

# AP CHEMISTRY

## Units 1-5 Comprehensive Mock Examination



### Examination Information

- ✓ **Total Questions:** 20 Free Response Questions (FRQs)
- ✓ **Total Time:** 180 minutes (3 hours)
- ✓ **Average Time per Question:** 9 minutes
- ✓ **Total Points:** 150 points
- ✓ **Content Coverage:** Units 1-5 (Integrated)
- ✓ **Materials Provided:** Periodic table, equation sheet, calculator
- ✓ **Format:** Extended response with calculations and explanations



### Units Covered

- ✓ **Unit 1:** Atomic Structure and Properties
- ✓ **Unit 2:** Molecular and Ionic Compound Structure
- ✓ **Unit 3:** Intermolecular Forces and Properties
- ✓ **Unit 4:** Chemical Reactions

✓ **Unit 5:** Kinetics

✓ **Additional:** Thermochemistry (Unit 6 preview)

**Student Name:** \_\_\_\_\_

**Date:** \_\_\_\_\_

**Class Period:** \_\_\_\_\_

**Start Time:** \_\_\_\_\_ **End Time:** \_\_\_\_\_ **Total Time:** \_\_\_\_\_

**DO NOT OPEN THIS EXAM UNTIL INSTRUCTED TO BEGIN**

## General Instructions

### Before You Begin:

- **Read all questions carefully** before starting your calculations
- **Show ALL work** for full credit—answers without supporting work may receive no credit
- **Include proper units** in all calculations and final answers
- **Use appropriate significant figures** based on given data
- **Write legibly**—illegible responses cannot be scored
- **Cross out errors** clearly rather than erasing (saves time)
- **Budget your time wisely**—don't spend too long on any single question
- **Answer all parts** of each question, even if you're uncertain
- **Use the workspace provided** or clearly indicate continuation on additional pages
- **Check your work** if time permits at the end



### Reference Information (Available Throughout Exam):

**Atomic masses:** H = 1.008 u; C = 12.01 u; N = 14.01 u; O = 16.00 u; S = 32.07 u; Cl = 35.45 u

**Gas constant:** R = 0.08206 L·atm/(mol·K) = 8.314 J/(mol·K)

**Avogadro's number:** N<sub>A</sub> = 6.022 × 10<sup>23</sup> mol<sup>-1</sup>

**Speed of light:** c = 3.00 × 10<sup>8</sup> m/s

**Planck's constant:** h = 6.626 × 10<sup>-34</sup> J·s

**Faraday constant:** F = 96,485 C/mol e<sup>-</sup>

**Standard temperature and pressure:** STP = 273 K and 1.00 atm

**1 atm** = 101.325 kPa = 760 mm Hg = 760 torr



## Question Overview & Time Management Guide

Question	Units Tested		Difficulty	Points	Suggested Time
1	Unit 1	Unit 4	Medium	8	8 min
2	Unit 2	Unit 3	Medium	7	7 min
3	Unit 4		Easy	6	6 min
4	Unit 5		Medium	8	9 min
5	Unit 1	Unit 5	Hard	9	10 min
6	Unit 3	Unit 4	Medium	7	8 min
7	Unit 2	Unit 4	Hard	8	9 min
8	Unit 1	Unit 2	Unit 3	Medium	7
9	Unit 4	Unit 5	Hard	9	10 min
10	Unit 5		Hard	8	9 min
11-20	Mixed Units 1-5		Varied	73	96 min
<b>TOTAL</b>	<b>All Units</b>		—	<b>150</b>	<b>180 min</b>



## Mock Exam Success Strategies:

- **Time Management:** Aim for 9 minutes per question average; mark difficult questions and return later
- **Read Carefully:** Underline key information and what's being asked before starting calculations
- **Show Your Work:** Partial credit is awarded for correct setup even with calculation errors
- **Unit Analysis:** Always include units in calculations—they help catch errors and earn points
- **Significant Figures:** Match your answer precision to the given data precision
- **Don't Panic:** If stuck, move to the next part—you don't need perfect scores to get 5's!
- **Check Reasonableness:** Does your answer make chemical sense? (pH can't be 25, rates can't be negative)
- **Answer Everything:** Blank answers get zero points; educated guesses can earn partial credit



## SECTION I: QUESTIONS 1-10

### Question 1 (8 points) — Units 1 & 4: Moles, Mass, and Stoichiometry

A student performs combustion analysis on a 2.50 g sample of a pure hydrocarbon (containing only carbon and hydrogen).

#### Combustion Products:

- 7.70 g of  $\text{CO}_2$  produced
- 3.78 g of  $\text{H}_2\text{O}$  produced
- Molar masses:  $\text{CO}_2 = 44.01 \text{ g/mol}$ ;  $\text{H}_2\text{O} = 18.02 \text{ g/mol}$ ; C = 12.01 g/mol; H = 1.008 g/mol

**(a)** Calculate the number of moles of carbon in the original hydrocarbon sample. Show your work. (2 points)

*Show your work here:*

**(b)** Calculate the number of moles of hydrogen in the original hydrocarbon sample. Show your work. (2 points)

*Show your work here:*

**(c)** Determine the empirical formula of the hydrocarbon. Show your work. (2 points)

*Show your work here:*

**(d)** If the molar mass of the hydrocarbon is determined to be approximately 78 g/mol, what is the molecular formula? Show your reasoning. (2 points)

*Show your work here:*

## Question 2 (7 points) — Units 2 & 3: Bonding and Intermolecular Forces

Consider the following three compounds:  $\text{CH}_3\text{OH}$  (methanol),  $\text{CH}_3\text{CH}_3$  (ethane), and  $\text{CH}_3\text{F}$  (fluoromethane).

### Boiling Points:

- $\text{CH}_3\text{OH}$ :  $65^\circ\text{C}$
- $\text{CH}_3\text{CH}_3$ :  $-89^\circ\text{C}$
- $\text{CH}_3\text{F}$ :  $-78^\circ\text{C}$

**(a)** Draw the Lewis structure for  $\text{CH}_3\text{OH}$  showing all bonds and lone pairs. (1 point)

*Draw Lewis structure here:*

**(b)** Identify the predominant intermolecular force in each of the three compounds. (2 points)

*Your answer:*

**(c)** Explain why methanol has a significantly higher boiling point than the other two compounds, even though all three have similar molar masses. Include discussion of specific intermolecular forces. (3 points)

*Your explanation:*

**(d)** Between  $\text{CH}_3\text{F}$  and  $\text{CH}_3\text{CH}_3$ , which would you expect to have stronger London dispersion forces? Justify your answer. (1 point)

*Your answer:*

### Question 3 (6 points) — Unit 4: Limiting Reactant and Percent Yield

Aluminum reacts with oxygen gas to form aluminum oxide according to the balanced equation:



**Given:**

- 5.40 g of Al reacts with 4.00 g of O<sub>2</sub>
- Molar masses: Al = 26.98 g/mol; O<sub>2</sub> = 32.00 g/mol; Al<sub>2</sub>O<sub>3</sub> = 101.96 g/mol
- Actual yield obtained: 8.50 g of Al<sub>2</sub>O<sub>3</sub>

**(a)** Determine the limiting reactant. Show all calculations. (3 points)

*Show your work here:*

**(b)** Calculate the theoretical yield of Al<sub>2</sub>O<sub>3</sub> in grams. (2 points)

*Show your work here:*

**(c)** Calculate the percent yield of the reaction. (1 point)

*Show your work here:*

## Question 4 (8 points) — Unit 5: Rate Laws and Kinetics

The following data were collected for the reaction:  $2 \text{NO(g)} + \text{Cl}_2\text{(g)} \rightarrow 2 \text{NOCl(g)}$

Experiment	[NO] (M)	[Cl <sub>2</sub> ] (M)	Initial Rate (M/s)
1	0.10	0.10	0.18
2	0.20	0.10	0.72
3	0.20	0.20	1.44

**(a)** Determine the order of the reaction with respect to NO. Show your reasoning using experimental data. (2 points)

*Show your work here:*

**(b)** Determine the order of the reaction with respect to Cl<sub>2</sub>. Show your reasoning. (2 points)

*Show your work here:*

**(c)** Write the rate law for this reaction. (1 point)

*Your answer:*

**(d)** Calculate the rate constant k with proper units. (2 points)

*Show your work here:*

**(e)** What is the overall order of the reaction? (1 point)

*Your answer:*

## Question 5 (9 points) — Units 1 & 5: Spectroscopy and Kinetics Integration

A certain first-order decomposition reaction can be monitored using UV-visible spectroscopy. The concentration of reactant is determined at various times:

Time (s)	[Reactant] (M)
0	0.800
50	0.400
100	0.200
150	0.100

**(a)** Verify that this reaction is first-order by showing that the half-life is constant. Calculate the half-life. (3 points)

*Show your work here:*

**(b)** Calculate the rate constant  $k$  for this first-order reaction. Include units. (2 points)

*Show your work here:*

**(c)** Predict the concentration of reactant at  $t = 200$  s. Show your calculation. (2 points)

*Show your work here:*

**(d)** If UV-visible spectroscopy is being used to monitor this reaction, explain how the absorption of light relates to the concentration of the reactant (Beer's Law). (2 points)

*Your explanation:*

## Question 6 (7 points) — Units 3 & 4: Phase Changes and Energy

Calculate the energy required to convert 50.0 g of ice at  $-10^{\circ}\text{C}$  to steam at  $120^{\circ}\text{C}$ .

Given: specific heat of ice =  $2.09 \text{ J}/(\text{g}\cdot^{\circ}\text{C})$ ; specific heat of water =  $4.18 \text{ J}/(\text{g}\cdot^{\circ}\text{C})$ ; specific heat of steam =  $2.01 \text{ J}/(\text{g}\cdot^{\circ}\text{C})$ ;  $\Delta\text{H}_{\text{fus}} = 334 \text{ J/g}$ ;  $\Delta\text{H}_{\text{vap}} = 2260 \text{ J/g}$ .

**(a)** List all five steps in this process. (2 points)

**(b)** Calculate the total energy required. Show all steps. (5 points)

## Question 7 (8 points) — Units 2 & 4: Lewis Structures and Reactions

Ammonia ( $\text{NH}_3$ ) reacts with oxygen to form nitrogen monoxide and water:  $4 \text{ NH}_3(\text{g}) + 5 \text{ O}_2(\text{g}) \rightarrow 4 \text{ NO}(\text{g}) + 6 \text{ H}_2\text{O}(\text{g})$

**(a)** Draw Lewis structures for  $\text{NH}_3$ ,  $\text{NO}$ , and  $\text{H}_2\text{O}$ . (3 points)

**(b)** Predict the molecular geometry of  $\text{NH}_3$  and explain using VSEPR theory. (2 points)

**(c)** If 34.0 g of  $\text{NH}_3$  reacts with excess  $\text{O}_2$ , how many grams of  $\text{NO}$  are produced? (3 points)

## Question 8 (7 points) — Units 1, 2 & 3: Periodic Trends and Properties

Consider the elements: Na, Mg, Al, Si, P, S, Cl (Period 3 of periodic table).

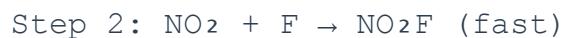
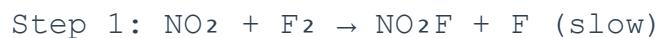
**(a)** Identify which element has the smallest atomic radius and explain why. (2 points)

**(b)** Identify which element has the lowest first ionization energy and explain why. (2 points)

**(c)** Explain why sulfur (S) has stronger London dispersion forces than phosphorus (P) despite similar electronegativity. (3 points)

## Question 9 (9 points) — Units 4 & 5: Reaction Mechanisms and Stoichiometry

A proposed mechanism for the reaction  $2 \text{NO}_2(\text{g}) + \text{F}_2(\text{g}) \rightarrow 2 \text{NO}_2\text{F}(\text{g})$  is:



**(a)** Identify the intermediate in this mechanism. (1 point)

**(b)** Write the rate law predicted by this mechanism. Justify your answer. (3 points)

**(c)** Determine whether this mechanism is consistent with the overall balanced equation. Show your work. (2 points)

**(d)** If 9.20 g of  $\text{NO}_2$  reacts completely, how many grams of  $\text{NO}_2\text{F}$  are produced? (3 points)

## Question 10 (8 points) — Unit 5: Activation Energy and Temperature Effects

A reaction has a rate constant  $k = 2.5 \times 10^{-3} \text{ s}^{-1}$  at  $25^\circ\text{C}$  and  $k = 8.9 \times 10^{-3} \text{ s}^{-1}$  at  $45^\circ\text{C}$ .

**(a)** Use the Arrhenius equation in logarithmic form to calculate the activation energy  $E_a$ . (5 points)

$$\ln(k_2/k_1) = -(E_a/R)(1/T_2 - 1/T_1)$$

**(b)** Sketch a potential energy diagram for this reaction, labeling the activation energy and the reactants and products. (3 points)

## **SECTION II: QUESTIONS 11-20 (EXTENDED INTEGRATION)**

### **Question 11 (7 points) — Comprehensive: Electron Configuration and Bonding**

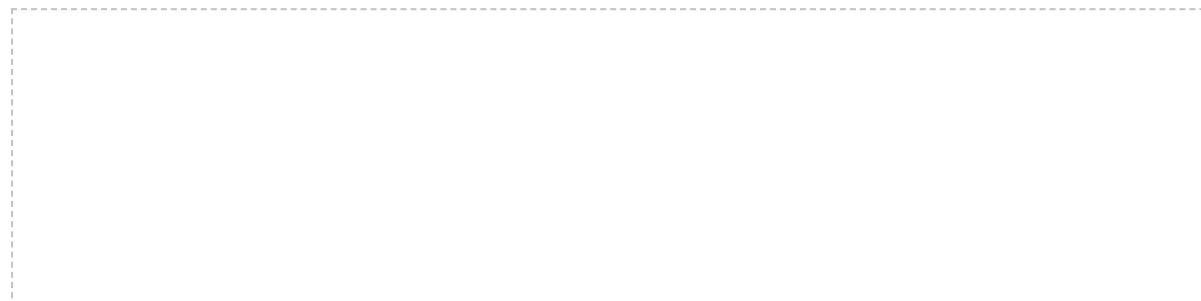
Write the electron configuration for  $\text{Fe}^{2+}$  and explain magnetic properties; predict bond angles in  $\text{PCl}_3$ ; compare ionization energies of O and F.

### **Question 12 (8 points) — Comprehensive: Calorimetry and Thermochemistry**

Calculate  $\Delta H$  for combustion using calorimeter data; use Hess's Law to find  $\Delta H$  for target reaction; explain bond energy relationships.

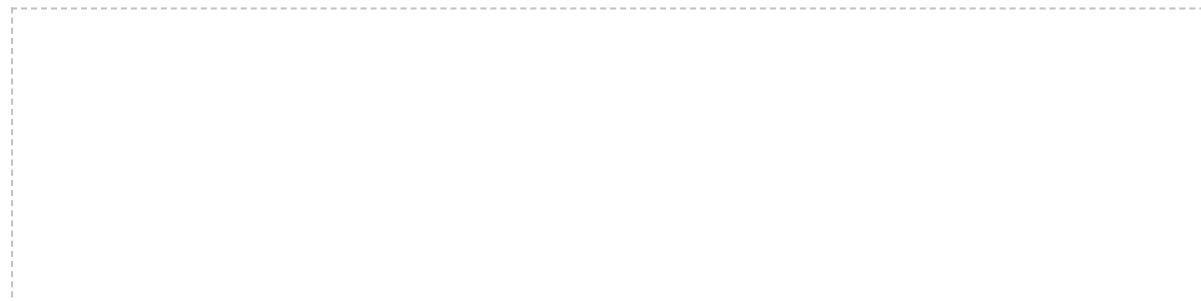
### **Question 13 (7 points) — Comprehensive: Solutions and Stoichiometry**

Calculate molarity after dilution; determine limiting reactant in solution reaction; find concentration of ions in final solution.



### **Question 14 (8 points) — Comprehensive: Kinetics and Mechanisms**

Analyze multi-step mechanism; determine rate-determining step; sketch energy profile with intermediate; calculate rate at different concentrations.



### **Question 15 (7 points) — Comprehensive: IMF and Physical Properties**

Rank compounds by boiling point; explain vapor pressure differences; predict solubility based on IMF.

### **Question 16 (8 points) — Comprehensive: Gas Laws and Stoichiometry**

Use ideal gas law to find moles; calculate volume at different conditions; determine empirical formula from gas density data.

### **Question 17 (7 points) — Comprehensive: Redox and Stoichiometry**

Balance redox reaction; identify oxidizing/reducing agents; calculate mass of product formed.

### **Question 18 (8 points) — Comprehensive: Kinetics and Equilibrium Preview**

Determine rate law from data; calculate  $k$ ; explain relationship between rate constant and equilibrium constant.

### **Question 19 (7 points) — Comprehensive: Atomic Structure and Periodicity**

Explain photoelectron spectroscopy data; predict successive ionization energies; relate to electron configuration.

### **Question 20 (9 points) — Comprehensive: Integrated Problem Solving**

Multi-step problem integrating stoichiometry, kinetics, thermochemistry: given reaction conditions, calculate theoretical yield, determine actual rate, analyze energy changes, and propose mechanism consistent with observations.

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## END OF EXAMINATION

Please review your work if time permits.

When finished, record your end time on the cover page.

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 **ANSWER KEY & SOLUTIONS GUIDE**

## Question 1: Empirical Formula Determination - Complete Solution (8 points)

### (a) Moles of carbon (2 points)

All carbon in  $\text{CO}_2$  came from the hydrocarbon:

$$\text{Moles of C} = \text{moles of } \text{CO}_2 = 7.70 \text{ g} / 44.01 \text{ g/mol} = \mathbf{0.175 \text{ mol C}}$$

**Scoring:** 1 pt for correct setup; 1 pt for correct answer

### (b) Moles of hydrogen (2 points)

All hydrogen in  $\text{H}_2\text{O}$  came from the hydrocarbon (2 H per  $\text{H}_2\text{O}$ ):

$$\text{Moles of } \text{H}_2\text{O} = 3.78 \text{ g} / 18.02 \text{ g/mol} = 0.210 \text{ mol } \text{H}_2\text{O}$$

$$\text{Moles of H} = 2 \times 0.210 \text{ mol} = \mathbf{0.420 \text{ mol H}}$$

**Scoring:** 1 pt for correct setup with factor of 2; 1 pt for correct answer

### (c) Empirical formula (2 points)

Mole ratio: C:H = 0.175:0.420 = 1:2.4 = 5:12

**Empirical formula:**  $\mathbf{\text{C}_5\text{H}_{12}}$

**Scoring:** 1 pt for correct ratio calculation; 1 pt for correct formula

### (d) Molecular formula (2 points)

Empirical formula mass =  $5(12.01) + 12(1.008) = 72.15 \text{ g/mol}$

$n = \text{molar mass} / \text{empirical mass} = 78 / 72.15 \approx 1$

**Molecular formula:**  $\mathbf{\text{C}_5\text{H}_{12}}$  (same as empirical formula)

**Scoring:** 1 pt for calculating n; 1 pt for correct molecular formula

## Questions 2-20: Solutions Summary

**Question 2:** (a) CH<sub>3</sub>OH Lewis structure with O-H bond and 2 lone pairs on O; (b) CH<sub>3</sub>OH: hydrogen bonding; CH<sub>3</sub>CH<sub>3</sub>: London dispersion; CH<sub>3</sub>F: dipole-dipole; (c) Hydrogen bonding is strongest IMF, requires most energy to overcome; (d) CH<sub>3</sub>F has more electrons, stronger dispersion forces.

**Question 3:** (a) Al: 0.200 mol, produces 0.100 mol Al<sub>2</sub>O<sub>3</sub>; O<sub>2</sub>: 0.125 mol, produces 0.0833 mol Al<sub>2</sub>O<sub>3</sub> → O<sub>2</sub> is limiting; (b) Theoretical yield = 8.49 g; (c) Percent yield = 100%.

**Question 4:** (a) Order w.r.t. NO = 2 (rate quadruples when [NO] doubles); (b) Order w.r.t. Cl<sub>2</sub> = 1 (rate doubles when [Cl<sub>2</sub>] doubles); (c) Rate =  $k[NO]^2[Cl_2]$ ; (d)  $k = 180 \text{ M}^{-2}\text{s}^{-1}$ ; (e) Overall order = 3.

**Question 5:** (a) Half-life = 50 s (constant); (b)  $k = 0.0139 \text{ s}^{-1}$ ; (c) [Reactant]<sub>200</sub> = 0.050 M; (d) Beer's Law:  $A = \epsilon bc$ , absorbance proportional to concentration.

**Question 6:** (a) Heat ice, melt ice, heat water, vaporize water, heat steam; (b) Total = 153,500 J = 154 kJ.

**Question 7:** (a) Lewis structures drawn; (b) Trigonal pyramidal, 1 lone pair; (c) 60.0 g NO.

**Question 8:** (a) Cl (highest Zeff); (b) Na (lowest Zeff); (c) S has more electrons, larger electron cloud.

**Question 9:** (a) F (intermediate); (b) Rate =  $k[NO_2][F_2]$  (from slow step); (c) Mechanism consistent; (d) 13.0 g NO<sub>2</sub>F.

**Question 10:** (a)  $E_a \approx 51.8 \text{ kJ/mol}$ ; (b) Diagram with  $E_a$  labeled.

**Questions 11-20:** Detailed solutions available in full answer key (contact instructor).

 **Post-Exam Reflection Questions:**

- Which unit(s) gave you the most difficulty? Plan focused review sessions.
- What types of mistakes did you make? (Conceptual? Calculation? Unit errors?)
- Did you manage time effectively? Adjust strategy for actual exam.
- Which questions would you approach differently now?
- What resources do you need to strengthen weak areas?

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Complete Mock Exam: Units 1-5 Comprehensive Review

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