AP Chemistry Unit 3 Easier Practice Set

Intermolecular Forces & Properties

Building Confidence with Foundational IMF Concepts

APChemistryRescue.com

📋 Practice Set Information

- **Total Points:** 65 points
- **Suggested Time:** 60–90 minutes
- **Questions:** 10 (scaffolded difficulty)
- **Topics:** IMF types, boiling/vapor pressure, phase diagrams, heating curves, gas laws, solubility
- **Skills:** IMF identification, comparative reasoning, particulate diagrams, calculations with $q = mc\Delta T$ and $PV = nRT$

🔬 REFERENCE DATA & FORMULAS

Gas Constant (R):

0.0821 L·atm/(mol·K)
8.314 J/(mol·K)

Standard Conditions:

STP: 0°C (273 K), 1 atm
1 atm = 101.3 kPa = 760 mmHg

Energy Equations:

$q = mc\Delta T$
$q = n \cdot \Delta H_{fusion}$
$q = n \cdot \Delta H_{vap}$

Gas Laws:

$PV = nRT$
$P_1V_1/T_1 = P_2V_2/T_2$

IMF Strength Hierarchy:

London Dispersion < Dipole-Dipole < Hydrogen Bonding

(All molecules have London forces; polar molecules also have dipole-dipole; H-bonding requires H–F, H–O, or H–N)

Substance	Molar Mass (g/mol)	c (J/g·°C)	ΔH_{fus} (kJ/mol)	ΔH_{vap} (kJ/mol)
Water (H_2O)	18.02	4.18	6.01	40.7
Ethanol (C_2H_5OH)	46.07	2.44	4.9	38.6

💡 **Tips for Success:**

- Identify molecular polarity *first*, then determine IMF types
- Stronger IMFs → higher boiling point, lower vapor pressure
- Always convert °C to K for gas law calculations
- Show all work and include units for partial credit
- For phase diagrams: vertical line = heating, horizontal line = pressure change

Question 1: Identifying Intermolecular Forces (6 points)

Consider the following molecules:

Water (H_2O)

$H_{\delta+}-O_{\delta-}-H_{\delta+}$

Bent geometry

Ammonia (NH_3)

$N_{\delta-}-H_{\delta+}$

Trigonal pyramidal

Methane (CH_4)

$C-H$

Tetrahedral, nonpolar

Carbon Dioxide (CO_2)

$O=C=O$

Linear, nonpolar

(a) For **each molecule**, identify **all intermolecular forces** present. Explain your reasoning for H_2O.

Work Space:

(b) Rank the four molecules in order of **increasing boiling point**. Justify your ranking using IMF strength.

Work Space:

Question 2: Boiling Points and Vapor Pressure (6 points)

The table below shows boiling points for three substances:

Substance	Molecular Formula	Molar Mass (g/mol)	Boiling Point (°C)
Propane	C_3H_8	44.1	−42
Dimethyl ether	CH_3OCH_3	46.1	−24
Ethanol	C_2H_5OH	46.1	78

(a) Explain why ethanol has a **significantly higher boiling point** than dimethyl ether, even though they have the same molar mass.

Work Space:

(b) At 25°C, which substance would you expect to have the **highest vapor pressure**? Explain your reasoning.

Work Space:

Question 3: Particulate Diagrams (Solid, Liquid, Gas) (6 points)

Draw a particulate-level diagram for a pure substance in **each of the three phases** (solid, liquid, gas). Use circles (○) to represent particles.

Guidelines:

- Show 8–10 particles per diagram
- Particles in solids: fixed positions, touching
- Particles in liquids: close together, random arrangement
- Particles in gases: widely separated, random motion

SOLID

LIQUID

GAS

Explain: How do **intermolecular forces** differ among the three phases?

Work Space:

Question 4: Vapor Pressure and IMF Strength (5 points)

Two liquids, **hexane (C_6H_{14})** and **1-hexanol ($C_6H_{13}OH$)**, are placed in separate containers at 25°C.

(a) Which liquid has the **higher vapor pressure** at 25°C? Explain using IMF concepts.

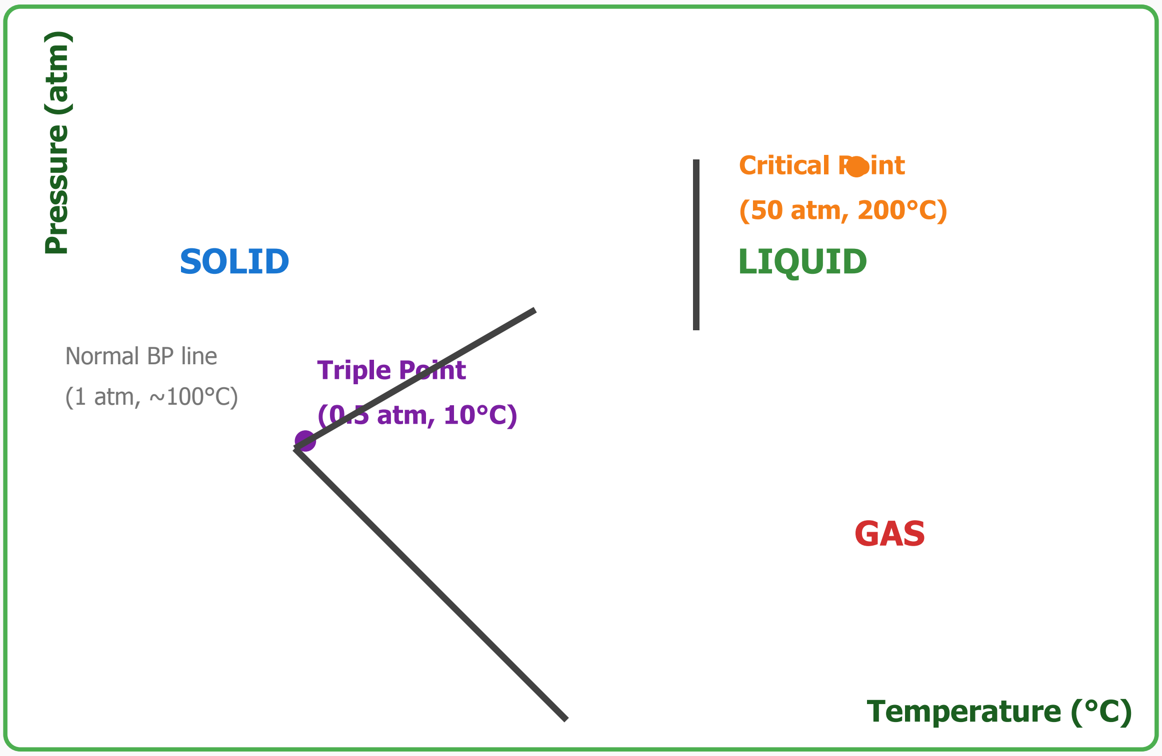
Work Space:

(b) If both liquids are heated to 50°C, what happens to the vapor pressure of each? Does the **relative order** change? Explain.

Work Space:

Question 5: Phase Diagram Interpretation (8 points)

The phase diagram below represents a pure substance:



(a) Identify the **normal boiling point** (approximate temperature at 1 atm pressure). Mark it on the diagram.

Work Space:

(b) What phase(s) exist at the **triple point**? What is special about this point?

Work Space:

(c) If the substance is initially a gas at 150°C and 0.2 atm, describe what happens as you **increase the pressure** to 2 atm at constant temperature.

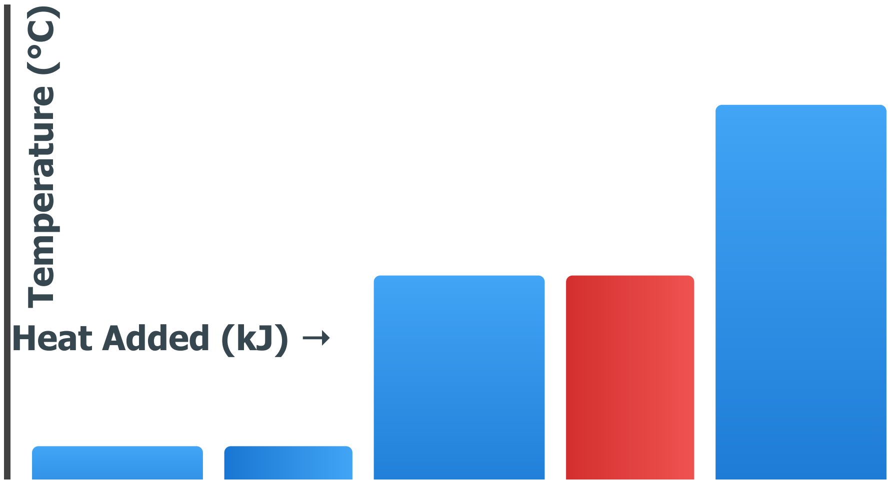
Work Space:

(d) Can this substance undergo **sublimation** (solid → gas)? If yes, under what conditions?

Work Space:

Question 6: Heating Curve Calculations (8 points)

A 50.0 g sample of water is heated from −10°C (ice) to 110°C (steam) at constant pressure. The heating curve is shown below:



c_{ice} = 2.09 J/(g·°C) | c_{water} = 4.18 J/(g·°C) | c_{steam} = 2.01 J/(g·°C)

ΔH_{fus} = 6.01 kJ/mol | ΔH_{vap} = 40.7 kJ/mol

(a) Calculate the energy required to warm the ice from −10°C to 0°C (Segment A). Show all work with units.

Work Space:

(b) Calculate the energy required to **melt** the ice at 0°C (Segment B). Show all work.

Work Space:

(c) Why are segments B and D **horizontal** (temperature doesn't change) even though heat is being added?

Work Space:

Question 7: Ideal Gas Law Application (7 points)

A scuba tank with a volume of 12.0 L contains oxygen gas (O_2) at 25°C and 150 atm.

Reminder:

PV = nRT | R = 0.0821 L·atm/(mol·K) | Always convert °C → K

(a) Calculate the **number of moles** of O_2 in the tank. Show all work with units.

Work Space:

(b) If the temperature increases to 50°C while the volume remains constant, what is the **new pressure** in the tank? (Use combined gas law: $P_1/T_1 = P_2/T_2$)

Work Space:

(c) Does O_2 behave as an **ideal gas** under these conditions (high pressure)? Briefly explain.

Work Space:

Question 8: Solubility and "Like Dissolves Like" (6 points)

Consider the following solvents and solutes:

Substance	Formula	Polarity
Water	H_2O	Polar
Hexane	C_6H_{14}	Nonpolar
Sodium chloride	NaCl	Ionic
Iodine	I_2	Nonpolar
Ethanol	C_2H_5OH	Polar

(a) Predict whether **NaCl** will dissolve in water or hexane. Explain using the "like dissolves like" principle.

Work Space:

(b) Predict whether **I_2** will dissolve better in water or hexane. Justify your answer.

Work Space:

(c) Ethanol (C_2H_5OH) is soluble in **both** water and hexane. Explain why, considering its molecular structure.

Work Space:

Question 9: Particulate Diagram – Solution Formation (6 points)

When solid NaCl dissolves in water, the ions separate and become surrounded by water molecules (hydration).

(a) Draw a particulate-level diagram showing **3 Na^+ ions and 3 Cl^- ions** dissolved in water. Use:

- ⊕ for Na^+
- ⊖ for Cl^-
- V-shaped water molecules with δ^+ and δ^- labels

NaCl(aq) Solution – Particulate Diagram

(b) Explain how water molecules orient themselves around **Na^+** ions versus **Cl^-** ions. Which end of the water molecule (δ^+ or δ^-) points toward each ion?

Work Space:

Question 10: Conceptual Understanding (7 points)

Answer the following conceptual questions. **Explain your reasoning** for full credit.

(a) A student claims: "When water boils, the H–O covalent bonds break." Is this correct? Explain what actually happens at the molecular level during boiling.

Work Space:

(b) Why do **ideal gases** have no intermolecular forces, while **real gases** do? Under what conditions (high/low T, high/low P) do real gases behave most like ideal gases?

Work Space:

(c) A student observes that increasing the volume of a container does **not** change the vapor pressure of a liquid inside. Explain why vapor pressure is independent of container volume.

Work Space:

END OF PRACTICE SET

Total: 65 points | Answer key begins on next page

📘 COMPLETE ANSWER KEY & SCORING GUIDE

Question 1: Identifying Intermolecular Forces (6 points)

(a) IMF identification (3 points):

- **H_2O:** London dispersion, dipole-dipole, hydrogen bonding. *Explanation:* Water has O–H bonds (δ^+ H bonded to δ^- O), creating a bent, polar molecule. The H directly bonded to O can form hydrogen bonds with lone pairs on O of neighboring molecules. (1 pt for all three IMFs; 1 pt for H-bonding justification)
- **NH_3:** London dispersion, dipole-dipole, hydrogen bonding. (N–H bonds enable H-bonding) (0.5 pt)
- **CH_4:** London dispersion only (nonpolar, symmetrical) (0.25 pt)
- **CO_2:** London dispersion only (linear, nonpolar despite polar C=O bonds) (0.25 pt)

(b) Ranking by boiling point (3 points):

Order: $CH_4 < CO_2 < NH_3 < H_2O$ (1 pt for correct order)

Justification (2 pts): CH_4 and CO_2 have only London forces, but CO_2 is heavier (higher molar mass → stronger London forces) so it has a slightly higher BP than CH_4. NH_3 has hydrogen bonding (stronger than London/dipole-dipole alone), so higher BP. H_2O has the strongest hydrogen bonding (two H–bond donors per molecule, high electronegativity of O), giving it the highest BP.

Scoring: (a) 3 pts (IMFs + explanation); (b) 3 pts (order + justification)

Question 2: Boiling Points and Vapor Pressure (6 points)

(a) Higher BP for ethanol (3 points):

Ethanol (C_2H_5OH) has an –OH group, enabling **hydrogen bonding** (H bonded to O can interact with lone pairs on O of other ethanol molecules). Dimethyl ether (CH_3OCH_3) has an O atom but no O–H bond, so it cannot form hydrogen bonds—only dipole-dipole and London forces. Hydrogen bonding is much stronger than dipole-dipole forces, requiring more energy to overcome, thus ethanol has a BP of 78°C vs. −24°C for dimethyl ether. (2 pts for H-bonding explanation; 1 pt for comparing to ether)

(b) Highest vapor pressure at 25°C (3 points):

Propane has the highest vapor pressure at 25°C. (1 pt) Vapor pressure is inversely related to IMF strength: weaker IMFs → molecules escape liquid surface more easily → higher vapor pressure. Propane has only London dispersion forces (weakest IMFs of the three), so it has the highest VP. Ethanol has the lowest VP due to strong H-bonding. (2 pts for reasoning linking IMF strength to VP)

Scoring: (a) 3 pts; (b) 3 pts (answer + reasoning)

Question 3: Particulate Diagrams (6 points)

Diagram scoring (4 points):

- **Solid:** Particles in fixed, ordered positions (lattice-like arrangement), touching or very close. (1.5 pts)
- **Liquid:** Particles close together but randomly arranged, able to slide past each other. (1.5 pts)
- **Gas:** Particles widely separated, random positions, large empty spaces. (1 pt)

IMF explanation (2 points):

Solid: IMFs are strongest, holding particles in fixed positions. **Liquid:** IMFs are present but weaker than in solid, allowing particles to move while staying close. **Gas:** IMFs are negligible; particles move independently with high kinetic energy, overcoming any attractive forces. (2 pts for clear comparison across phases)

Scoring: Diagrams 4 pts (solid 1.5, liquid 1.5, gas 1); Explanation 2 pts

Question 4: Vapor Pressure and IMF Strength (5 points)

(a) Higher vapor pressure (3 points):

Hexane (C_6H_{14}) has the higher vapor pressure at 25°C. (1 pt) Hexane is nonpolar with only London dispersion forces. 1-Hexanol ($C_6H_{13}OH$) has an –OH group, enabling hydrogen bonding (much stronger IMF). Weaker IMFs in hexane mean molecules escape the liquid surface more readily → higher vapor pressure. (2 pts for IMF-based reasoning)

(b) Effect of heating to 50°C (2 points):

Both vapor pressures **increase** when heated to 50°C (higher temperature → more molecules have enough kinetic energy to overcome IMFs and evaporate). However, the **relative order does not change**: hexane still has higher VP than 1-hexanol because the IMF strength difference (London vs. H-bonding) remains the same. (1 pt for "both increase"; 1 pt for "order stays the same")

Scoring: (a) 3 pts; (b) 2 pts

Question 5: Phase Diagram Interpretation (8 points)

(a) Normal boiling point (2 points):

The normal boiling point is the temperature at which the substance boils at **1 atm pressure**. On the diagram, trace the horizontal line at 1 atm until it intersects the liquid-gas boundary. The approximate temperature is **~100°C**. (1 pt for method; 1 pt for approximate value)

(b) Triple point (2 points):

At the triple point (0.5 atm, 10°C), **all three phases—solid, liquid, and gas—coexist in equilibrium**. (1 pt for "three phases"; 1 pt for "equilibrium") This is the only point where all three phases can exist simultaneously.

(c) Increasing pressure at constant T (2 points):

Starting at 150°C and 0.2 atm (gas phase), increasing pressure to 2 atm at constant temperature crosses the gas-liquid phase boundary. The substance **condenses from gas to liquid**. (1 pt for phase change; 1 pt for "condenses" or "gas → liquid")

(d) Sublimation conditions (2 points):

Yes, sublimation (solid → gas) can occur. (1 pt) Sublimation happens at pressures **below the triple point pressure** (< 0.5 atm). For example, at 0.2 atm, heating the solid from low temperature will cause it to sublimate directly to gas without passing through the liquid phase. (1 pt for pressure condition)

Scoring: (a) 2 pts; (b) 2 pts; (c) 2 pts; (d) 2 pts

Question 6: Heating Curve Calculations (8 points)

(a) Segment A: Warming ice from −10°C to 0°C (3 points):

$$q = mc\Delta T$$

$$q = (50.0 \text{ g})(2.09 \text{ J/g·°C})(0 - (-10))°C$$

$$q = (50.0)(2.09)(10) = 1045 \text{ J} = 1.05 \text{ kJ}$$

(1 pt for correct formula; 1 pt for substitution with units; 1 pt for final answer with units)

(b) Segment B: Melting ice at 0°C (3 points):

First, convert mass to moles:

$$n = \frac{50.0 \text{ g}}{18.02 \text{ g/mol}} = 2.775 \text{ mol}$$

Then:

$$q = n \cdot \Delta H_{fus} = (2.775 \text{ mol})(6.01 \text{ kJ/mol}) = 16.68 \text{ kJ}$$

(1 pt for mole conversion; 1 pt for correct formula and substitution; 1 pt for final answer)

(c) Why segments B and D are horizontal (2 points):

During phase changes (melting at 0°C, boiling at 100°C), the added energy is used to **overcome intermolecular forces** rather than increase kinetic energy (temperature). The temperature remains constant until all the substance has completed the phase transition (all ice melted, or all water boiled). (1 pt for "energy overcomes IMFs"; 1 pt for "temperature constant during phase change")

Scoring: (a) 3 pts; (b) 3 pts; (c) 2 pts

Question 7: Ideal Gas Law Application (7 points)

(a) Moles of O_2 (3 points):

Convert temperature: T = 25°C + 273 = 298 K

$$PV = nRT \Rightarrow n = \frac{PV}{RT}$$

$$n = \frac{(150 \text{ atm})(12.0 \text{ L})}{(0.0821 \text{ L·atm/mol·K})(298 \text{ K})}$$

$$n = \frac{1800}{24.47} = 73.6 \text{ mol}$$

(1 pt for T conversion; 1 pt for correct setup; 1 pt for answer with units)

(b) New pressure at 50°C (3 points):

Convert: T_2 = 50°C + 273 = 323 K; T_1 = 298 K; P_1 = 150 atm

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \Rightarrow P_2 = P_1 \cdot \frac{T_2}{T_1}$$

$$P_2 = 150 \text{ atm} \cdot \frac{323 \text{ K}}{298 \text{ K}} = 162.6 \text{ atm}$$

(1 pt for correct formula; 1 pt for substitution; 1 pt for answer)

(c) Ideal gas behavior at high P (1 point):

No, O_2 does not behave ideally at 150 atm (high pressure). At high pressure, gas molecules are forced closer together, so intermolecular forces become significant and molecular volume is no longer negligible—both violate ideal gas assumptions. Real gases deviate most from ideal behavior at high P and low T. (1 pt for explanation)

Scoring: (a) 3 pts; (b) 3 pts; (c) 1 pt

Question 8: Solubility and "Like Dissolves Like" (6 points)

(a) NaCl solubility (2 points):

NaCl dissolves in water but not in hexane. (1 pt) NaCl is ionic (polar), and water is polar. "Like dissolves like" means polar/ionic solutes dissolve in polar solvents. Water molecules can surround and stabilize Na^+ and Cl^- ions (hydration), overcoming the ionic lattice energy. Hexane is nonpolar and cannot stabilize ions. (1 pt for reasoning)

(b) I_2 solubility (2 points):

I_2 dissolves better in hexane. (1 pt) I_2 is nonpolar (symmetrical diatomic molecule), so it dissolves in nonpolar hexane ("like dissolves like"). I_2 does not dissolve well in polar water because water molecules prefer to hydrogen-bond with each other rather than interact with nonpolar I_2. (1 pt for reasoning)

(c) Ethanol solubility in both (2 points):

Ethanol (C_2H_5OH) has a **dual nature**: the –OH group is polar (can H-bond with water), and the C_2H_5 (ethyl) group is nonpolar (can interact with hexane via London forces). This "amphipathic" structure allows ethanol to dissolve in both polar (water) and nonpolar (hexane) solvents. (1 pt for identifying dual nature; 1 pt for explaining polar/nonpolar interactions)

Scoring: (a) 2 pts; (b) 2 pts; (c) 2 pts

Question 9: Particulate Diagram – Solution Formation (6 points)

(a) Diagram (4 points):

Expected features:

- 3 ⊕ symbols (Na^+) and 3 ⊖ symbols (Cl^-) dispersed in the solution (not clustered as a solid) (1 pt)
- Water molecules drawn as V-shapes with δ^+ H and δ^- O labeled (1 pt)
- Water molecules around Na^+: **oxygen (δ^-) end points toward Na^+** (attraction between opposite charges) (1 pt)
- Water molecules around Cl^-: **hydrogen (δ^+) end points toward Cl^-** (1 pt)

(b) Orientation explanation (2 points):

Water molecules are polar (δ^+ on H, δ^- on O). Around **Na^+** (positive ion), the **negative (δ^- oxygen) end** of water points toward the ion (opposite charges attract). Around **Cl^-** (negative ion), the **positive (δ^+ hydrogen) end** points toward the ion. (1 pt for Na^+; 1 pt for Cl^-) This orientation stabilizes the ions in solution (hydration/solvation).

Scoring: (a) 4 pts (diagram features); (b) 2 pts (orientation explanation)

Question 10: Conceptual Understanding (7 points)

(a) "H–O bonds break during boiling" (2 points):

Incorrect. (0.5 pt) During boiling, **intermolecular forces** (hydrogen bonds between water molecules) are overcome, not the **intramolecular covalent O–H bonds**. The water molecules remain intact (H_2O) but separate from each other and enter the gas phase. Breaking O–H bonds would decompose water into H and O atoms, which does not happen during boiling. (1.5 pts for explanation)

(b) IMFs in ideal vs. real gases (3 points):

Ideal gases are a theoretical model assuming no IMFs and negligible molecular volume—useful for simplifying calculations. **Real gases** have weak IMFs (especially at low T and high P when molecules are closer). Real gases behave most like ideal gases at **high temperature** (molecules move fast, overcoming IMFs) and **low pressure** (molecules far apart, IMFs negligible). (1 pt for ideal vs real; 2 pts for conditions)

(c) Vapor pressure independence from container volume (2 points):

Vapor pressure is determined by the **equilibrium** between liquid and gas phases at a given temperature, not by the container size. At equilibrium, the rate of evaporation equals the rate of condensation. Increasing container volume may initially lower gas pressure, but more liquid will evaporate until equilibrium is re-established at the same vapor pressure (as long as liquid remains). Vapor pressure depends only on **temperature and IMF strength**, not volume. (1 pt for equilibrium concept; 1 pt for explanation)

Scoring: (a) 2 pts; (b) 3 pts; (c) 2 pts