Consider the statement:
"As H₂O changes from a liquid form to a gaseous form, the H-O bonds of the water are breaking." Support or refute this statement with a complete explanation.

(2)
Does the following contain (1) polar bonds and (2) an overall dipole moment?
- a. CO₂
- b. HCN
- c. H₂
- d. CH₃Cl
- e. F₂
- f. Ne
Show the interactions of components of LiCl (aq) in a beaker. Include only one formula unit of LiCl and no more than 10 molecules of water. Include: Identity of ions (symbol and charge) & proper orientation of particles.
a. At 25°C and 1 atm, F₂ is a gas whereas Br₂ is a liquid.
b. The melting point of NaCl is 801°C, whereas MgS is greater than 2000°C.
c. Ammonia, NH₃, dissolves readily in water, whereas PH₃ is moderately soluble.
d. CH₃OCH₃ is a liquid at room temperature whereas C₂H₆ is a gas.
e. KCl is a solid at room temperature whereas HCl is a liquid.
Compare the strength of the intermolecular forces listed below between H₂O and H₂S:
   a. Dipole to dipole intermolecular attractions
   b. London dispersion intermolecular attractions

At a pressure of 1 atm, the boiling point of NH₃(l) is higher than NF₃(l).
   a. Identify the hybridization in each molecule.
   b. Is the bond angle of each less than, greater than, or equal to 109.5°? Justify your answer.
   c. Identify the intermolecular force(s) in each substance.
   d. Account for the difference in the boiling points of each substance.

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1. SiO₂ melts at 2230°C, whereas CO₂ melts at 78°C.
2. The boiling point of CH₃Cl(l) is higher than the boiling point of HCl.
3. CH₃Cl is not soluble in water whereas CH₃N₂ is soluble.
4. H₂O boils up on a table whereas CH₃COCH₃ just spreads out and evaporates easily.
5. MgCl₂ melts at 795°C whereas KCl melts at 83°C.

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6. Even though NH₃ and CH₃Cl have similar molar masses, NH₃ has a much higher boiling point of 33°C
   whereas CH₃Cl has a boil point of -164°C.
7. As standard temperature and pressure, hexane (C₆H₁₄) is a liquid and ethane (C₂H₆) is a gas.
8. CaO melts at a much higher temperature than KF.
9. Even though both are made up of ionic bonds, CCl₄ melts at a much higher temperature than F₂.
10. LiF has a much higher melting point than CaO.

Oct 11-7:37 AM

<table>
<thead>
<tr>
<th>Substance</th>
<th>Boiling Point (°C)</th>
<th>Bond Length (Åm)</th>
<th>Bond Strength (kJ mol⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O</td>
<td>100.15</td>
<td>153</td>
<td>460</td>
</tr>
<tr>
<td>N₂</td>
<td>-195.79</td>
<td>110</td>
<td>942</td>
</tr>
<tr>
<td>O₂</td>
<td>-182.95</td>
<td>121</td>
<td>494</td>
</tr>
<tr>
<td>Cl₂</td>
<td>-134.34</td>
<td>199</td>
<td>243</td>
</tr>
</tbody>
</table>

Explain the differences in the properties given in the table above for each of the following pairs of molecules:
   a. Explain the bond strengths of N₂ and O₂.
   b. Explain the bond lengths of H₂ and Cl₂.
   c. Explain the boiling points of O₂ and Cl₂.
   d. Use the principles of molecular bonding to explain why H₂O is a liquid at standard temperature and pressure, whereas H₂ and O₂ are both gases.
 Identify the types of intermolecular forces that exist in the two structures above.

d) Explain why the water boils at 87°C in La Paz, Bolivia, which is 3600 m above sea level, and at 100°C at sea level.

d) Carbon tetrafluoride, CF₄, has a higher boiling point than methane, CH₄.

I. Identify the type(s) of intermolecular force(s) in each compound.

II. Explain why the boiling points of these structures differ.
1) A liquid whose molecules are held together by which of the following forces would be expected to have the lowest boiling point?
(A) Ionic bonds
(B) London dispersion forces
(C) Hydrogen bonds
(D) Metallic bonds
(E) Network bonds

2) Which of the following lists of species is in order of increasing boiling points?
(A) H₂, N₂, NH₃
(B) N₂, H₂, NH₃
(C) NH₃, H₂, N₂
(D) NH₃, N₂, H₂
(E) H₂, NH₃, N₂
1) Which of the compounds listed below would require the greatest energy to separate it into ions in the gaseous state?
   (A) NaCl
   (B) NaI
   (C) MgO
   (D) Na₂O
   (E) MgCl₂

2) Which of the molecules listed below has the largest dipole moment?
   (A) Cl₂
   (B) HCl
   (C) SO₃
   (D) NH₃
   (E) N₂

a) Ammonia, NH₃, has a higher boiling point than nitrogen trifluoride, NF₃.

I. Identify the type(s) of intermolecular force(s) in each compound.

II. Explain why the boiling points of these structures differ.

a) Explain why the temperature of solid H₂O remains constant during the melting process, even though heat continues to be absorbed. What happens to the heat that is absorbed?

I. H H H H H
   H C C C C C H
   H H H H H

II. H H H H H
   H C C C C H
   H H H H H

Which of the above structures has the largest standard heat of vaporization, ΔH_{vap} value? Justify your answer.
(a) Draw the Lewis electron-dot diagram for Ethyne.

(b) Which of the four molecules has the shortest carbon-to-carbon bond? Explain.

(c) Ethanoic Acid is given below. What is the geometry around Cx and Cy?

(d) Consider the statement, “As ethanol boils, energy goes into breaking C-C bonds, C-H bonds, C-O bonds, and O-H bonds.” Is this statement true or false? Justify your answer.

(e) Identify a compound from the table above that is nonpolar.

(f) Ethanol is completely soluble in water, whereas ethanethiol is slightly soluble. Explain in terms of intermolecular forces.
1) In this molecule, oxygen forms sp³ hybrid orbitals.
2) This molecule contains one unpaired electron.
3) This molecule contains no π (π) bonds.
4) Oxygen has an oxidation state of zero in this molecule.

1) If the carbon-to-carbon bond in C₂H₆ is found to have a bond energy of 350 kJ/mol and a bond length of 1.5 angstroms. Explain what the relative bond energy and length of the carbon-to-carbon bond for C₂H₄ would be.

2) A pure sample of KClO₃ (FW = 123.5) is found to contain 71 grams of chlorine atoms. What is the mass of the sample?

(A) 122 grams
(B) 170 grams
(C) 209 grams
(D) 245 grams
(E) 293 grams
1) The first ionization energy for magnesium is 730 kJ/mol. The third ionization energy is 7700 kJ/mol. What is most likely the value for the second ionization energy?

(A) 490 kJ/mol  
(B) 1400 kJ/mol  
(C) 4200 kJ/mol  
(D) 7100 kJ/mol  
(E) 8400 kJ/mol

2) Which of the following groups below is (are) listed in order from lowest to highest melting point?

I. KI, LiF, BeO  
II. F₂, Cl₂, Br₂  
III. K, Na, Li

(a) The structures for glucose, C₆H₁₂O₆, and cyclohexane, C₆H₁₂, are shown below.

[Diagram of glucose and cyclohexane structures]

Identify the type(s) of intermolecular attractive forces in

(i) pure glucose  
(ii) pure cyclohexane

(b) Glucose is soluble in water but cyclohexane is not soluble in water. Explain.

Consider the two processes represented below.

Process 1: H₂O(l) → H₂O(g) \[ΔS^\circ = +64.9 \text{ J mol}^{-1}\]

Process 2: H₂O(l) → H₂(g) + \(\frac{1}{2}\) O₂(g) \[ΔS^\circ = +295 \text{ J mol}^{-1}\]

(i) For each of the two processes, identify the type(s) of intermolecular or intermolecular attractive force that must be overcome for the process to occur.

(ii) Indicate whether you agree or disagree with the statement in the box below. Support your answer with a short explanation.

When water boils, H₂O molecules break apart to form hydrogen molecules and oxygen molecules.
2008 Form A Practice Exam Question

Use principles of atomic structure, bonding, and intermolecular forces to respond to each of the following. Your responses must include specific information about all substances referred to in each question.

(a) At a pressure of 1 atm, the boiling point of NH₃ (l) is 240 K, whereas the boiling point of NF₃ (l) is 244 K.
   (i) Identify the intermolecular force(s) in each substance.
   (ii) Account for the difference in the boiling points of the substances.

(b) The melting point of KCl(s) is 773°C, whereas the melting point of NaCl(s) is 801°C.
   (i) Identify the type of bonding in each substance.
   (ii) Account for the difference in the melting points of the substances.

---

(a) As shown in the table below, the first ionization energies of Si, P, and Cl show a trend.

<table>
<thead>
<tr>
<th>Element</th>
<th>First Ionization Energy (kJ mol⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>736</td>
</tr>
<tr>
<td>P</td>
<td>1022</td>
</tr>
<tr>
<td>Cl</td>
<td>1284</td>
</tr>
</tbody>
</table>

(i) For each of the three elements, identify the quantum level (e.g., n = 1, n = 2, etc.) of the valence electron in the atom.

(ii) Explain the reason for the trend in first ionization energy.

(b) A certain element has two stable isotopes. The mass of one of the isotopes is 6.93 amu and the mass of the other isotope is 6.95 amu.
   (i) Identify the element (be sure to justify your answer).
   (ii) Which isotope is more abundant? Justify your answer.
The Lewis dot structure of propane, CH₃CH₂CH₃, and methanoic acid, HCONH₂, are shown above. In the table below, write the type(s) of intermolecular attractive forces that occur in each substance.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Boiling Point</th>
<th>Intermolecular Attractive Force(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propane</td>
<td>229 K</td>
<td></td>
</tr>
<tr>
<td>Methanoic acid</td>
<td>374 K</td>
<td></td>
</tr>
</tbody>
</table>

Use principles of intermolecular attractive forces to explain why methanoic acid has a higher boiling point than propane.

(a) Draw a complete Lewis electron dot structure for the CO₂ molecule. Include all valence electrons in your structure.

(b) The carbon-oxygen bond length in CO₂ is 1.16 Å. In the carbon-nitrogen bond length in CN₂, expected to be greater than, less than, or equal to this value? Justify your answer.

(c) The bond energy of the carbon-oxygen bond in CO₂ is 771 kJ/mol. In the bond energy of the carbon-nitrogen bond in CN₂ expected to be greater than, less than, or equal to this value? Justify your answer.

Account for each of the following observations about pairs of substances. In your answers, use appropriate principles of chemistry and/or intermolecular forces. In each part, your answer must include references to specific substances.

(a) Even though NH₃ and CH₄ have similar molecular masses, NH₃ has a much higher normal boiling point (-33°C) than CH₄ (-164°C).

(b) At 25°C and 1.0 atm, ethanol (C₂H₅OH) is a liquid and benzene (C₆H₆) is a gas.

(c) Ethanol sublimes at a much higher temperature (114°C) than benzene (80°C).

(d) MgO melts at a much higher temperature (2,852°C) than NaF (993°C).
Questions 13-16 refer to the following descriptions of bonding in different types of solids:

A. Lattice of positive and negative ions held together by electrostatic forces.
B. Closest packed lattice with delocalized electrons throughout.
C. Strong angle covalent bonds with weak intermolecular forces.
D. Strong multiple covalent bonds with weak intermolecular forces.
E. Macromolecules held together with strong polar bonds.

13. Cerium chloride, CeCl₃
14. Gold, Au(s)
15. Carbon dioxide, CO₂
16. Methane, CH₄

40. Of the following molecules, which has the largest dipole moment?

(A) CO
(B) CO₂
(C) O₂
(D) HF
(E) F₂

Use appropriate chemical principles to account for each of the following observations. In each part, your response must include specific interactions and/ or solubility. 

(a) At 25°C and 1 atm, F₂ is a gas, whereas I₂ is a solid.
(b) The melting point of NaCl is 66°C, whereas the melting point of CaCl₂ is 490°C.
(c) The shape of the IO₃⁻ ion is square planar, whereas the shape of the BF₃⁺ ion is tetrahedral.
(d) Ammonia, NH₃, is very soluble in water, whereas phosphine, PH₃, is only moderately soluble in water.

5. Explain each of the following in terms of the electronic structure and/or bonding of the compounds involved.

(a) At ordinary conditions, H₂S (normal boiling point = -60°C) is a liquid, whereas H₂O (normal boiling point = 100°C) is a gas.
(b) Molecules of Na₂S are ionic; whereas molecules of Na₂O are covalent.
(c) The N₂O bond in the NO₂⁻ ion are equal in length, whereas they are unequal in NO₂⁻.
(d) For sulfur, the fluorides SF₂, SF₃, and SF₄ are known to exist, whereas for oxygen only O₂ is known to exist.
Unknown Lab

BaCl₂ NaCl NH₄Cl Pb(NO₃)₂
AgNO₃ CoCl₂

Can only use to identify:
- Appearance
- H₂O
- 1M Na₃PO₄
- 1M NaOH
- 1M KI
(a) Discuss how the trend in the melting points of the substances tabulated above can be explained in terms of the types of attractive forces and/or bonds in these substances.
Questions 1-6 refer to the diagram below.

The graph below shows the temperature change as a sample of pure substance is cooled at a constant rate from a gas to a liquid to a solid. Separate regions are labeled I through V.

**What is the approximate boiling point of the substance above?**

- (A) 90°C
- (B) 80°C
- (C) 50°C
- (D) 40°C

**What is the approximate freezing point of the substance above?**

- (A) 90°C
- (B) 80°C
- (C) 50°C
- (D) 40°C
78. Which region represents the greatest change in potential energy?

(A) IV  
(B) III  
(C) II  
(D) I

79. Which region represents the cooling of the liquid phase?

(A) IV  
(B) III  
(C) II  
(D) I

80. Which region represents the region of highest kinetic energy?

(A) IV  
(B) III  
(C) II  
(D) I

81. Which pairing lists the liquid with the higher vapor pressure first? Assume both liquids are observed at room temperature and 1 atm.

(A) motor oil, water  
(B) rubbing alcohol, motor oil  
(C) mineral oil, water  
(D) milk, perfume

62. The term that describes the amount of heat required to convert one mole of a solid at its melting point to a liquid at this temperature is

(A) Heat of fusion  
(B) Heat of sublimation  
(C) Heat of combustion  
(D) Heat of vaporization
The best explanation below for why C₃H₈ has a higher normal boiling point than CH₄ is the

(A) greater molar mass  
(B) greater London Dispersion forces  
(C) greater polarity  
(D) presence of hydrogen bonding

Questions 9-12: Choose your answers from the choices below.

(A) Germanium, Ge, is a solid where the atoms are bonded to each other much like those of carbon in a diamond.  
(B) Glycerol, C₃H₅(OH)₃, is an alcohol.  
(C) Lithium chloride, LiCl, is a white crystalline solid.  
(D) Propane, C₃H₈, is a gas which can be liquefied only at low temperatures or high pressures.

Considering only the above substances, identify the substance with:

- the highest melting point  
- the greatest hardness in the solid phase  
- the lowest heat of vaporization  
- conductivity in the fused or melted state, but not in the solid state  
- "hydrogen bonding"

Ice cubes and snowmen shrink in size even when the temperature stays well below freezing, due to

(A) vaporization  
(B) sublimation  
(C) excitation  
(D) evaporation
90. Which liquid below would be expected to have the highest equilibrium vapor pressure at room temperature, 25°C?

(A) CHCl₃
(B) H₂O
(C) CCl₄
(D) All three would have the same equilibrium vapor pressure at 25°C.

91. Which pairing has the substance with the higher melting point listed first?

(A) Rb or K
(B) LiCl or C₄H₁₀
(C) CO₂ or CS₂
(D) Cs or Fe

92. The explanation for why CH₄ is relatively insoluble in water is related to

(A) the dipole-dipole attractions between H₂O molecules are stronger than the attractions between H₂O and CH₄ molecules
(B) the size of CH₄ molecules is larger than the size of H₂O molecules
(C) the dipole-dipole attractions between CH₄ molecules are greater than attractions between CH₄ and H₂O molecules
(D) the attractions between CH₄ molecules are stronger than the attractions between CH₄ and H₂O molecules due to “hydrogen bonding” between CH₄ molecules

93. Which characteristic is most closely associated with covalent network solids?

(A) High thermal conductivity, high degree of hardness
(B) High electrical conductivity, high thermal conductivity
(C) High melting points, high degree of hardness
(D) High ductility, low electrical conductivity
Questions 19–23. Select your answers to questions 19–23 from the choices below.

(A) An ionic solid
(B) A metallic solid
(C) A planar covalent solid
(D) A molecular compound with non-polar molecules

94. Cu, copper wire
95. CO₂, dry ice
96. C₆H₆, benzene
97. LiNO₃, lithium nitrate crystals
98. C(gr), powdered graphite

99. Inexpensive sealed hand-boilers work on the principle that

(A) Liquids have just one characteristic boiling point
(B) Liquids boil when their vapor pressure = “atmospheric” (ambient) pressure.
(C) Liquids will not boil under low atmospheric pressure conditions.
(D) Heat from one’s hand is insufficient to boil a liquid.

100. Which intermolecular forces are NOT found in liquified NH₃?

(A) Ionic bonds
(B) Dipole-dipole attractions
(C) London Dispersion forces
(D) “Hydrogen bonds”
5. The molar mass of an unknown solid, which is nonvolatile and a nonelectrolyte, is to be determined by the freezing-point depression method. The pure solvent used in the experiment freezes at 10°C and has a known molal freezing-point depression constant, \(K_f\). Assume that the following materials are also available.

- test tubes
- stirrer
- pipet
- thermometer
- balance
- beaker
- stopwatch
- graph paper
- hot-water bath
- ice

(a) Using the two sets of axes provided below, sketch cooling curves for (i) the pure solvent and for (ii) the solution as each is cooled from 20°C to 0.0°C.

![Cooling Curves Diagram]

(b) Information from these graphs may be used to determine the molar mass of the unknown solid.

(i) Describe the measurements that must be made to determine the molar mass of the unknown solid by this method.

(ii) Show the setup(s) for the calculation(s) that must be performed to determine the molar mass of the unknown solid from the experimental data.

(iii) Explain how the difference(s) between the two graphs in part (a) can be used to obtain information needed to calculate the molar mass of the unknown solid.

(c) Suppose that during the experiment a significant but unknown amount of solvent evaporates from the test tube. What effect would this have on the calculated value of the molar mass of the solid (i.e., too large, too small, or no effect)? Justify your answer.

(d) Show the setup for the calculation of the percentage error in a student’s result if the student obtains a value of 126 g mol\(^{-1}\) for the molar mass of the solid when the actual value is 120. g mol\(^{-1}\).
8. Account for each of the following observations about pairs of substances. In your answers, use appropriate principles of chemical bonding and/or intermolecular forces. In each part, your answer must include references to both substances.

(a) Even though NH₃ and CH₄ have similar molecular masses, NH₃ has a much higher normal boiling point (−33°C) than CH₄ (−164°C).

(b) At 25°C and 1.0 atm, ethane (C₂H₆) is a gas and hexane (C₆H₁₄) is a liquid.

(c) Si melts at a much higher temperature (1,410°C) than Cl₂ (−101°C).

(d) MgO melts at a much higher temperature (2,852°C) than NaF (993°C).

END OF EXAMINATION
Question 8

(8 points)

For each part, the student earns credit by indicating what kind of bonding and/or intermolecular forces are present, and giving some information about their relative strengths. The student can earn one point for giving the correct type of bonding and/or intermolecular forces present in both of the species in any part.

(a) \( \text{NH}_3 \) has hydrogen bonding between molecules (or dipole-dipole interactions between molecules), and \( \text{CH}_4 \) has London dispersion forces. The intermolecular forces in \( \text{NH}_3 \) are stronger than those in \( \text{CH}_4 \).

- No credit earned for only a discussion of lone pairs of electrons.
- No credit earned for saying only that \( \text{NH}_3 \) is polar and \( \text{CH}_4 \) is nonpolar (with no more discussion).

(b) \( \text{C}_2\text{H}_6 \) and \( \text{C}_6\text{H}_{14} \) both have London dispersion forces. The forces in \( \text{C}_6\text{H}_{14} \) are stronger because the molecule is larger and more polarizable.

- Credit is earned for other accurate explanations of London dispersion forces.
- No credit is earned for saying only that \( \text{C}_6\text{H}_{14} \) is heavier or has more mass.

(c) Si is a network covalent solid (or a macromolecule) with strong covalent bonds between atoms. \( \text{Cl}_2 \) has discrete molecules with weak London dispersion forces between the molecules. Therefore, more energy is required to break the stronger bonds of Si than the weak intermolecular forces of \( \text{Cl}_2 \).

- No credit is earned for saying only that Si forms a lattice.

(d) MgO and NaF are both ionic solids (or ions are listed to indicate this). The +2 and −2 charges in MgO result in a greater attraction between ions than the +1 and −1 charges in NaF (or according to Coulomb’s Law, the attraction between +2 ions and −2 ions is greater than that between +1 ions and −1 ions, or student shows calculations using Coulomb’s Law).

- Credit is earned also for stating that the lattice energy of MgO is greater than the lattice energy of NaF.
- No credit is earned for only a discussion of electronegativity.
- Since the sizes are about the same, no credit is earned for only a size argument.
6. 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 0.10 \textit{M} NaCl(aq) is higher than that of 0.10 \textit{M} C\textsubscript{12}H\textsubscript{22}O\textsubscript{11}(aq).

(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.
7. Use appropriate chemical principles to account for each of the following observations. In each part, your response must include specific information about both substances.

(a) At 25°C and 1 atm, F₂ is a gas, whereas I₂ is a solid.

(b) The melting point of NaF is 993°C, whereas the melting point of CsCl is 645°C.

(c) The shape of the ICl₄⁻ ion is square planar, whereas the shape of the BF₄⁻ ion is tetrahedral.

(d) Ammonia, NH₃, is very soluble in water, whereas phosphine, PH₃, is only moderately soluble in water.
2. Answer the following questions about a pure compound that contains only carbon, hydrogen, and oxygen.

(a) A 0.7549 g sample of the compound burns in \( \text{O}_2(g) \) to produce 1.9061 g of \( \text{CO}_2(g) \) and 0.3370 g of \( \text{H}_2\text{O}(g) \).

(i) Calculate the individual masses of C, H, and O in the 0.7549 g sample.

(ii) Determine the empirical formula for the compound.

(b) A 0.5246 g sample of the compound was dissolved in 10.0012 g of lauric acid, and it was determined that the freezing point of the lauric acid was lowered by 1.68°C. The value of \( K_f \) of lauric acid is 3.90°C m\(^{-1}\). Assume that the compound does not dissociate in lauric acid.

(i) Calculate the molality of the compound dissolved in the lauric acid.

(ii) Calculate the molar mass of the compound from the information provided.

(c) Without doing any calculations, explain how to determine the molecular formula of the compound based on the answers to parts (a)(ii) and (b)(ii).

(d) Further tests indicate that a 0.10 \( M \) aqueous solution of the compound has a pH of 2.6. Identify the organic functional group that accounts for this pH.