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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: $N_a = 6.022 \times 10^{23}$ mol^{-1}

Speed of light: $c = 3.00 \times 10^{8}$ m/s

Planck's constant: $h = 6.626 \times 10^{-34}$ J·s

Faraday constant: F = 96,485 C/mol e^-

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	8 min
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
TOTAL	**All Units**	—	**150**	**180 min**

💡 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 CO_2 produced
- 3.78 g of H_2O produced
- Molar masses: CO_2 = 44.01 g/mol; H_2O = 18.02 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: CH_3OH (methanol), CH_3CH_3 (ethane), and CH_3F (fluoromethane).

> **Boiling Points:**
> • CH_3OH: 65°C
> • CH_3CH_3: −89°C
> • CH_3F: −78°C

(a) Draw the Lewis structure for CH_3OH 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 CH_3F and CH_3CH_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:

$$4\ Al(s) + 3\ O_2(g) \rightarrow 2\ Al_2O_3(s)$$

Given:

- 5.40 g of Al reacts with 4.00 g of O_2
- Molar masses: Al = 26.98 g/mol; O_2 = 32.00 g/mol; Al_2O_3 = 101.96 g/mol
- Actual yield obtained: 8.50 g of Al_2O_3

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

Show your work here:

(b) Calculate the theoretical yield of Al_2O_3 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: $2\ NO(g) + Cl_2(g) \rightarrow 2\ NOCl(g)$

Experiment	[NO] (M)	$[Cl_2]$ (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_2. 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°C to steam at 120°C. Given: specific heat of ice = 2.09 J/(g·°C); specific heat of water = 4.18 J/(g·°C); specific heat of steam = 2.01 J/(g·°C); ΔHfus = 334 J/g; ΔHvap = 2260 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 (NH_3) reacts with oxygen to form nitrogen monoxide and water: $4\ NH_3(g) + 5\ O_2(g) \rightarrow 4\ NO(g) + 6\ H_2O(g)$

(a) Draw Lewis structures for NH_3, NO, and H_2O. (3 points)

(b) Predict the molecular geometry of NH_3 and explain using VSEPR theory. (2 points)

(c) If 34.0 g of NH_3 reacts with excess O_2, how many grams of 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 $2\ NO_2(g) + F_2(g) \rightarrow 2\ NO_2F(g)$ is:

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Step 1: NO₂ + F₂ → NO₂F + F (slow)
Step 2: NO₂ + F → NO₂F (fast)
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(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 NO_2 reacts completely, how many grams of NO_2F are produced? (3 points)

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

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

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

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

(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 Fe^{2+} and explain magnetic properties; predict bond angles in PCl_3; compare ionization energies of O and F.

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

Calculate ΔH for combustion using calorimeter data; use Hess's Law to find ΔH 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.

END OF EXAMINATION

Please review your work if time permits.

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

🎯 ANSWER KEY & SOLUTIONS GUIDE

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

(a) Moles of carbon (2 points)

All carbon in CO_2 came from the hydrocarbon:
Moles of C = moles of CO_2 = 7.70 g / 44.01 g/mol = **0.175 mol C**

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

(b) Moles of hydrogen (2 points)

All hydrogen in H_2O came from the hydrocarbon (2 H per H_2O):
Moles of H_2O = 3.78 g / 18.02 g/mol = 0.210 mol H_2O
Moles of H = 2 × 0.210 mol = **0.420 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: C_5H_{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 g/mol
n = molar mass / empirical mass = 78 / 72.15 ≈ 1
Molecular formula: C_5H_{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_3OH Lewis structure with O-H bond and 2 lone pairs on O; (b) CH_3OH: hydrogen bonding; CH_3CH_3: London dispersion; CH_3F: dipole-dipole; (c) Hydrogen bonding is strongest IMF, requires most energy to overcome; (d) CH_3F has more electrons, stronger dispersion forces.

Question 3: (a) Al: 0.200 mol, produces 0.100 mol Al_2O_3; O_2: 0.125 mol, produces 0.0833 mol Al_2O_3 → O_2 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_2 = 1 (rate doubles when $[Cl_2]$ doubles); (c) Rate = $k[NO]^2[Cl_2]$; (d) k = 180 $M^{-2}s^{-1}$; (e) Overall order = 3.

Question 5: (a) Half-life = 50 s (constant); (b) k = 0.0139 s^{-1}; (c) $[Reactant]_{200}$ = 0.050 M; (d) Beer's Law: A = εbc, 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_2F.

Question 10: (a) Ea ≈ 51.8 kJ/mol; (b) Diagram with Ea 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?
