1. (10 points) Consider the phase diagram for iodine shown here and answer each of the following questions.
   a. What is the normal boiling point for iodine? 184.4 °C
   b. What is mp for iodine at 1 atm? 113.6 °C
   c. What state is present at rt and normal atmospheric pressure? solid
   d. What state is present at 186 °C and 1.0 atm? gas
   e. If a dynamic equilibrium is established between the solid and liquid phases, name a change you can make to increase the amount of liquid.
      Increase the temperature

2. (16 points) SHOW ALL WORK. Which of the following molecules are polar? IF₅ Polar

   IF₅

   BH₃ Nonpolar

   BH₃
PF$_5$  Nonpolar

SBr$_2$  Polar

ClO$_4^-$  Nonpolar

O$_2^2-$  Nonpolar

IF$_4^-$  Nonpolar

TeF$_4$  Polar
3. (18 points) **SHOW ALL WORK.** Benzene has a heat of vaporization of 30.72 kJ/mol and a normal bp of 80.1 °C. At what temperature does benzene boil when the external pressure is 445 torr?

Clausius-Claperon: \[ \ln \frac{P_2}{P_1} = -\frac{\Delta H_{\text{vap}}}{R} \left( \frac{1}{T_2} - \frac{1}{T_1} \right) \]

Let; \( P_2 = 760 \text{ torr} \), \( T_2 = 353.25 \text{K} \), \( P_1 = 445 \text{ torr} \), \( T_1 = x \)

\[
\ln 760 \text{ torr} = -30720 \text{ J/mol} \times \left( \frac{1}{353.25} - \frac{1}{x} \right) \times \frac{1}{445 \text{ torr}} \times 8.314 \text{ J/mol K}
\]

\[
\ln(1.7078) = (-3694.97)(1/353.25 - 1/x)
\]

\[
0.53521 = (-3694.97) \left( \frac{1}{353.25} - \frac{1}{x} \right)
\]

\[-0.0001448 = 1/353.25 - 1/x = 0.00283085 - 1/x
\]

\[0.00297565 = 1/x \]

\[x = T_2 = 336.1 \text{ K} = -62.9 \text{ °C} \]

4. (12 points) For each of the following pairs, decide which has the greater bond angle, or if they are equal, and *defend your answer*: [note; no credit without an explanation]

a) \( \text{NO}_2^- \) or \( \text{NO}_3^- \)

\[
\begin{array}{c}
\text{N} \\
\text{O} \\
\text{O} \\
\end{array} 
\]

angle <120° due to lone pair

\[
\begin{array}{c}
\Theta \\
\text{N} \\
\text{O} \\
\end{array} 
\]

\[
\begin{array}{c}
\Theta \\
\text{O} \\
\text{O} \\
\end{array} 
\]
angle = 120° due to resonance all are equivalent
=> larger bond angle

b) NO₂ or NO₂⁺

\[
\begin{array}{c}
\text{O} \\
\text{N} \\
\text{O}
\end{array}
\]

angle ~120°

\[
\begin{array}{c}
\text{O} \\
\text{N} \\
\text{O}
\end{array}
\]

angle = 180°

=> larger bond angle

5. (5 points) When a thin glass tube is put into water, the water rises 1.4 cm. When the same tube is put into hexane, the hexane rises only 0.4 cm. Explain the difference.

Water can generate strong adhesive interactions with the glass (due to the dipoles at the surface of the glass), but hexane is nonpolar and cannot interact strongly with the glass surface.

6. (12 points) For the following organic molecule, give the valence bond description of the bonding. For the sketch, show only one example of each type of bond. (e.g. in H₂O only draw one O-H bond)

<table>
<thead>
<tr>
<th>Formula</th>
<th>EG at central atom</th>
<th>Hybridization at central atom</th>
<th>Draw the orbital interaction(s)</th>
<th>Is bond σ or π?</th>
</tr>
</thead>
<tbody>
<tr>
<td>NF₃</td>
<td>4</td>
<td>sp³</td>
<td><img src="image" alt="NF3_image" /></td>
<td>σ</td>
</tr>
<tr>
<td>ClO₄⁻</td>
<td>6</td>
<td>sp³d²</td>
<td><img src="image" alt="ClO4_image" /></td>
<td>σ</td>
</tr>
</tbody>
</table>

![ClO4_image](image)
7. (12 points) a) Label the strongest type of intermolecular attraction for each material, then b) explain the melting point data in terms of molecular attractive forces.

<table>
<thead>
<tr>
<th>mp</th>
<th>Strongest intermolecular attractive force</th>
</tr>
</thead>
<tbody>
<tr>
<td>F₂</td>
<td>-220 °C London Dispersion Force</td>
</tr>
<tr>
<td>PH₃</td>
<td>-133 °C Dipole-dipole</td>
</tr>
<tr>
<td>HBr</td>
<td>-87 °C Dipole-dipole</td>
</tr>
<tr>
<td>CH₃OH</td>
<td>98 °C H-bonding</td>
</tr>
</tbody>
</table>

b) Explain:
As the strength of the intermolecular force increases, the melting point increases. Also, between HBr and PH₃, HBr has a larger dipole moment and so its dipole-dipole interactions are stronger. MP increases with stronger forces because it takes more energy to break apart strong forces.

8. (14 points) **SHOW ALL WORK.** According to MO theory, which has the highest bond order, bond energy, and shortest bond length? O₂, O₂⁻, or O₂⁺? Include an MO diagram in your answer.

![MO diagram](image-url)
Bond Order = $\frac{1}{2} \left[ \# \text{ bonded } e^- - \# \text{ antibonded } e^- \right]$

$O_2 = \frac{1}{2} \left[ 8 - 4 \right] = 2$

$O_2^- = \frac{1}{2} \left[ 8 - 5 \right] = 1.5$

$O_2^+ = \frac{1}{2} \left[ 8 - 3 \right] = 2.5$
Bond Length: $O_2^- > O_2 > O_2^+$

Bond Energy: $O_2^+ > O_2 > O_2^-$

9. (6 points) In each blank write $>$, $<$ or $=$ as appropriate.

<table>
<thead>
<tr>
<th>Strength of intermolecular forces in $H_2O$</th>
<th>$&lt;$</th>
<th>Strength of intramolecular forces in $CH_3OH$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity of $CH_4$</td>
<td>$&lt;$</td>
<td>Viscosity of $CH_3Cl$</td>
</tr>
<tr>
<td>bp of $CO_2$</td>
<td>$&lt;$</td>
<td>bp of $NO_2$</td>
</tr>
</tbody>
</table>

10. (12 points) Briefly define the following terms.

axial (in VSEPR theory) – Location of atoms that are above & below the equatorial plane in a trigonal bipyramidal structure (labeled as $a$ in pic)

$\sigma$ bond – head-to-head overlap along the bond axis with zero nodes along the bonding axis

triple point – $T$ and $P$ where all 3 phases coexist in equilibrium

11. (18 points) SHOW ALL WORK. The vapor pressure of $CCl_3F$ at 300 K is 856 torr. If 12.6 g of $CCl_3F$ is enclosed in a 1.0-L container, will any liquid be present? If so, what mass of liquid?

$856 \text{ torr} \times 1 \text{ atm} = 1.1263 \text{ atm}$

$\frac{760 \text{ torr}}{}$

$n = \frac{PV}{RT} = \frac{1.12632 \text{ atm} \times 1.0 \text{ L}}{0.008206 \text{ L} \cdot \text{atm} \times 300 \text{ K}} = 0.04575 \text{ mol}$

$0.04575 \text{ mol} \times 137.36 \text{ g} = 6.2845 \text{ g}$

$12.6 \text{ g} - 6.2845 \text{ g} = 6.3 \text{ g}$
**yes** liquid will be present

**12. (15 points) SHOW ALL WORK.** Given 400.0 g of hot tea at 80.0 °C, what mass of ice at 0 °C must be added to obtain iced tea at 10.0 °C? For tea, $C_s = 4.184 \text{ J/g} \cdot ^\circ \text{C}$ and $\Delta H_{\text{fus}}$ for ice is 6.01 kJ/mol. [note; to simplify, ignore the contribution of the melted ice warming to 10 °C.]

$q = m \cdot C_s \cdot \Delta T$

$q = (400.0 \text{ g})(4.184 \text{ J/g} \cdot ^\circ \text{C})(70.0 ^\circ \text{C}) = 117152 \text{ J needed}$

$$\frac{117152 \text{ J} \times 1 \text{ mol}}{6010 \text{ J}} = 19.49 \text{ mol ice} \times 18.015 \text{ g/mol} = \boxed{351 \text{ g}}$$
1. (10 points) Consider the phase diagram for substance A shown here and answer each of the following questions.
   a. What is the normal boiling point for A? 72°C
   b. What is mp for A at 1 atm? 28°C
   c. What state is present at rt and normal atmospheric pressure? solid
   d. What state is present at 75 °C and 1.0 atm? gas
   e. If a dynamic equilibrium is established between the solid and liquid phases, name a change you can make to increase the amount of solid. Decrease the temperature

2. (16 points) SHOW ALL WORK. Which of the following molecules are polar?
   ClO4⁻ Polar
   CO₂ Nonpolar

---

All equations must be balanced and show phases for full credit. Significant figures count, and box your answers!
PCl$_3$F$_2$  Nonpolar

NF$_3$  Polar

NO$_3^-$  Nonpolar

NO$^-$  Polar

AsCl$_4^+$  Nonpolar

ICl$_3$  Polar
3. (18 points) **SHOW ALL WORK.** Nitrogen has a heat of vaporization of 5.92 kJ/mol and a normal bp of -196 °C. At what temperature does nitrogen boil when the external pressure is 1028 torr?

Clausius-Claperon: \( \ln \frac{P_2}{P_1} = -\frac{\Delta H_{vap}}{R} \left( \frac{1}{T_2} - \frac{1}{T_1} \right) \)

Let; \( P_2 = 1028 \text{ torr}, T_2 = x, P_1 = 760 \text{ torr}, T_1 = 77 \text{ K} \)

\[
\ln \frac{1028 \text{ torr}}{760 \text{ torr}} = -\frac{5920 \text{ J/mol}}{8.314 \text{ J/mol K}} \left( \frac{1}{x} - \frac{1}{77} \right) = \ln(1.3526) = (-712.05) \left( \frac{1}{x} - \frac{1}{77} \right)
\]

0.030295 = - (712.05) \left( \frac{1}{x} - \frac{1}{77} \right)

-0.000424199 = 1/x - 1/77 = 1/x - 0.012961

0.012537 = 1/x

\( x = T_2 = 80 \text{ K} = -193 \text{ °C} \)

4. (12 points) For each of the following pairs, decide which has the greater bond angle, or if they are equal, and *defend your answer*: [note; no credit without an explanation]

a) ClO\(_4^-\) or ClO\(_3^-\)

angle = 109.5°

=> Larger Bond Angle
angle = <109.5°

b) NO₂ or NO₂⁻

angle ~120°
=> Larger Bond Angle; larger angle because the single e⁻ repels less than a pair of e⁻

5. (5 points) When a thin glass tube is put into water, the water rises 1.4 cm. When the same tube is put into hexane, the hexane rises only 0.4 cm. Explain the difference. Water can generate strong adhesive interactions with the glass (due to the dipoles at the surface of the glass), but hexane is nonpolar and cannot interact strongly with the glass surface.

6. (12 points) For the following organic molecule, give the valence bond description of the bonding. For the sketch, show only one example of each type of bond. (e.g. in H₂O only draw one O-H bond)

<table>
<thead>
<tr>
<th>Formula</th>
<th>EG at central atom</th>
<th>Hybridization at central atom</th>
<th>Draw the orbital interaction(s)</th>
<th>Is bond σ or π?</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCl₄</td>
<td>4</td>
<td>sp³</td>
<td>C—Cl</td>
<td>σ</td>
</tr>
</tbody>
</table>

12
7. (12 points) a) Label the strongest type of intermolecular attraction for each material, then b) explain the melting point data in terms of molecular attractive forces.

a)

<table>
<thead>
<tr>
<th>Material</th>
<th>mp</th>
<th>Strongest intermolecular attractive force</th>
</tr>
</thead>
<tbody>
<tr>
<td>He</td>
<td>-272 °C</td>
<td>London Dispersion Force</td>
</tr>
<tr>
<td>Kr</td>
<td>-157 °C</td>
<td>London Dispersion Force</td>
</tr>
<tr>
<td>H₂Te</td>
<td>-49 °C</td>
<td>Dipole-dipole</td>
</tr>
<tr>
<td>MgF₂</td>
<td>1261 °C</td>
<td>Ion-ion (ionic bonds)</td>
</tr>
</tbody>
</table>

b) Explain:
As the strength of the intermolecular forces increase, the mp increases. Also, the LDF of Kr is greater than that of He due to its larger size, which is why Kr has the higher melting point.

mp increases with stronger forces because it takes more energy to break apart strong forces.

8. (14 points) **SHOW ALL WORK.** According to MO theory, which has the highest bond order, bond energy, and shortest bond length? C₂, C₂⁺, C₂⁻? Include an MO diagram in your answer.
$\text{C}_2$

$\text{C}_2^+$
Bond Order = $\frac{1}{2} \left[ \text{# bonded } e^- - \text{# antibonded } e^- \right]$

$C_2 = \frac{1}{2} [6-2] = 2$

$C_2^+ = \frac{1}{2} [5-2] = 1.5$

$C_2^- = \frac{1}{2} [7-2] = 2.5$

Bond Length: $C_2^+ > C_2 > C_2^-$

Bond Energy: $C_2^- > C_2 > C_2^+$

9. (6 points) In each blank write $>$, $<$ or $=$ as appropriate.

<table>
<thead>
<tr>
<th>Strength of intermolecular forces in MgCl$_2$</th>
<th>=</th>
<th>Strength of intramolecular forces in MgCl$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity of CH$_3$OH</td>
<td>$&gt;$</td>
<td>Viscosity of H$_2$CO</td>
</tr>
<tr>
<td>bp of CS$_2$</td>
<td>$&gt;$</td>
<td>bp of CO$_2$</td>
</tr>
</tbody>
</table>

10. (12 points) **Briefly** define the following terms.

**equatorial (in VSEPR theory)** – In the tbp shape, the three terminal positions that are coplanar and at 120° angles from each other. (labeled e in the pic)
π bond – "side-to-side" overlap of p orbitals

deposition – phase change from gas to solid

11. (18 points) SHOW ALL WORK. The vapor pressure of CCl₃F at 300 K is 856 torr. If 11.5 g of CCl₃F is enclosed in a 1.0-L container, will any liquid be present? If so, what mass of liquid?

\[
\text{856 torr} \times \frac{1 \text{ atm}}{760 \text{ torr}} = 1.1263 \text{ atm}
\]

\[
n = \frac{PV}{RT} = \frac{1.1263 \text{ atm} \times 1.0 \text{ L}}{0.008206 \text{ L} \cdot \text{atm} \times 300 \text{ K}} = 0.04575 \text{ mol}
\]

\[
0.04575 \text{ mol} \times 137.36 \text{ g} = 6.2845 \text{ g}; \text{ so } 11.5 \text{ g} - 6.2845 \text{ g} = 5.2 \text{ g}
\]

\text{yes; liquid will be present}

12. (15 points) SHOW ALL WORK. Given 425.0 g of hot tea at 78.0 °C, what mass of ice at 0 °C must be added to obtain iced tea at 15.0 °C? For tea, \(C_s = 4.184 \text{ J/g} \cdot ^\circ \text{C}\) and \(\Delta H_{\text{fus}}\) for ice is 6.01 kJ/mol. [note; to simplify, ignore the contribution of the melted ice warming to 15 °C.]

\[
q = m \cdot C_s \cdot \Delta T
\]

\[
q = (425.0 \text{ g})(4.184 \text{ J/g} \cdot ^\circ \text{C})(63.0 ^\circ \text{C}) = 112026 \text{ J needed}
\]

\[
\frac{112036 \text{ J} \times \text{mol}}{6010 \text{ J}} = 18.64 \text{ mol ice} \times 18.015 \text{ g/mol} = 336 \text{ g}
\]
All equations must be balanced and show phases for full credit. Significant figures count, and box your answers!

1. (10 points) Consider the phase diagram for substance X shown here and answer each of the following questions.
   a. What is the normal boiling point for X? 211 °C
   b. What is mp for X at 1 atm? 121 °C
   c. What state is present at rt and normal atmospheric pressure? solid
   d. What state is present at 213 °C and 1.0 atm? gas
   e. If a dynamic equilibrium is established between the solid and liquid phases, name a change you can make to increase the amount of liquid. Increase the temperature

2. (16 points) SHOW ALL WORK. Which of the following molecules are polar? SOF₄ polar
   XeO₃ Polar
CCl$_4$ Nonpolar

ClO$_3^-$ Polar

BrO$^-$ Polar

PCl$_4^+$ Nonpolar

SO$_3^{2-}$ Polar

SO$_4^{2-}$ Nonpolar
3. (18 points) **SHOW ALL WORK.** Ammonia has a heat of vaporization of 24.7 kJ/mol and a normal bp of -33.3 °C. At what temperature does ammonia boil when the external pressure is 456 torr?

Clausius-Clapeyron: \[
\ln \frac{P_1}{P_2} = \frac{-\Delta H_{vap}}{R} \left( \frac{1}{T_1} - \frac{1}{T_2} \right)
\]

Let; \(P_1=760 \text{ torr}, T_1=239.85 \text{ K}, P_2 = 456 \text{ torr}, T_2 = x \text{ K}\)

\[
\ln \frac{760 \text{ torr}}{456 \text{ torr}} = \frac{-24700 \text{ J/mol}}{8.314 \text{ J/mol K}} \left( \frac{1}{239.85} - \frac{1}{x} \right)
\]

\[
\ln(1.6667) = (-2970.892) \left( \frac{1}{239.85} - \frac{1}{x} \right)
\]

\[
0.510826 = (-2970.892) \left( \frac{1}{239.85} - \frac{1}{x} \right)
\]

\[
-0.000171943 = 1/239.85 - 1/x = 0.004169272 - 1/x
\]

\[
0.00434125 = 1/x
\]

\[
T_2 = 230.4 \text{ K} = -42.8 \degree \text{C}
\]

4. (12 points) For each of the following pairs, decide which has the greater bond angle, or if they are equal, and **defend your answer:** [note; no credit without an explanation]

a) NO₂⁻ or NO₂⁺

Angle <120°

b) NO₃⁻ or ClO₃⁻
angle = 120°
=> Larger bond angle

angle = <109.5°

5. (5 points) When a thin glass tube is put into water, the water rises 1.4 cm. When the same tube is put into hexane, the hexane rises only 0.4 cm. Explain the difference. Water can generate strong adhesive interactions with the glass (due to the dipoles at the surface of the glass), but hexane is nonpolar and cannot interact strongly with the glass surface.

6. (12 points) For the following organic molecule, give the valence bond description of the bonding. For the sketch, show only one example of each type of bond. (e.g. in H₂O only draw one O-H bond)

<table>
<thead>
<tr>
<th>Formula</th>
<th>EG at central atom</th>
<th>Hybridization at central atom</th>
<th>Draw the orbital interaction(s)</th>
<th>Is bond σ or π?</th>
</tr>
</thead>
<tbody>
<tr>
<td>SBr₂</td>
<td>4</td>
<td>sp³</td>
<td><img src="image" alt="S-Br bond" /></td>
<td>σ</td>
</tr>
<tr>
<td>IF₅</td>
<td>6</td>
<td>sp²d²</td>
<td><img src="image" alt="I-F bond" /></td>
<td>σ</td>
</tr>
</tbody>
</table>

7. (12 points) a) Label the strongest type of intermolecular attraction for each material, then b) explain the melting point data in terms of molecular attractive forces.

a)
<table>
<thead>
<tr>
<th></th>
<th>mp</th>
<th>Strongest intermolecular attractive force</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiH₄</td>
<td>-185 °C</td>
<td>London Dispersion Force</td>
</tr>
<tr>
<td>Kr</td>
<td>-157 °C</td>
<td>London Dispersion Force</td>
</tr>
<tr>
<td>HBr</td>
<td>-87 °C</td>
<td>Dipole-dipole</td>
</tr>
<tr>
<td>NCl₃</td>
<td>-40 °C</td>
<td>Dipole-dipole</td>
</tr>
</tbody>
</table>

b) Explain: dipole-dipole > London Dispersion Force
The dipole-dipole in NCl₃ is greater than that of HBr due to NCl₃ being larger than HBr, which is why it has the higher mp. Also, the LDF in Kr is greater than that of SiH₄ due to Kr being larger than SiH₄, which is why it has the higher mp.

mp increases with stronger forces because it takes more energy to break apart strong forces.

8. (14 points) **SHOW ALL WORK.** According to MO theory, which has the highest bond order, bond energy, and shortest bond length? N₂, N₂⁻, or N₂⁺? Include an MO diagram in your answer.

![MO diagram for N₂](image)
Bond Order = \( \frac{1}{2} \) [# bonded e\(^-\) - # antibonded e\(^-\)]
N\(_2\) = \( \frac{1}{2} \) [8-2] = 3
N\(_2^+\) = \( \frac{1}{2} \) [8-3] = 2.5
\[ \text{N}_2^- = \frac{1}{2} [7-2] = 2.5 \]

Bond Length: \( \text{N}_2^+ = \text{N}_2^- > \text{N}_2 \)

Bond Energy: \( \text{N}_2 > \text{N}_2^+ = \text{N}_2^- \)

9. (6 points) In each blank write >, < or = as appropriate.

<table>
<thead>
<tr>
<th>Strength of intermolecular forces in ( \text{CH}_4 )</th>
<th>&lt;</th>
<th>Strength of intramolecular forces in ( \text{CH}_3\text{OH} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity of ( \text{CH}_3\text{CH}_2\text{CH}_2\text{OH} )</td>
<td>&gt;</td>
<td>Viscosity of ( \text{CH}_3\text{OH} )</td>
</tr>
<tr>
<td>bp of ( \text{NH}_3 )</td>
<td>&gt;</td>
<td>bp of ( \text{CH}_4 )</td>
</tr>
</tbody>
</table>

10. (12 points) Briefly define the following terms.

hybridization – In valence bond theory, combination of 2 or more atomic orbitals on the same atom to form a new set of “Hybrid Atomic Orbitals” used in bonding.

antibonding orbital – In molecular orbital theory, an orbital overlap resulting in destructive interference where energy increases as atoms are brought closer together, indicating a net repulsion rather than a net attraction.

critical point – T and P upper limits on the liquid-gas curve of a phase diagram

11. (18 points) SHOW ALL WORK. The vapor pressure of \( \text{CCl}_3\text{F} \) at 300 K is 856 torr. If 12.2 g of \( \text{CCl}_3\text{F} \) is enclosed in a 1.0-L container, will any liquid be present? If so, what mass of liquid?

\[
856 \text{ torr} \times \frac{1 \text{ atm}}{760 \text{ torr}} = 1.1263 \text{ atm}
\]

\[
n = \frac{PV}{RT} = \frac{1.12632 \text{ atm} \times 1.0 \text{ L}}{0.008206 \text{ L} \cdot \text{atm} \times 300 \text{ K}} = 0.04575 \text{ mol}
\]

\[
0.04575 \text{ mol} \times 137.36 \text{ g} = 6.2845 \text{ g}; \text{ so } 12.2 - 6.2845 = 5.9 \text{ g}
\]

\[\text{yes; liquid will be present}\]
12. (15 points) SHOW ALL WORK. Given 450.0 g of hot tea at 75.0 °C, what mass of ice at 0 °C must be added to obtain iced tea at 15.0 °C? For tea, \( C_s = 4.184 \text{ J/g°C} \) and \( \Delta H_{fus} \) for ice is 6.01 kJ/mol. [note; to simplify, ignore the contribution of the melted ice warming to 15 °C.]

\[
q = m \cdot C_s \cdot \Delta T
\]

\[
q = (450.0 \text{ g})(4.184 \text{ J/g°C})(60.0 \text{ °C}) = 122968 \text{ J needed}
\]

\[
\frac{122968 \text{ J}}{6010 \text{ J/mol}} \times \text{ mol} = 20.46 \text{ mol ice} \times 18.015 \text{ g/mol} = \boxed{339 \text{ g}}
\]