidic, or acidic anhydrides). |

One point is earned for each description.

(c) Each of three beakers contains a 0.1 \(M\) solution of one of the following solutes: potassium chloride, silver nitrate, or sodium sulfide. The three beakers are labeled randomly as solution 1, solution 2, and solution 3. Shown below is a partially completed table of observations made of the results of combining small amounts of different pairs of the solutions.
(i) Write the chemical formula of the black precipitate.

<table>
<thead>
<tr>
<th>Solution 1</th>
<th>Solution 2</th>
<th>Solution 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution 1</td>
<td>black precipitate</td>
<td></td>
</tr>
<tr>
<td>Solution 2</td>
<td></td>
<td>no reaction</td>
</tr>
<tr>
<td>Solution 3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The black precipitate is $\text{Ag}_2\text{S}$.

One point is earned for the correct formula.

(ii) Describe the expected results of mixing solution 1 with solution 3.

A precipitate will be produced when the two solutions are mixed.

One point is earned for the correct observation.

(iii) Identify each of the solutions 1, 2, and 3.

Solution 1 is silver nitrate.
Solution 2 is sodium sulfide.
Solution 3 is potassium chloride.

One point is earned for the correct identification of all three solutions.
2 Al(s) + 2 KOH(aq) + 4 H₂SO₄(aq) + 22 H₂O(l) → 2 KAl(SO₄)₂·12H₂O(s) + 3 H₂(g)

5. In an experiment, a student synthesizes alum, KAl(SO₄)₂·12H₂O(s), by reacting aluminum metal with potassium hydroxide and sulfuric acid, as represented in the balanced equation above.

(a) In order to synthesize alum, the student must prepare a 5.0 M solution of sulfuric acid. Describe the procedure for preparing 50.0 mL of 5.0 M H₂SO₄ using any of the chemicals and equipment listed below. Indicate specific amounts and equipment where appropriate.

| 10.0 M H₂SO₄ | 50.0 mL volumetric flask |
| Distilled water | 50.0 mL buret |
| 100 mL graduated cylinder | 25.0 mL pipet |
| 100 mL beaker | 50 mL beaker |

(b) Calculate the minimum volume of 5.0 M H₂SO₄ that the student must use to react completely with 2.7 g of aluminum metal.

(c) As the reaction solution cools, alum crystals precipitate. The student filters the mixture and dries the crystals, then measures their mass.

   (i) If the student weighs the crystals before they are completely dry, would the calculated percent yield be greater than, less than, or equal to the actual percent yield? Explain.

   (ii) Cooling the reaction solution in an ice bath improves the percent yield obtained. Explain.

(d) The student heats crystals of pure alum, KAl(SO₄)₂·12H₂O(s), in an open crucible to a constant mass. The mass of the sample after heating is less than the mass before heating. Explain.
In an experiment, a student synthesizes alum, KAl(SO₄)₂·12H₂O(s), by reacting aluminum metal with potassium hydroxide and sulfuric acid, as represented in the balanced equation above.

(a) In order to synthesize alum, the student must prepare a 5.0 M solution of sulfuric acid. Describe the procedure for preparing 50.0 mL of 5.0 M H₂SO₄ using any of the chemicals and equipment listed below. Indicate specific amounts and equipment where appropriate.

| 10.0 M H₂SO₄ | 50.0 mL volumetric flask |
| Distilled water | 50.0 mL buret |
| 100 mL graduated cylinder | 25.0 mL pipet |
| 100 mL beaker | 50 mL beaker |

\[
\begin{align*}
(50.0 \text{ mL}) \left( \frac{1 \text{ L}}{1000 \text{ mL}} \right) \left( \frac{5.0 \text{ mol } \text{H}_2\text{SO}_4}{1 \text{ L}} \right) &= 0.25 \text{ mol } \text{H}_2\text{SO}_4 \\
(0.25 \text{ mol } \text{H}_2\text{SO}_4) \left( \frac{1 \text{ L}}{10 \text{ mol } \text{H}_2\text{SO}_4} \right) \left( \frac{1000 \text{ mL}}{1 \text{ L}} \right) &= 25.0 \text{ mL of } 10.0 \text{ M } \text{H}_2\text{SO}_4
\end{align*}
\]

Put on goggles. Measure approximately 20 mL of distilled water using the 100 mL graduated cylinder, and add the distilled water to the 50.0 mL volumetric flask. Measure 25.0 mL of the 10.0 M H₂SO₄ using the 25.0 mL pipet, and transfer the concentrated acid slowly, with occasional swirling, to the 50.0 mL volumetric flask containing the distilled water. After adding all the concentrated acid, carefully add distilled water until the meniscus of the solution is at the 50.0 mL mark on the neck of the flask at 20°C.

(b) Calculate the minimum volume of 5.0 M H₂SO₄ that the student must use to react completely with 2.7 g aluminum metal.

\[
V_{\text{H}_2\text{SO}_4} = (2.7 \text{ g Al}) \left( \frac{1 \text{ mol Al}}{27.0 \text{ g Al}} \right) \left( \frac{4 \text{ mol } \text{H}_2\text{SO}_4}{2 \text{ mol Al}} \right) \left( \frac{1 \text{ L}}{5.0 \text{ mol } \text{H}_2\text{SO}_4} \right)
\]

\[
V_{\text{H}_2\text{SO}_4} = 0.040 \text{ L}
\]

One point is earned for the number of moles of Al.
One point is earned for the correct stoichiometry.
One point is earned for the answer.
(c) As the reaction solution cools, alum crystals precipitate. The student filters the mixture and dries the crystals, then measures their mass.

(i) If the student weighs the crystals before they are completely dry, would the calculated percent yield be greater than, less than, or equal to the actual percent yield? Explain.

If the $\text{KAl(SO}_4\text{)}_2\cdot12\text{H}_2\text{O(s)}$ crystals have not been properly dried, there will be excess water present, making the mass of the product greater than it should be and the calculated percent yield too high. Therefore, the calculated percent yield will be greater than the actual percent yield. One point is earned for the prediction and a correct explanation.

(ii) Cooling the reaction solution in an ice bath improves the percent yield obtained. Explain.

If the solubility of $\text{KAl(SO}_4\text{)}_2\cdot12\text{H}_2\text{O(s)}$ decreases with decreasing temperature, cooling the reaction solution would result in the precipitation of more $\text{KAl(SO}_4\text{)}_2\cdot12\text{H}_2\text{O(s)}$. One point is earned for the correct explanation.

(d) The student heats crystals of pure alum, $\text{KAl(SO}_4\text{)}_2\cdot12\text{H}_2\text{O(s)}$, in an open crucible to a constant mass. The mass of the sample after heating is less than the mass before heating. Explain.

$\text{KAl(SO}_4\text{)}_2\cdot12\text{H}_2\text{O(s)}$ is a hydrate. For the mass of the sample to be less after heating, the water of hydration must be lost. Heating the sample of $\text{KAl(SO}_4\text{)}_2\cdot12\text{H}_2\text{O(s)}$ crystals will drive off the water first, decreasing the mass of the sample. One point is earned for the correct explanation.
5. A student carries out an experiment to determine the equilibrium constant for a reaction by colorimetric (spectrophotometric) analysis. The production of the red-colored species \( \text{FeSCN}^{2+}(aq) \) is monitored.

(a) The optimum wavelength for the measurement of \([\text{FeSCN}^{2+}]\) must first be determined. The plot of absorbance, \( A \), versus wavelength, \( \lambda \), for \( \text{FeSCN}^{2+}(aq) \) is given below. What is the optimum wavelength for this experiment? Justify your answer.

![Absorbance vs Wavelength Graph]

(b) A calibration plot for the concentration of \( \text{FeSCN}^{2+}(aq) \) is prepared at the optimum wavelength. The data below give the absorbances measured for a set of solutions of known concentration of \( \text{FeSCN}^{2+}(aq) \).

<table>
<thead>
<tr>
<th>Concentration (mol L(^{-1}))</th>
<th>Absorbance</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 1.1 \times 10^{-4} )</td>
<td>0.030</td>
</tr>
<tr>
<td>( 3.0 \times 10^{-4} )</td>
<td>0.065</td>
</tr>
<tr>
<td>( 8.0 \times 10^{-4} )</td>
<td>0.160</td>
</tr>
<tr>
<td>( 12 \times 10^{-4} )</td>
<td>0.239</td>
</tr>
<tr>
<td>( 18 \times 10^{-4} )</td>
<td>0.340</td>
</tr>
</tbody>
</table>
2006 AP® CHEMISTRY FREE-RESPONSE QUESTIONS (Form B)

(i) Draw a Beer’s law calibration plot of all the data on the grid below. Indicate the scale on the horizontal axis by labeling it with appropriate values.

(ii) An FeSCN$^{2+}(aq)$ solution of unknown concentration has an absorbance of 0.300. Use the plot you drew in part (i) to determine the concentration, in moles per liter, of this solution.

(c) The purpose of the experiment is to determine the equilibrium constant for the reaction represented below.

\[
\text{Fe}^{3+}(aq) + \text{SCN}^- (aq) \rightleftharpoons \text{FeSCN}^{2+}(aq)
\]

(i) Write the equilibrium-constant expression for $K_c$.

(ii) The student combines solutions of Fe(NO$_3$)$_3$ and KSCN to produce a solution in which the initial concentrations of Fe$^{3+}(aq)$ and SCN$^-(aq)$ are both $6.0 \times 10^{-3}$ M. The absorbance of this solution is measured, and the equilibrium FeSCN$^{2+}(aq)$ concentration is found to be $1.0 \times 10^{-3}$ M. Determine the value of $K_c$.

(d) If the student’s equilibrium FeSCN$^{2+}(aq)$ solution of unknown concentration fades to a lighter color before the student measures its absorbance, will the calculated value of $K_c$ be too high, too low, or unaffected? Justify your answer.
Question 5

5. A student carries out an experiment to determine the equilibrium constant for a reaction by colorimetric (spectrophotometric) analysis. The production of the red-colored species FeSCN$^{2+}$(aq) is monitored.

(a) The optimum wavelength for the measurement of [FeSCN$^{2+}$] must first be determined. The plot of absorbance, A, versus wavelength, λ, for FeSCN$^{2+}$(aq) is given below. What is the optimum wavelength for this experiment? Justify your answer.

![Absorbance vs. Wavelength Graph]

The optimum wavelength is 450 nm because that is the wavelength of maximum absorbance by FeSCN$^{2+}$(aq).

One point is earned for the correct answer with justification.

(b) A calibration plot for the concentration of FeSCN$^{2+}$(aq) is prepared at the optimum wavelength. The data below give the absorbances measured for a set of solutions of known concentration of FeSCN$^{2+}$(aq).

<table>
<thead>
<tr>
<th>Concentration (mol L$^{-1}$)</th>
<th>Absorbance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 × 10$^{-4}$</td>
<td>0.030</td>
</tr>
<tr>
<td>3.0 × 10$^{-4}$</td>
<td>0.065</td>
</tr>
<tr>
<td>8.0 × 10$^{-4}$</td>
<td>0.160</td>
</tr>
<tr>
<td>12 × 10$^{-4}$</td>
<td>0.239</td>
</tr>
<tr>
<td>18 × 10$^{-4}$</td>
<td>0.340</td>
</tr>
</tbody>
</table>
Question 5 (continued)

(i) Draw a Beer’s law calibration plot of all the data on the grid below. Indicate the scale on the horizontal axis by labeling it with appropriate values.

![Absorbance vs Concentration graph](image)

One point is earned for a straight-line plot.
One point is earned for a correctly scaled horizontal axis.

(ii) An FeSCN$^{2+}$(aq) solution of unknown concentration has an absorbance of 0.300. Use the plot you drew in part (i) to determine the concentration, in moles per liter, of this solution.

See plot in part (i). At $A = 0.300$, [FeSCN$^{2+}$] is approximately $16 \times 10^{-4}$ mol L$^{-1}$.

One point is earned for the correct answer.
(c) The purpose of the experiment is to determine the equilibrium constant for the reaction represented below.

\[ \text{Fe}^{3+}(aq) + \text{SCN}^{-}(aq) \rightleftharpoons \text{FeSCN}^{2+}(aq) \]

(i) Write the equilibrium-constant expression for \( K_c \).

\[
K_c = \frac{[\text{FeSCN}^{2+}]}{[\text{Fe}^{3+}] [\text{SCN}^{-}]} \\
\text{One point is earned for the correct expression.}
\]

(ii) The student combines solutions of \( \text{Fe(NO}_3)_3 \) and \( \text{KSCN} \) to produce a solution in which the initial concentrations of \( \text{Fe}^{3+}(aq) \) and \( \text{SCN}^{-}(aq) \) are both \( 6.0 \times 10^{-3} \) M. The absorbance of this solution is measured, and the equilibrium \( \text{FeSCN}^{2+}(aq) \) concentration is found to be \( 1.0 \times 10^{-3} \) M. Determine the value of \( K_c \).

\[
\begin{array}{ccc}
\text{Fe}^{3+}(aq) & \text{SCN}^{-}(aq) & \text{FeSCN}^{2+}(aq) \\
\hline
\text{I} & 6.0 \times 10^{-3} \text{ M} & 6.0 \times 10^{-3} \text{ M} & 0 \\
\text{C} & -1.0 \times 10^{-3} \text{ M} & -1.0 \times 10^{-3} \text{ M} & +1.0 \times 10^{-3} \text{ M} \\
\text{E} & 5.0 \times 10^{-3} \text{ M} & 5.0 \times 10^{-3} \text{ M} & +1.0 \times 10^{-3} \text{ M} \\
\hline
K_c = \frac{1.0 \times 10^{-3}}{(5.0 \times 10^{-3})(5.0 \times 10^{-3})} & = 40. \\
\end{array}
\]

One point is earned for the correct equilibrium concentration.

One point is earned for the correct substitutions and the calculated value.

(d) If the student's equilibrium \( \text{FeSCN}^{2+}(aq) \) solution of unknown concentration fades to a lighter color before the student measures its absorbance, will the calculated value of \( K_c \) be too high, too low, or unaffected? Justify your answer.

The value of \( K_c \) will be too low; the lower absorbance reading indicates a lower [\( \text{FeSCN}^{2+} \)] than actually existed before the fading occurred, so substitution of a lower [\( \text{FeSCN}^{2+} \)] into the equilibrium expression will result in a lower value of \( K_c \).

One point is earned for the correct prediction.

One point is earned for the correct justification.
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 graded on the basis of the accuracy and relevance of the information cited. Explanations should be clear and well organized. Examples and equations may be included in your responses where appropriate. Specific answers are preferable to broad, diffuse responses.

5. The identity of an unknown solid is to be determined. The compound is one of the seven salts in the following table.

<table>
<thead>
<tr>
<th>Al(NO₃)₃·9H₂O</th>
<th>BaCl₂·2H₂O</th>
<th>CaCO₃</th>
<th>CuSO₄·5H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>BaSO₄</td>
<td>Ni(NO₃)₂·6H₂O</td>
<td></td>
</tr>
</tbody>
</table>

Use the results of the following observations or laboratory tests to explain how each compound in the table may be eliminated or confirmed. The tests are done in sequence from (a) through (e).

(a) The unknown compound is white. In the table below, cross out the two compounds that can be eliminated using this observation. Be sure to cross out these same two compounds in the tables in parts (b), (c), and (d).

<table>
<thead>
<tr>
<th>Al(NO₃)₃·9H₂O</th>
<th>BaCl₂·2H₂O</th>
<th>CaCO₃</th>
<th>CuSO₄·5H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>BaSO₄</td>
<td>Ni(NO₃)₂·6H₂O</td>
<td></td>
</tr>
</tbody>
</table>

(b) When the unknown compound is added to water, it dissolves readily. In the table below, cross out the two compounds that can be eliminated using this test. Be sure to cross out these same two compounds in the tables in parts (c) and (d).

<table>
<thead>
<tr>
<th>Al(NO₃)₃·9H₂O</th>
<th>BaCl₂·2H₂O</th>
<th>CaCO₃</th>
<th>CuSO₄·5H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>BaSO₄</td>
<td>Ni(NO₃)₂·6H₂O</td>
<td></td>
</tr>
</tbody>
</table>

(c) When AgNO₃(aq) is added to an aqueous solution of the unknown compound, a white precipitate forms. In the table below, cross out each compound that can be eliminated using this test. Be sure to cross out the same compound(s) in the table in part (d).

<table>
<thead>
<tr>
<th>Al(NO₃)₃·9H₂O</th>
<th>BaCl₂·2H₂O</th>
<th>CaCO₃</th>
<th>CuSO₄·5H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>BaSO₄</td>
<td>Ni(NO₃)₂·6H₂O</td>
<td></td>
</tr>
</tbody>
</table>
(d) When the unknown compound is carefully heated, it loses mass. In the table below, cross out each compound that can be eliminated using this test.

<table>
<thead>
<tr>
<th>Al(NO₃)₃·9H₂O</th>
<th>BaCl₂·2H₂O</th>
<th>CaCO₃</th>
<th>CuSO₄·5H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>BaSO₄</td>
<td>Ni(NO₃)₂·6H₂O</td>
<td></td>
</tr>
</tbody>
</table>

(e) Describe a test that can be used to confirm the identity of the unknown compound identified in part (d). Limit your confirmation test to a reaction between an aqueous solution of the unknown compound and an aqueous solution of one of the other soluble salts listed in the tables. Describe the expected results of the test; include the formula(s) of any product(s).
The identity of an unknown solid is to be determined. The compound is one of the seven salts in the following table.

<table>
<thead>
<tr>
<th>Al(NO₃)₃·9H₂O</th>
<th>BaCl₂·2H₂O</th>
<th>CaCO₃</th>
<th>CuSO₄·5H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>BaSO₄</td>
<td></td>
<td>Ni(NO₃)₂·6H₂O</td>
</tr>
</tbody>
</table>

Use the results of the following observations or laboratory tests to explain how each compound in the table may be eliminated or confirmed. The tests are done in sequence from (a) through (e).

(a) The unknown compound is white. In the table below, cross out the two compounds that can be eliminated using this observation. Be sure to cross out these same two compounds in the tables in parts (b), (c), and (d).

<table>
<thead>
<tr>
<th>Al(NO₃)₃·9H₂O</th>
<th>BaCl₂·2H₂O</th>
<th>CaCO₃</th>
<th>CuSO₄·5H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>BaSO₄</td>
<td></td>
<td>Ni(NO₃)₂·6H₂O</td>
</tr>
</tbody>
</table>

One point is earned for each correctly crossed-out compound.

(b) When the unknown compound is added to water, it dissolves readily. In the table below, cross out the two compounds that can be eliminated using this test. Be sure to cross out these same two compounds in the tables in parts (c) and (d).

<table>
<thead>
<tr>
<th>Al(NO₃)₃·9H₂O</th>
<th>BaCl₂·2H₂O</th>
<th>CaCO₃</th>
<th>CuSO₄·5H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>BaSO₄</td>
<td></td>
<td>Ni(NO₃)₂·6H₂O</td>
</tr>
</tbody>
</table>

One point is earned for each additional correctly crossed-out compound.

(c) When AgNO₃(aq) is added to an aqueous solution of the unknown compound, a white precipitate forms. In the table below, cross out each compound that can be eliminated using this test. Be sure to cross out the same compound(s) in the table in part (d).

<table>
<thead>
<tr>
<th>Al(NO₃)₃·9H₂O</th>
<th>BaCl₂·2H₂O</th>
<th>CaCO₃</th>
<th>CuSO₄·5H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>BaSO₄</td>
<td></td>
<td>Ni(NO₃)₂·6H₂O</td>
</tr>
</tbody>
</table>

One point is earned for crossing out Al(NO₃)₃·9H₂O or for crossing out Ni(NO₃)₂·6H₂O if it had not been crossed out earlier.
(d) When the unknown compound is carefully heated, it loses mass. In the table below, cross out each compound that can be eliminated using this test.

<table>
<thead>
<tr>
<th></th>
<th>Al(NO₃)₃⋅9H₂O</th>
<th>BaCl₂⋅2H₂O</th>
<th>CaCO₃</th>
<th>CuSO₄⋅5H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crossed out</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NaCl</td>
<td></td>
<td>BaSO₄</td>
<td>Ni(NO₃)₂⋅6H₂O</td>
<td></td>
</tr>
</tbody>
</table>

One point is earned for crossing out NaCl or for crossing out either CaCO₃ or BaSO₄ if they had not been crossed out earlier.

(e) Describe a test that can be used to confirm the identity of the unknown compound identified in part (d). Limit your confirmation test to a reaction between an aqueous solution of the unknown compound and an aqueous solution of one of the other soluble salts listed in the tables above. Describe the expected results of the test; include the formula(s) of any product(s).

| Mix an aqueous solution of BaCl₂⋅2H₂O with an aqueous solution of CuSO₄⋅5H₂O. The BaSO₄ will precipitate. | One point is earned for describing a precipitation reaction between the compound left in part (d) and another compound given in the problem. One point is earned for a correct identification of a precipitate that would form upon the mixing of the chosen solutions. |
5. The identity of an unknown solid is to be determined. The compound is one of the seven salts in the following table.

| Al(NO₃)₃·9H₂O | BaCl₂·2H₂O | CaCO₃ | CuSO₄·5H₂O | NaCl | BaSO₄ | Ni(NO₃)₂·6H₂O |

Use the results of the following observations or laboratory tests to explain how each compound in the table may be eliminated or confirmed. The tests are done in sequence from (a) through (e).

(a) The unknown compound is white. In the table below, cross out the two compounds that can be eliminated using this observation. Be sure to cross out these same two compounds in the tables in parts (b), (c), and (d).

| Al(NO₃)₃·9H₂O | BaCl₂·2H₂O | CaCO₃ | CuSO₄·5H₂O | NaCl | BaSO₄ | Ni(NO₃)₂·6H₂O |

(b) When the unknown compound is added to water, it dissolves readily. In the table below, cross out the two compounds that can be eliminated using this test. Be sure to cross out these same two compounds in the tables in parts (c) and (d).

| Al(NO₃)₃·9H₂O | BaCl₂·2H₂O | CaCO₃ | CuSO₄·5H₂O | NaCl | BaSO₄ | Ni(NO₃)₂·6H₂O |

(c) When AgNO₃(aq) is added to an aqueous solution of the unknown compound, a white precipitate forms. In the table below, cross out each compound that can be eliminated using this test. Be sure to cross out the same compound(s) in the table in part (d).

| Al(NO₃)₃·9H₂O | BaCl₂·2H₂O | CaCO₃ | CuSO₄·5H₂O | NaCl | BaSO₄ | Ni(NO₃)₂·6H₂O |

(d) When the unknown compound is carefully heated, it loses mass. In the table below, cross out each compound that can be eliminated using this test.

| Al(NO₃)₃·9H₂O | BaCl₂·2H₂O | CaCO₃ | CuSO₄·5H₂O | NaCl | BaSO₄ | Ni(NO₃)₂·6H₂O |

(e) Describe a test that can be used to confirm the identity of the unknown compound identified in part (d). Limit your confirmation test to a reaction between an aqueous solution of the unknown compound and an aqueous solution of one of the other soluble salts listed in the tables. Describe the expected results of the test; include the formula(s) of any product(s).
2. A student is assigned the task of determining the mass percent of silver in an alloy of copper and silver by dissolving a sample of the alloy in excess nitric acid and then precipitating the silver as AgCl.

First the student prepares 50. mL of 6 M HNO₃.

(a) The student is provided with a stock solution of 16 M HNO₃, two 100 mL graduated cylinders that can be read to ±1 mL, a 100 mL beaker that can be read to ±10 mL, safety goggles, rubber gloves, a glass stirring rod, a dropper, and distilled H₂O.

(i) Calculate the volume, in mL, of 16 M HNO₃ that the student should use for preparing 50. mL of 6 M HNO₃.

(ii) Briefly list the steps of an appropriate and safe procedure for preparing the 50. mL of 6 M HNO₃. Only materials selected from those provided to the student (listed above) may be used.

(iii) Explain why it is not necessary to use a volumetric flask (calibrated to 50.00 mL ±0.05 mL) to perform the dilution.

(iv) During the preparation of the solution, the student accidentally spills about 1 mL of 16 M HNO₃ on the bench top. The student finds three bottles containing liquids sitting near the spill: a bottle of distilled water, a bottle of 5 percent NaHCO₃(aq), and a bottle of saturated NaCl(aq). Which of the liquids is best to use in cleaning up the spill? Justify your choice.

Then the student pours 25 mL of the 6 M HNO₃ into a beaker and adds a 0.6489 g sample of the alloy. After the sample completely reacts with the acid, some saturated NaCl(aq) is added to the beaker, resulting in the formation of an AgCl precipitate. Additional NaCl(aq) is added until no more precipitate is observed to form. The precipitate is filtered, washed, dried, and weighed to constant mass in a filter crucible. The data are shown in the table below.

<table>
<thead>
<tr>
<th>Mass of sample of copper-silver alloy</th>
<th>0.6489 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of dry filter crucible</td>
<td>28.7210 g</td>
</tr>
<tr>
<td>Mass of filter crucible and precipitate (first weighing)</td>
<td>29.3587 g</td>
</tr>
<tr>
<td>Mass of filter crucible and precipitate (second weighing)</td>
<td>29.2599 g</td>
</tr>
<tr>
<td>Mass of filter crucible and precipitate (third weighing)</td>
<td>29.2598 g</td>
</tr>
</tbody>
</table>

(b) Calculate the number of moles of AgCl precipitate collected.

(c) Calculate the mass percent of silver in the alloy of copper and silver.

© 2011 The College Board.
Visit the College Board on the Web: www.collegeboard.org.

GO ON TO THE NEXT PAGE.
A student is assigned the task of determining the mass percent of silver in an alloy of copper and silver by dissolving a sample of the alloy in excess nitric acid and then precipitating the silver as AgCl.

First the student prepares 50. mL of 6 M HNO₃.

(a) The student is provided with a stock solution of 16 M HNO₃, two 100 mL graduated cylinders that can be read to ±1 mL, a 100 mL beaker that can be read to ±10 mL, safety goggles, rubber gloves, a glass stirring rod, a dropper, and distilled H₂O.

(i) Calculate the volume, in mL, of 16 M HNO₃ that the student should use for preparing 50. mL of 6 M HNO₃.

(ii) Briefly list the steps of an appropriate and safe procedure for preparing the 50. mL of 6 M HNO₃. Only materials selected from those provided to the student (listed above) may be used.

(iii) Explain why it is not necessary to use a volumetric flask (calibrated to 50.00 mL ±0.05 mL) to perform the dilution.

(iv) During the preparation of the solution, the student accidentally spills about 1 mL of 16 M HNO₃ on the bench top. The student finds three bottles containing liquids sitting near the spill: a bottle of distilled water, a bottle of 5 percent NaHCO₃(aq), and a bottle of saturated NaCl(aq). Which of the liquids is best to use in cleaning up the spill? Justify your choice.

Then the student pours 25 mL of the 6 M HNO₃ into a beaker and adds a 0.6489 g sample of the alloy. After the sample completely reacts with the acid, some saturated NaCl(aq) is added to the beaker, resulting in the formation of an AgCl precipitate. Additional NaCl(aq) is added until no more precipitate is observed to form. The precipitate is filtered, washed, dried, and weighed to constant mass in a filter crucible. The data are shown in the table below.

| Mass of sample of copper-silver alloy | 0.6489 g |
| Mass of dry filter crucible            | 28.7210 g |
| Mass of filter crucible & precipitate (first weighing) | 29.3587 g |
| Mass of filter crucible & precipitate (second weighing) | 29.2599 g |
| Mass of filter crucible & precipitate (third weighing) | 29.2598 g |

(b) Calculate the number of moles of AgCl precipitate collected.

(c) Calculate the mass percent of silver in the alloy of copper and silver.
Question 2

A student is assigned the task of determining the mass percent of silver in an alloy of copper and silver by dissolving a sample of the alloy in excess nitric acid and then precipitating the silver as AgCl.

First the student prepares 50. mL of 6 \( M \) HNO\(_3\).

(a) The student is provided with a stock solution of 16 \( M \) HNO\(_3\), two 100 mL graduated cylinders that can be read to \( \pm 1 \) mL, a 100 mL beaker that can be read to \( \pm 10 \) mL, safety goggles, rubber gloves, a glass stirring rod, a dropper, and distilled H\(_2\)O.

   (i) Calculate the volume, in mL, of 16 \( M \) HNO\(_3\) that the student should use for preparing 50. mL of 6 \( M \) HNO\(_3\).

\[
\text{moles before dilution} = \text{moles after dilution} \\
M_iV_i = M_fV_f \\
(16 \ M)(V_i) = (6 \ M)(50. \ mL) \\
V_i = 19 \ mL \text{ or } 20 \ mL \text{ (to one significant figure)}
\]

1 point is earned for the correct volume.

(ii) Briefly list the steps of an appropriate and safe procedure for preparing the 50. mL of 6 \( M \) HNO\(_3\). Only materials selected from those provided to the student (listed above) may be used.

Wear safety goggles and rubber gloves. Then measure 19 mL of 16 \( M \) HNO\(_3\) using a 100 mL graduated cylinder. Measure 31 mL of distilled H\(_2\)O using a 100 mL graduated cylinder. Transfer the water to a 100 mL beaker. Add the acid to the water with stirring.

1 point is earned for properly measuring the volume of 16 \( M \) HNO\(_3\) and preparing a 6 \( M \) HNO\(_3\) acid solution.

1 point is earned for wearing protective gear and for adding acid to water.

(iii) Explain why it is not necessary to use a volumetric flask (calibrated to 50.00 mL \( \pm 0.05 \) mL) to perform the dilution.

The graduated cylinders provide sufficient precision in volume measurement to provide two significant figures, making the use of the volumetric flask unnecessary.

1 point is earned for an acceptable explanation.

(iv) During the preparation of the solution, the student accidentally spills about 1 mL of 16 \( M \) HNO\(_3\) on the bench top. The student finds three bottles containing liquids sitting near the spill: a bottle of distilled water, a bottle of 5 percent NaHCO\(_3\)(aq), and a bottle of saturated NaCl(aq). Which of the liquids is best to use in cleaning up the spill? Justify your choice.
NaHCO₃ (aq) should be used. The HCO₃⁻ ion will react as a base to neutralize the HNO₃. 1 point is earned for the correct choice with explanation.

Then the student pours 25 mL of the 6 M HNO₃ into a beaker and adds a 0.6489 g sample of the alloy. After the sample completely reacts with the acid, some saturated NaCl(aq) is added to the beaker, resulting in the formation of an AgCl precipitate. Additional NaCl(aq) is added until no more precipitate is observed to form. The precipitate is filtered, washed, dried, and weighed to constant mass in a filter crucible. The data are shown in the table below.

| Mass of sample of copper-silver alloy | 0.6489 g |
| Mass of dry filter crucible | 28.7210 g |
| Mass of filter crucible and precipitate (first weighing) | 29.3587 g |
| Mass of filter crucible and precipitate (second weighing) | 29.2599 g |
| Mass of filter crucible and precipitate (third weighing) | 29.2598 g |

(b) Calculate the number of moles of AgCl precipitate collected.

\[
\text{mass of AgCl collected} = (29.2598 - 28.7210) \text{ g} = 0.5388 \text{ g}
\]

\[
\frac{0.5388 \text{ g}}{(107.87 + 35.45) \text{ g mol}^{-1}} = 3.759 \times 10^{-3} \text{ mol AgCl}
\]

1 point is earned for the correct mass of AgCl.
1 point is earned for the correct number of moles of AgCl given with the correct number of significant figures.

(c) Calculate the mass percent of silver in the alloy of copper and silver.

\[
3.759 \times 10^{-3} \text{ mol Ag} \times \frac{107.87 \text{ g Ag}}{1 \text{ mol Ag}} = 0.4055 \text{ g Ag}
\]

\[
\frac{0.4055 \text{ g}}{0.6489 \text{ g}} \times 100\% = 62.49\% \text{ Ag}
\]

1 point is earned for the correct setup and the correct calculation of the mass of Ag.
1 point is earned for the correct percent of Ag.
A student is assigned the task of determining the mass percent of silver in an alloy of copper and silver by dissolving a sample of the alloy in excess nitric acid and then precipitating the silver as AgCl.

First the student prepares 50. mL of 6 M HNO₃.

(a) The student is provided with a stock solution of 16 M HNO₃, two 100 mL graduated cylinders that can be read to ±1 mL, a 100 mL beaker that can be read to ±10 mL, safety goggles, rubber gloves, a glass stirring rod, a dropper, and distilled H₂O.

(i) Calculate the volume, in mL, of 16 M HNO₃ that the student should use for preparing 50. mL of 6 M HNO₃.

(ii) Briefly list the steps of an appropriate and safe procedure for preparing the 50. mL of 6 M HNO₃. Only materials selected from those provided to the student (listed above) may be used.

(iii) Explain why it is not necessary to use a volumetric flask (calibrated to 50.00 mL ±0.05 mL) to perform the dilution.

(iv) During the preparation of the solution, the student accidentally spills about 1 mL of 16 M HNO₃ on the bench top. The student finds three bottles containing liquids sitting near the spill: a bottle of distilled water, a bottle of 5 percent NaHCO₃(aq), and a bottle of saturated NaCl(aq). Which of the liquids is best to use in cleaning up the spill? Justify your choice.

Then the student pours 25 mL of the 6 M HNO₃ into a beaker and adds a 0.6489 g sample of the alloy. After the sample completely reacts with the acid, some saturated NaCl(aq) is added to the beaker, resulting in the formation of an AgCl precipitate. Additional NaCl(aq) is added until no more precipitate is observed to form. The precipitate is filtered, washed, dried, and weighed to constant mass in a filter crucible. The data are shown in the table below.

<table>
<thead>
<tr>
<th>Mass of sample of copper-silver alloy</th>
<th>0.6489 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of dry filter crucible</td>
<td>28.7210 g</td>
</tr>
<tr>
<td>Mass of filter crucible &amp; precipitate (first weighing)</td>
<td>29.3587 g</td>
</tr>
<tr>
<td>Mass of filter crucible &amp; precipitate (second weighing)</td>
<td>29.2599 g</td>
</tr>
<tr>
<td>Mass of filter crucible &amp; precipitate (third weighing)</td>
<td>29.2598 g</td>
</tr>
</tbody>
</table>

(b) Calculate the number of moles of AgCl precipitate collected.
(c) Calculate the mass percent of silver in the alloy of copper and silver.
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. A student is instructed to prepare 100.0 mL of 1.250 $M$ NaOH from a stock solution of 5.000 $M$ NaOH. The student follows the proper safety guidelines.

(a) Calculate the volume of 5.000 $M$ NaOH needed to accurately prepare 100.0 mL of 1.250 $M$ NaOH solution.

(b) Describe the steps in a procedure to prepare 100.0 mL of 1.250 $M$ NaOH solution using 5.000 $M$ NaOH and equipment selected from the list below.

<table>
<thead>
<tr>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balance</td>
</tr>
<tr>
<td>25 mL Erlenmeyer flask</td>
</tr>
<tr>
<td>50 mL buret</td>
</tr>
<tr>
<td>100 mL Florence flask</td>
</tr>
<tr>
<td>Eyedropper</td>
</tr>
<tr>
<td>Drying oven</td>
</tr>
<tr>
<td>100 mL graduated cylinder</td>
</tr>
<tr>
<td>25 mL pipet</td>
</tr>
<tr>
<td>Wash bottle of distilled H$_2$O</td>
</tr>
<tr>
<td>Crucible</td>
</tr>
<tr>
<td>100 mL volumetric flask</td>
</tr>
<tr>
<td>100 mL beaker</td>
</tr>
</tbody>
</table>

(c) The student is given 50.0 mL of a 1.00 $M$ solution of a weak, monoprotic acid, HA. The solution is titrated with the 1.250 $M$ NaOH to the endpoint. (Assume that the endpoint is at the equivalence point.)

(i) Explain why the solution is basic at the equivalence point of the titration. Include a chemical equation as part of your explanation.

(ii) Identify the indicator in the table below that would be best for the titration. Justify your choice.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>p$K_a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methyl red</td>
<td>5</td>
</tr>
<tr>
<td>Bromothymol blue</td>
<td>7</td>
</tr>
<tr>
<td>Phenolphthalein</td>
<td>9</td>
</tr>
</tbody>
</table>

(d) The student is given another 50.0 mL sample of 1.00 $M$ HA, which the student adds to the solution that had been titrated to the endpoint in part (c). The result is a solution with a pH of 5.0.

(i) What is the value of the acid-dissociation constant, $K_a$, for the weak acid? Explain your reasoning.

(ii) Explain why the addition of a few drops of 1.250 $M$ NaOH to the resulting solution does not appreciably change its pH.
A student is instructed to prepare 100.0 mL of 1.250 M NaOH from a stock solution of 5.000 M NaOH. The student follows the proper safety guidelines.

(a) Calculate the volume of 5.000 M NaOH needed to accurately prepare 100.0 mL of 1.250 M NaOH solution.

\[
V_1 = \frac{M_2 V_2}{M_1} = \frac{(1.250 \text{ M})(100.0 \text{ mL})}{5.000 \text{ M}} = 25.00 \text{ mL}
\]

1 point is earned for the correct volume.

(b) Describe the steps in a procedure to prepare 100.0 mL of 1.250 M NaOH solution using 5.000 M NaOH and equipment selected from the list below.

- Balance
- 25 mL Erlenmeyer flask
- 100 mL graduated cylinder
- 100 mL volumetric flask
- 50 mL buret
- 100 mL Florence flask
- 25 mL pipet
- 100 mL beaker
- Eyedropper
- Drying oven
- Wash bottle of distilled H₂O
- Crucible

Pipet 25.00 mL of 5.000 M NaOH solution into the 100 mL volumetric flask.

Fill the volumetric flask to the calibration line with distilled water; using an eyedropper for the last few drops is advised.

Cap the volumetric flask and invert several times to ensure homogeneity.

1 point is earned for descriptions of any two of the three steps.

An additional point is earned if all three steps are described.

(c) The student is given 50.0 mL of a 1.00 M solution of a weak, monoprotic acid, HA. The solution is titrated with the 1.250 M NaOH to the endpoint. (Assume that the endpoint is at the equivalence point.)

(i) Explain why the solution is basic at the equivalence point of the titration. Include a chemical equation as part of your explanation.

When a weak acid is titrated with a strong base, the reaction forms water and the A⁻ ion.

\[
\text{HA} + \text{OH}^- \rightleftharpoons \text{A}^- + \text{H}_2\text{O}
\]

The A⁻ ion formed in the titration reacts with the solvent water to release OH⁻ ions, making the solution basic at the equivalence point.

\[
\text{A}^- + \text{H}_2\text{O} \rightleftharpoons \text{HA} + \text{OH}^-
\]

1 point is earned for either the correct equation or a clear statement that the conjugate base, A⁻, is a (weak) base.

1 point is earned for indicating that the solution is basic because of the formation of OH⁻.
(ii) Identify the indicator in the table below that would be best for the titration. Justify your choice.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>$pK_a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methyl red</td>
<td>5</td>
</tr>
<tr>
<td>Bromothymol blue</td>
<td>7</td>
</tr>
<tr>
<td>Phenolphthalein</td>
<td>9</td>
</tr>
</tbody>
</table>

Because the pH is basic at the equivalence point, it is best to use an indicator that changes color in basic solution. Therefore, phenolphthalein would be the best indicator for the titration. 1 point is earned for an answer consistent with the answer to part (c)(i) with justification.

(d) The student is given another 50.0 mL sample of 1.00 M HA, which the student adds to the solution that had been titrated to the endpoint in part (c). The result is a solution with a pH of 5.0.

(i) What is the value of the acid-dissociation constant, $K_a$, for the weak acid? Explain your reasoning.

The resulting solution is at the half-equivalence-point, where $[HA] = [A^-]$, thus $\text{pH} = pK_a = 5.0 \Rightarrow K_a = 1 \times 10^{-5}$. 1 point is earned for showing that the system is at the half-equivalence point.

1 point is earned for the correct value of $K_a$.

(ii) Explain why the addition of a few drops of 1.250 M NaOH to the resulting solution does not appreciably change its pH.

The resulting solution is a buffer; therefore adding a few drops of acid or base does not appreciably change the pH. 1 point is earned for indicating that the solution is a buffer.
YOU MAY USE YOUR CALCULATOR FOR THIS SECTION.

**Directions:** Questions 1–3 are long free-response questions that require about 20 minutes each to answer and are worth 10 points each. Questions 4–7 are short free-response questions that require about 7 minutes each to answer and are worth 4 points each.

Write your response in the space provided following each question. Examples and equations may be included in your responses where appropriate. For calculations, clearly show the method used and the steps involved in arriving at your answers. You must show your work to receive credit for your answer. Pay attention to significant figures.

<table>
<thead>
<tr>
<th>Mass of KI tablet</th>
<th>0.425 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of thoroughly dried filter paper</td>
<td>1.462 g</td>
</tr>
<tr>
<td>Mass of filter paper + precipitate after first drying</td>
<td>1.775 g</td>
</tr>
<tr>
<td>Mass of filter paper + precipitate after second drying</td>
<td>1.699 g</td>
</tr>
<tr>
<td>Mass of filter paper + precipitate after third drying</td>
<td>1.698 g</td>
</tr>
</tbody>
</table>

1. A student is given the task of determining the I\(^-\) content of tablets that contain KI and an inert, water-soluble sugar as a filler. A tablet is dissolved in 50.0 mL of distilled water, and an excess of 0.20 \(M\) Pb(NO\(_3\))\(_2\)(aq) is added to the solution. A yellow precipitate forms, which is then filtered, washed, and dried. The data from the experiment are shown in the table above.

(a) For the chemical reaction that occurs when the precipitate forms,

(i) write a balanced, net-ionic equation for the reaction, and

(ii) explain why the reaction is best represented by a net-ionic equation.

(b) Explain the purpose of drying and weighing the filter paper with the precipitate three times.

(c) In the filtrate solution, is [K\(^+\)] greater than, less than, or equal to [NO\(_3\)^-]? Justify your answer.

(d) Calculate the number of moles of precipitate that is produced in the experiment.

(e) Calculate the mass percent of I\(^-\) in the tablet.

(f) In another trial, the student dissolves a tablet in 55.0 mL of water instead of 50.0 mL of water. Predict whether the experimentally determined mass percent of I\(^-\) will be greater than, less than, or equal to the amount calculated in part (e). Justify your answer.
A student is given the task of determining the $I^-$ content of tablets that contain KI and an inert, water-soluble sugar as a filler. A tablet is dissolved in 50.0 mL of distilled water, and an excess of $0.20 \, M \, Pb(NO_3)_2(aq)$ is added to the solution. A yellow precipitate forms, which is then filtered, washed, and dried. The data from the experiment are shown in the table above.

(a) For the chemical reaction that occurs when the precipitate forms,
   (i) write a balanced, net-ionic equation for the reaction, and

   $$ \text{Pb}^{2+} + 2 \text{I}^- \rightarrow \text{PbI}_2 $$

   1 point is earned for a balanced net-ionic equation.

   (ii) explain why the reaction is best represented by a net-ionic equation.

   The net-ionic equation shows the formation of the \( \text{PbI}_2(s) \) from \(\text{Pb}^{2+}(aq) \) and \(\text{I}^-(aq) \) ions, omitting the non-reacting species (spectator ions), \(\text{K}^+(aq) \) and \(\text{NO}_3^-(aq) \).

   1 point is earned for a valid explanation.

(b) Explain the purpose of drying and weighing the filter paper with the precipitate three times.

   The filter paper and precipitate must be dried several times (to a constant mass) to ensure that all the water has been driven off.

   1 point is earned for a valid explanation.

(c) In the filtrate solution, is $[K^+]$ greater than, less than, or equal to $[NO_3^-]$? Justify your answer.

   $[K^+]$ is less than $[NO_3^-]$ because the source of the $NO_3^-$, the $0.20 \, M \, Pb(NO_3)_2(aq)$, was added in excess.

   1 point is earned for a correct comparison with a valid explanation.
(d) Calculate the number of moles of precipitate that is produced in the experiment.

\[
1.698 \text{ g} - 1.462 \text{ g} = 0.236 \text{ g PbI}_2(s)
\]

\[
0.236 \text{ g PbI}_2 \times \frac{1 \text{ mol PbI}_2}{461.0 \text{ g PbI}_2} = 5.12 \times 10^{-4} \text{ mol PbI}_2
\]

1 point is earned for the correct number of moles of PbI\(_2(s)\) precipitate.

(e) Calculate the mass percent of I\(^-\) in the tablet.

\[
\frac{5.12 \times 10^{-4} \text{ mol PbI}_2 \times \frac{2 \text{ mol I}^-}{1 \text{ mol PbI}_2}}{1.02 \times 10^{-3} \text{ mol I}^- \times \frac{126.91 \text{ g I}^-}{1 \text{ mol I}^-}} = 0.130 \text{ g I}^- \text{ in one tablet}
\]

\[
\frac{0.130 \text{ g I}^-}{0.425 \text{ g KI tablet}} = 0.306 = 30.6\% \text{ I}^- \text{ per KI tablet}
\]

1 point is earned for determining the number of moles of I\(^-\) in one tablet.

1 point is earned for calculating the mass percent of I\(^-\) in the KI tablet.

(f) In another trial, the student dissolves a tablet in 55.0 mL of water instead of 50.0 mL of water. Predict whether the experimentally determined mass percent of I\(^-\) will be greater than, less than, or equal to the amount calculated in part (e). Justify your answer.

The mass percent of I\(^-\) will be the same. Pb\(^{2+}(aq)\) was added in excess, ensuring that essentially no I\(^-\) remained in solution. The additional water is removed by filtration and drying, leaving the same mass of dried precipitate.

1 point is earned for correct comparison with a valid justification.

(g) A student in another lab also wants to determine the I\(^-\) content of a KI tablet but does not have access to Pb(NO\(_3\)_2). However, the student does have access to 0.20 M AgNO\(_3\), which reacts with I\(^-(aq)\) to produce AgI(s). The value of \(K_{sp}\) for AgI is \(8.5 \times 10^{-17}\).

(i) Will the substitution of AgNO\(_3\) for Pb(NO\(_3\)_2) result in the precipitation of the I\(^-\) ion from solution? Justify your answer.

Yes. Addition of an excess of 0.20 M AgNO\(_3\)(aq) will precipitate all of the I\(^-\) ion present in the solution because AgI is insoluble, as evidenced by its low value of \(K_{sp}\).

1 point is earned for the correct answer with a valid justification.

(ii) The student only has access to one KI tablet and a balance that can measure to the nearest 0.01 g. Will the student be able to determine the mass of AgI produced to three significant figures? Justify your answer.
No. If masses can be measured to ±0.01 g, then the mass of the dry AgI(s) precipitate (which is less than 1 g) will be known to only two significant figures.

1 point is earned for a correct answer with a valid justification.
Solutions — CHAPTER 5
MULTIPLE-CHOICE QUESTIONS

Questions 1–3 should be answered using the responses below.

(A) molarity
(B) molality
(C) mass percent
(D) mole fraction

1. Which concentration unit can be calculated from masses of solute and solvent alone?

2. Which concentration unit varies with a change in temperature?

3. Which concentration unit is typically used to determine molar masses by freezing point depression?
   (assumed prior knowledge in current AP Curriculum)

4. What is the molarity of the Li⁺ ion in a solution prepared by dissolving 2.20 g of Li₂SO₄ (MM = 110.0 g/mol) in enough H₂O to make 50.0 mL of solution?
   (A) 2.00 × 10⁻² M
   (B) 4.00 × 10⁻² M
   (C) 0.400 M
   (D) 0.800 M

5. How many moles of HNO₃ must be added to 200.0 mL of H₂O to give a solution with a pH = 1.00?
   (A) 0.020
   (B) 0.20
   (C) 0.50
   (D) 2.0
Questions 6–8 should be answered on the basis of the equations below.

(A) \( \text{NaCl}(s) + \text{H}_2\text{O}(l) \rightarrow \text{NaCl}(aq) \)
(B) \( \text{HCl}(aq) + \text{AgNO}_3(aq) \rightarrow \text{AgCl}(s) + \text{HNO}_3(aq) \)
(C) \( 2 \text{HCl}(aq) + \text{Mg(OH)}_2(aq) \rightarrow \text{MgCl}_2(aq) + 2 \text{H}_2\text{O}(l) \)
(D) \( 2 \text{HCl}(aq) + \text{NaOCl}(aq) \rightarrow \text{NaCl}(aq) + \text{Cl}_2(g) + \text{H}_2\text{O}(l) \)

6. Which equation represents an oxidation-reduction reaction?

7. Which equation represents a precipitation reaction?

8. Which equation represents an acid-base reaction?

Questions 9–10 should be answered on the basis of the information below.

A student is asked to determine the molarity of \( \text{Ca}^{2+} \) ions in 50.0 mL of solution by adding a 10% excess of \( \text{Na}_2\text{CO}_3 \) to precipitate \( \text{CaCO}_3 \) (\( MM \) 100.0). The precipitate was filtered, washed, dried, and weighed to give 1.20 g of \( \text{CaCO}_3(s) \).

9. Based on this information what molarity should the student report?

(A) 0.00060 \( M \)
(B) 0.012 \( M \)
(D) 0.24 \( M \)
(D) 4.2 \( M \)

10. If the actual value of the molarity is 10% higher than that reported by the student, which procedural error could be responsible?

(A) The student used a 20% excess of \( \text{Na}_2\text{CO}_3 \) rather than the suggested 10%.
(B) The student did not subtract the weight of the filter paper from that of the filter paper plus the precipitate.
(C) The precipitate was not washed sufficiently to remove excess \( \text{Na}_2\text{CO}_3 \).
(D) All of the precipitate was not transferred from the beaker to the filter.
Questions 11–12 should be answered on the basis of the information below.

A student is asked to determine the molarity of a strong base solution by titrating it with a 0.250 \( M \) solution of \( \text{H}_2\text{SO}_4 \). The student is instructed to pipet a 20.0 mL portion of the strong base solution into a conical flask, to add two drops of an indicator that changes at pH = 7 and to dispense the standard \( \text{H}_2\text{SO}_4 \) solution from a buret until the solution undergoes a permanent color change. The initial buret reading is 5.00 mL and the final reading is 30.00 mL at the equivalence point.

11. What is the \([\text{OH}^-]\) in the strong base solution?

(A) 0.313 \( M \)  
(B) 0.625 \( M \)  
(C) 0.375 \( M \)  
(D) 0.750 \( M \)

12. Which procedural error will result in a strong base molarity that is too high?

(A) Using 4 drops of indicator rather than the recommended 2 drops  
(B) Using an indicator that changes at pH = 5 rather than at pH = 7  
(C) Using a conical flask that contains several drops of \( \text{H}_2\text{O} \)  
(D) Using a buret with a tip filled with air rather than the \( \text{H}_2\text{SO}_4 \) solution

13. Of the following the most acidic solution is the one with

(A) \([\text{H}^+] = 1 \times 10^{-2} \ M\)  
(B) \([\text{OH}^-] = 1 \times 10^{-3} \ M\)  
(C) pH = 3  
(D) pOH = 9

14. Which equation best describes the net changes based upon the observation that solid silver nitrate and solid potassium chloride are soluble in water and these solutions react to form insoluble silver chloride and soluble potassium nitrate when mixed.

(A) \( \text{AgNO}_3(s) + \text{KCl}(s) \rightarrow \text{AgCl}(s) + \text{KNO}_3(s) \)  
(B) \( \text{AgNO}_3(s) + \text{KCl}(s) \rightarrow \text{AgCl}(s) + \text{KNO}_3(aq) \)  
(C) \( \text{AgNO}_3(aq) + \text{KCl}(aq) \rightarrow \text{AgCl}(s) + \text{KNO}_3(aq) \)  
(D) \( \text{Ag}^+(aq) + \text{Cl}^-(aq) \rightarrow \text{AgCl}(s) \)
15. According to Coulomb's Law, which of the following compounds is least soluble?

(A) KOH
(B) K₂SO₄
(C) Ca(OH)₂
(D) CaSO₄

16. If the salt M⁺X⁻ dissolves in H₂O with the absorption of energy, which of the interactions below is the strongest?

(A) M⁺---X⁻
(B) M⁺---OH₂
(C) X⁻---HOH
(D) HOH---OH₂

17. What is the value of ΔH° for the process MgF₂(s) → Mg²⁺(aq) + 2 F⁻(aq) based on the following information?

\[ \Delta H°_{\text{lat}} = 2922 \text{ kJ/mol}, \quad \Delta H°_{\text{hyd}} \text{Mg}^{2+} = -179 \text{ kJ/mol}, \quad \Delta H°_{\text{hyd}} \text{F}^- = -74 \text{ kJ/mol} \]

(A) 2669 kJ/mol
(B) 2595 kJ/mol
(C) -2595 kJ/mol
(D) -2669 kJ/mol

18. The ΔS°_{hyd} values (in J/mol K) in the table below represent the changes in S° values relative to the S°_{gas}. Which of the following explanations accounts best for the trend in these values?

<table>
<thead>
<tr>
<th>ion</th>
<th>Li⁺</th>
<th>Na⁺</th>
<th>K⁺</th>
<th>Cs⁺</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔS°_{hyd}, J/mol·K</td>
<td>-119</td>
<td>-88</td>
<td>-53</td>
<td>-37</td>
</tr>
</tbody>
</table>

(A) Hydration releases less heat as the ions become larger.
(B) Hydration releases more heat as the ions become larger.
(C) The H₂O molecules are held more tightly as the ions become larger.
(D) The H₂O molecules are held less tightly as the ions become larger.

19. What change occurs during the reaction MnO₄⁻ → Mn²⁺?

(A) Five electrons are gained.
(B) Five electrons are lost.
(C) Three electrons are gained.
(D) Three electrons are lost.
20. How many hydrogen bonds are shown in the diagram below?

\[
\begin{array}{c}
H \\
H - N \cdot \cdot H - O \\
H
\end{array}
\]

(A) one  
(B) two  
(C) five  
(D) six

**Questions 21–22** should be answered using the following responses.

(A) column chromatography  
(B) filtration  
(C) fractional distillation  
(D) simple distillation

21. Which technique should be used for the separation of two liquids with very similar boiling points?

22. Which technique should be used for the separation of a solid from a solution?

23. Which statement is correct about the separation of substances A, B, and C in the paper chromatogram below?

\[
\begin{array}{c}
\text{Origin} \\
A \\
B \\
C \\
\text{Solvent front}
\end{array}
\]

(A) A is more soluble in the solvent than B.  
(B) B is more soluble in the solvent than C.  
(C) B is adsorbed more strongly by the paper than C.  
(D) B is adsorbed more strongly by the paper than A.
24. How many L of 0.0200 \( M \) KMnO\(_4\) solution are required to react with 0.0400 mol of Cl\(^-\) ions according to the equation below?

\[
2 \text{ MnO}_4^- (aq) + 10 \text{ Cl}^- (aq) + 16 \text{ H}^+ (aq) \rightarrow 2 \text{ Mn}^{2+} (aq) + 5 \text{ Cl}_2 (g) + 8 \text{ H}_2 \text{O (l)}
\]

(A) 0.00800  
(B) 0.0160  
(C) 0.200  
(D) 0.400

25. A 30.0 mL portion of 0.100 \( M \) Ba(OH)\(_2\) is mixed with 20.0 mL of 0.200 \( M \) HNO\(_3\). What is the molarity of the excess reactant, H\(^+\) or OH\(^-\), in the final solution?

(A) 0.0010 \( M \) H\(^+\)  
(B) 0.020 \( M \) H\(^+\)  
(C) 0.0020 \( M \) OH\(^-\)  
(D) 0.040 \( M \) OH\(^-\)

The next questions are provided for Teacher discretion, because they are “Assumed prior knowledge” in current AP Chemistry and no longer assessed on the AP Chemistry exam. However, we have included them here for optional use by classroom teachers for review with local competitions.

26. What is the molality of a solution prepared by dissolving 3.00 g of urea, CO(NH\(_2\))\(_2\), (\( MM = 60.0 \)) in 200. g of H\(_2\)O?

(A) 0.0100  
(B) 0.0500  
(C) 0.250  
(D) 10.0

27. What is the molality of an aqueous solution that freezes at \(-0.372^\circ C\)? (\( k_f = -1.86^\circ /m \))

(A) 0.0200  
(B) 0.200  
(C) 0.500  
(D) 5.00
28. A solution prepared by dissolving 1.80 g of an unknown alcohol in 10.0 g of H₂O freezes at −5.58°C. What is the molar mass of the alcohol? (k_f = −1.86°/m)

(A) 54  
(B) 60  
(C) 180  
(D) 300

29. A mixture of 56 g of N₂ and 32 g of O₂ exerts a total pressure of 1.5 atm. What is the partial pressure of O₂?

(A) 0.33 atm  
(B) 0.50 atm  
(C) 0.55 atm  
(D) 1.0 atm