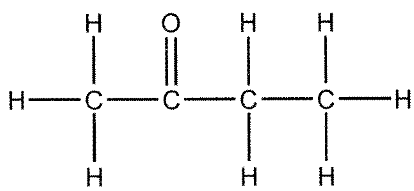
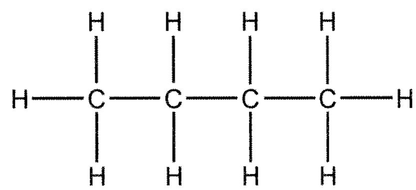
NMSI SUPER PROBLEM

Answer the following questions using your knowledge of intermolecular forces and molecular structure. Your response must include specific information about all substances in each question.

A. The structures for butanone, $CH_3COCH_2CH_3$, and *n*-butane, $CH_3CH_2CH_2CH_3$, are shown below.





Identify the type of intermolecular forces in

(i) Butanone

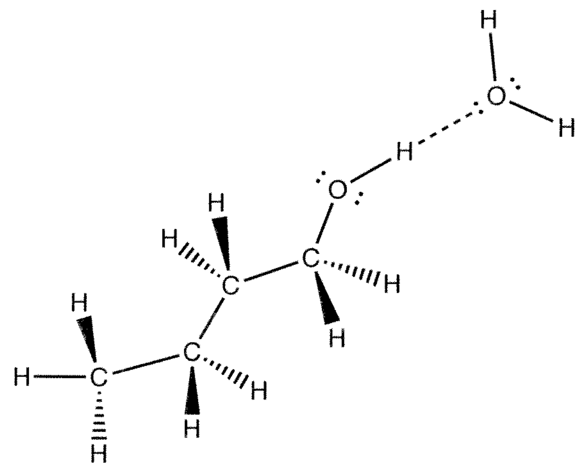
(ii) *n*-butane

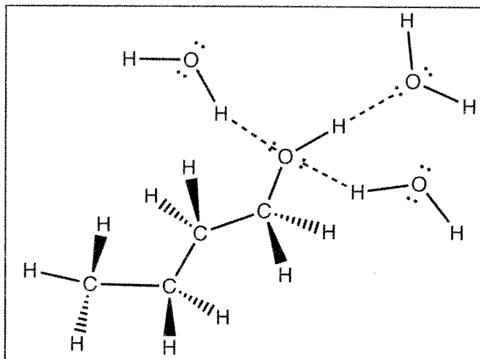
Molecules of butanone are polar due to the dipole moment created by the unequal distribution of electron density, therefore these molecules exhibit dipole-dipole forces as well as London dispersion forces. Molecules of butane are non-polar (they have a symmetrical distribution of electron density) therefore exhibit only London dispersion forces.	**1 point** for identifying dipole-dipole forces in butanone. **1 point** for identifying London dispersion forces in butane.

B. Butanone is much more soluble in H_2O than is *n*-butane. Account for this difference.

Butanone is polar and thus is capable of forming dipole-dipole intermolecular interactions with the polar water molecules. That type of strong interaction does not exist between non-polar butane molecules and water, thus butane is not very soluble in water.	**1 point** for indicating that the solubility of butanone depends on similar intermolecular interactions with those of water and that butane is different. **1 point** for stating that butanone dissolves in water because it can form dipole-dipole interactions with the water molecules and butane cannot.

C. The substance *n*-butanol ($CH_3CH_2CH_2CH_2OH$) is shown below forming a hydrogen bond with a water molecule, as represented with a dashed line. There are 2 more locations where a water molecule would hydrogen bond with *n*-butanol. Draw both water molecules in their correct orientation where they would hydrogen bond with the *n*-butanol molecule.



	**1 point** for *each* of the two water molecules forming a hydrogen bond with the oxygen on *n*-butanol. The hydrogen atom on water must be aligned to the oxygen on the *n*-butanol.

D. Predict whether the enthalpy of vaporization, ΔH°_{vap}, for *n*-butanol will be greater than 32.2 kJ mol^{-1}; less than 21.0 kJ mol^{-1}; or between 21.0 kJ mol^{-1} and 32.2 kJ mol^{-1}. Explain

Substance	ΔH°_{vap} (kJ mol^{-1})
n-butane ($CH_3CH_2CH_2CH_3$)	21.0
Butanone ($CH_3COCH_2CH_3$)	32.2
n-butanol ($CH_3CH_2CH_2CH_2OH$)	?

Butanone exhibits dipole-dipole forces, *n*-butane exhibits only London dispersion forces, and *n*-butanol molecules are polar and exhibit hydrogen binding forces. In similar sized molecules the hydrogen binding forces are stronger than either dipole-dipole or London dispersion forces, the ΔH°_{vap}, for *n*-butanol will be greater than that of butanone, or greater than 32.2 kJ mol^{-1}.	**1 point** for predicting that the ΔH°_{vap}, for *n*-butanol will be greater than 32.2 kJ mol^{-1}, with a correct explanation about the strengths of the intermolecular forces.

E. Consider the three chloride compounds and the information in the table below.

Substance	Melting Point
PCl_3	– 93.9°C
KCl	776°C
NaCl	801°C

Account for the difference in melting points.

PCl_3 is polar and its molecules are attracted to one another with dipole-dipole forces. KCl is ionic and is held together with electrostatic forces (ionic bonds). NaCl is ionic and is held together with electrostatic forces (ionic bonds). Ionic bonds are stronger than dipole-dipole interactions, thus it takes more energy to overcome these forces; therefore NaCl and KCl melt at a much higher temperature than does PCl_3. Coulomb's Law explains the difference in the melting points of NaCl and KCl. The charges on the ions are the same in both compounds, but the Na^+ ion has a smaller radius than the K^+ ion, which makes the lattice energy of NaCl greater than that of KCl. This means more energy is required to overcome the forces in NaCl than in KCl; thus NaCl will have a higher melting point.	**1 point** for indicating that NaCl and KCl are held together with ionic bonds and that PCl_3 has dipole-dipole forces **1 point** for stating that ionic bonds are stronger than dipole-dipole interactgions and require more energy to overcome them. **1 point** for indicating that NaCl has a greater lattice energy than KCl because the sodium ions are smaller and more attracted to the chloride ions than are the potassium ions.

The table below provides information about three of the noble gases.

Substance	Boiling Point (K)	Solubility in Water ($cm^3\ kg^{-1}$)
Ne	27.3	10.5
Ar	?	?
Xe	166.6	108.1

F. Neon has a much lower boiling point than xenon. Explain.

Noble gases exhibit only London dispersion forces. Ne has fewer electrons than does Xe; the fewer the electrons the less polarizable the cloud, the weaker the attractive forces, the lower the boiling point.	**1 point** for identifying that both Ne and Xe have London dispersion forces. **1 point** for stating that Ne's electron cloud is less polarizable and therefore its attractive forces are less than Xe.

G. Xenon is much more soluble in water than neon. Explain

They both have only London forces whereas water has hydrogen binding forces. The more polarizable the cloud the better the substance can interact with water's attractive forces, the more soluble the substance. Xe has more electrons and its electron cloud is more polarizable than neon thus it is more soluble.	**1 point** for Xe has greater attractive forces than Ne. **1 point** for stating that the greater the attractive forces the greater the interaction with (and thus the solubility in) water.

H. Would argon's solubility in water be greater than or less than that of xenon?

Less than Xenon They both have only London forces whereas water has hydrogen binding forces. The more polarizable the cloud the better the substance can interact with water's attractive forces, the more soluble the substance. Argon has an electron cloud that is less polarizable than Xe so it will be less soluble in water.	**1 point** for less than Xenon **1 point** for stating that the greater the attractive forces the greater the interaction with (and thus the solubility in) water.

I. Give samples of liquid argon and liquid xenon – in separate, identical, closed containers at the same temperature – which would have the greatest vapor pressure?

Argon They both have only London forces but Argon has an electron cloud that is less polarizable than xenon. The less polarizable the cloud the easier it is for the molecules to enter the vapor phase. The more molecules in the vapor phase the greater the vapor pressure.	**1 point** for Argon **1 point** for stating that the lesser the attractive forces the easier it will vaporize and thus the higher the vapor pressure.

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4 Points

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, F_2 is a gas, whereas I_2 is a solid.

Both F_2 and I_2 are nonpolar, so the only intermolecular attractive forces are London dispersion forces. I_2 is solid because the electrons in the I_2 molecule occupy a larger volume and are more polarizable compared to the electrons in the F_2 molecule. As a result, the dispersion forces are considerably stronger in I_2 compared to F_2.	1 point for indicating that both molecules have dispersion forces as IMFs 1 point for indicating that I_2 molecules are more polarizable than F_2 molecules

(b) Ammonia, NH_3, is very soluble in water, whereas phosphine, PH_3, is only moderately soluble in water.

Ammonia has hydrogen-bonding intermolecular forces, whereas phosphine has dipole-dipole and/or dispersion intermolecular forces. Water also has hydrogen-bonding intermolecular attractive forces. Ammonia is more soluble in water than phosphine because ammonia molecules can hydrogen-bond with water molecules, whereas phosphine molecules cannot hydrogen-bond with water molecules.	1 point for indicating that NH_3 can form hydrogen bonds but PH_3 cannot 1 point for indicating that NH_3 can form hydrogen bonds with water, but PH_3 cannot

(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) NH_3 has hydrogen bonding between molecules (***or*** dipole-dipole interactions between molecules), and CH_4 has London dispersion forces. The intermolecular forces in NH_3 are stronger than those in CH_4. — ***2 points***

- No credit earned for only a discussion of lone pairs of electrons.
- No credit earned for saying only that NH_3 is polar and CH_4 is nonpolar (with no more discussion).

(b) C_2H_6 and C_6H_{14} both have London dispersion forces. The forces in C_6H_{14} are stronger because the molecule is larger and more polarizable. — ***2 points***

- Credit is earned for other accurate explanations of London dispersion forces.
- No credit is earned for saying only that C_6H_{14} is heavier or has more mass.

(c) Si is a network covalent solid (***or*** a macromolecule) with strong covalent bonds between atoms. 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 Cl_2. — ***2 points***

- 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). — ***2 points***

- 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.

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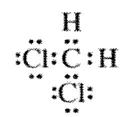
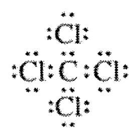
4 Points

Use the information in the following table to answer the questions below.

Name	Lewis Electron-Dot Diagram	Boiling Point (°C)	Vapor Pressure at 20°C (mm Hg)
Dichloromethane		39.6	353
Carbon tetrachloride		76.7	89

(a) Dichloromethane has a greater solubility in water than carbon tetrachloride has. Account for this observation in terms of the intermolecular forces between <u>each</u> of the solutes and water.

CH_2Cl_2 is polar, whereas CCl_4 is not. Therefore, CH_2Cl_2 interacts with H_2O via dipole-dipole forces, while CCl_4 only interacts with water via dipole/induced dipole forces or LDFs, which would be weaker. As a result, CH_2Cl_2 has a greater solubility.	2 points are earned for a rationale that references the types of IMFs between each compound and water.

(b) In terms of intermolecular forces, explain why dichloromethane has a higher vapor pressure than carbon tetrachloride.

Because CH_2Cl_2 has the higher vapor pressure, the combination of LDFs and dipole-dipole forces in CH_2Cl_2 must be weaker than the strong LDFs in CCl_4.	2 points are earned (1 point for referencing the type(s) of IMFs in <u>each</u> of the two compounds).

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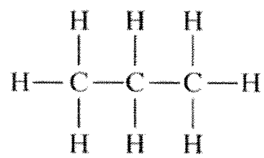
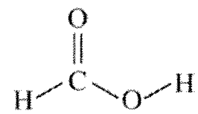
(3 Points)



Propane



Methanoic Acid

(a) The complete structural formulas of propane, C_3H_8, and methanoic acid, HCOOH, are shown above. In the table below, write the type(s) of intermolecular attractive forces(s) that occur in each substance.

Substance	Boiling Point	Intermolecular Attractive Force(s)
Propane	229 K	
Methanoic acid	374 K	

Propane has dispersion forces. Methanoic acid has dispersion forces and hydrogen bonding forces.	One point is earned for IMFs in propane. One point is earned for IMFs in methanoic acid.

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

Hydrogen bonding IMFs among methanoic acid molecules are much stronger than dispersion forces among propane molecules. The stronger the IMFs, the more energy it takes to overcome them. Therefore, methanoic acid has a higher boiling point than propane.	One point is earned for comparing the strengths of the IMFs.