AP Chemistry Unit 6 Problem Sets: IMFs, Liquids, and Solids

Problem Set 1: Intermolecular Forces

1

The following equations describe water boiling vs. water decomposing:

$H_2O\ (l) \Rightarrow H_2O\ (g)$

$2H_2O\ (l) \Rightarrow 2H_2\ (g) + O_2\ (g)$

a)What types of bonds must be broken in each case?

b)Given that water boils at 100°C but decomposes at 3000°C, what does this say about the relative strength of the bonds involved in each case? Explain.

2

Explain why water evaporates at room temperature, even though its boiling point is 100°C.

3

4. Is it possible for the dispersion forces in a particular substance to be stronger than the hydrogen bonding forces in another substance? Explain your answer.

4

35. Identify the most important types of interparticle forces present in the solids of each of the following substances.

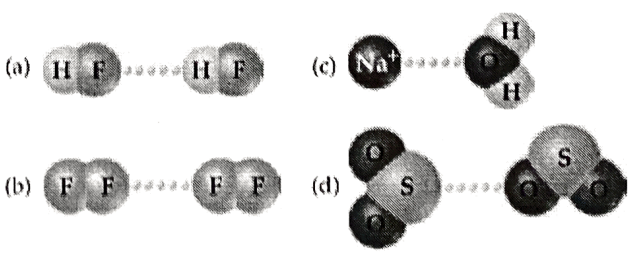
a. Ar
b. HCl
c. HF
d. $CaCl_2$
e. CH_4
f. CO
g. $NaNO_3$

5

11.15 Describe the intermolecular forces that must be overcome to convert each of the following from a liquid or solid to a gas: (a) I_2, (b) CH_3CH_2OH, (c) H_2Se.

6

11.2 **(a)** What kind of intermolecular attractive force is shown in each of the following cases? **(b)** Predict which two interactions are stronger than the other two. [Section 11.2]



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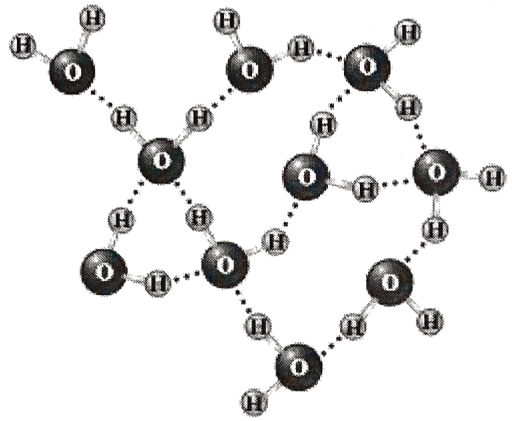
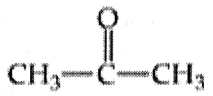
13. In the diagram below, which lines represent the hydrogen bonding?



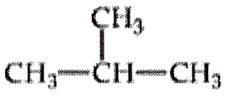
a. the dotted lines between the hydrogen atoms of one water molecule and the oxygen atoms of a different water molecule
b. the solid lines between a hydrogen atom and oxygen atom in the same water molecule
c. Both the solid lines and dotted lines represent hydrogen bonding.
d. There are no hydrogen bonds represented in the diagram.

8

11.16 What type of intermolecular force accounts for the following differences in each case? **(a)** CH_3OH boils at 65 °C, CH_3SH boils at 6 °C. **(b)** Xe is liquid at atmospheric pressure and 120 K, whereas Ar is a gas. **(c)** Kr, atomic weight 84, boils at 120.9 K, whereas Cl_2, molecular weight about 71, boils at 238 K. **(d)** Acetone boils at 56 °C, whereas 2-methylpropane boils at −12 °C.



Acetone



2-Methylpropane

9

11.17 **(a)** What is meant by the term *polarizability*? **(b)** Which of the following atoms would you expect to be most polarizable: N, P, As, Sb? Explain. **(c)** Put the following molecules in order of increasing polarizability: $GeCl_4$, CH_4, $SiCl_4$, SiH_4, and $GeBr_4$. **(d)** Predict the order of boiling points of the substances in part (c).

10

11.18 True or false:

(a) The more polarizable the molecules, the stronger the dispersion forces between them.
(b) The boiling points of the noble gases decrease as you go down the column in the periodic table.
(c) In general, the smaller the molecule, the stronger the dispersion forces.
(d) All other factors being the same, dispersion forces between molecules increase with the number of electrons in the molecules.

11

37. Predict which substance in each of the following pairs would have the greater intermolecular forces.

a. CO_2 or OCS
b. SeO_2 or SO_2
c. $CH_3CH_2CH_2NH_2$ or $H_2NCH_2CH_2NH_2$
d. CH_3CH_3 or H_2CO
e. CH_3OH or H_2CO

12

11.23 **(a)** What atoms must a molecule contain to participate in hydrogen bonding with other molecules of the same kind? **(b)** Which of the following molecules can form hydrogen bonds with other molecules of the same kind: CH_3F, CH_3NH_2, CH_3OH, CH_3Br?

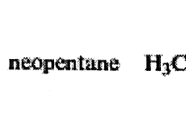
13

11.24 Rationalize the difference in boiling points between the members of the following pairs of substances: **(a)** HF (20 °C) and HCl (−85 °C), **(b)** $CHCl_3$ (61 °C) and $CHBr_3$ (150 °C), **(c)** Br_2 (59 °C) and ICl (97 °C).

14

39. Rationalize the difference in boiling points for each of the following pairs of substances:

a. *n*-pentane $CH_3CH_2CH_2CH_2CH_3$ 36.2°C

neopentane  9.5°C

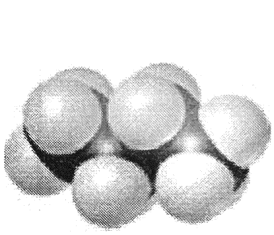
b. HF 20°C
HCl −85°C

c. HCl −85°C
LiCl 1360°C

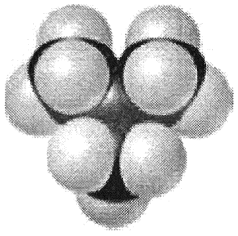
d. *n*-pentane $CH_3CH_2CH_2CH_2CH_3$ 36.2°C
n-hexane $CH_3CH_2CH_2CH_2CH_2CH_3$ 69°C

15

11.21 Butane and 2-methylpropane, whose space-filling models are shown, are both nonpolar and have the same molecular formula, yet butane has the higher boiling point (−0.5 °C compared to −11.7 °C). Explain.



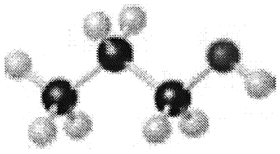
(a) Butane



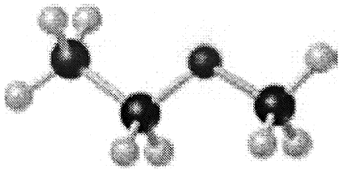
(b) 2-Methylpropane

16

11.5 The following molecules have the same molecular formula (C_3H_8O), yet they have different normal boiling points, as shown. Rationalize the difference in boiling points.



(a) Propanol
97.2 °C



(b) Ethyl methyl ether
10.8 °C

Problem Set 2: Liquids and their Properties

1

17. Use the kinetic molecular theory to explain why a liquid gets cooler as it evaporates from an insulated container.

2

21. How does each of the following affect the rate of evaporation of a liquid in an open dish?

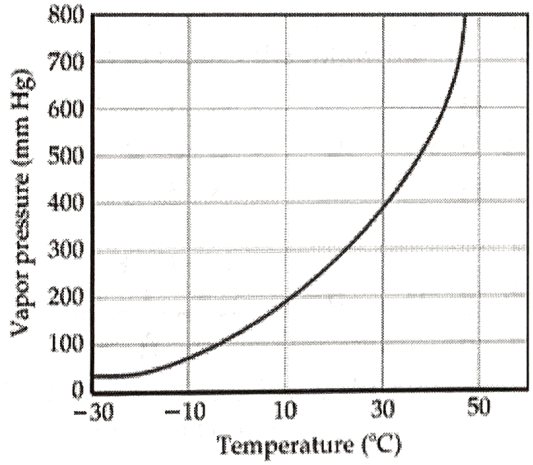
a. intermolecular forces

b. temperature

c. surface area

3

11.4 Using the following graph of CS_2 data, determine **(a)** the approximate vapor pressure of CS_2 at 30 °C, **(b)** the temperature at which the vapor pressure equals 300 torr, **(c)** the normal boiling point of CS_2.



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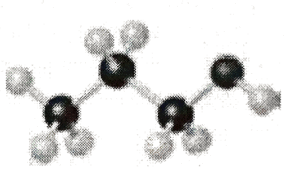
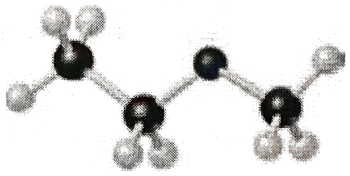
11.5 The following molecules have the same molecular formula (C_3H_8O), yet they have different normal boiling points, as shown. Rationalize the difference in boiling points. [Sections 11.2 and 11.5]



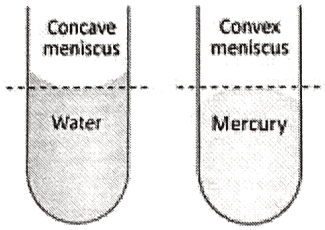
(a) Propanol
97.2 °C



(b) Ethyl methyl ether
10.8 °C

5

The shape of the meniscus of water in a glass tube is different from that in mercury in a glass tube. Why?



6

11.3 The molecular models of glycerol and 1-propanol are given here.

(a) Glycerol

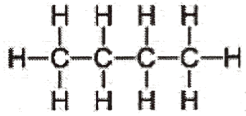
(b) 1-propanol

Do you expect the viscosity of glycerol to be larger or smaller than that of 1-propanol? Explain.

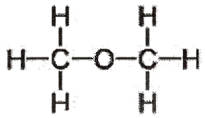
7

List all intermolecular forces present in each liquid, and use them to predict the following:

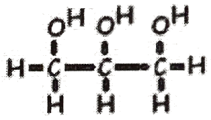
a.



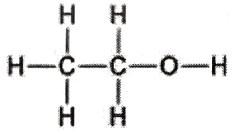
b.



c.



d.



Which substance should have the highest…

i) viscosity ii) boiling point iii)vapor pressure

8

42. In each of the following groups of substances, pick the one that has the given property. Justify each answer.

a. highest boiling point: CCl_4, CF_4, CBr_4

b. lowest freezing point: LiF, F_2, HCl

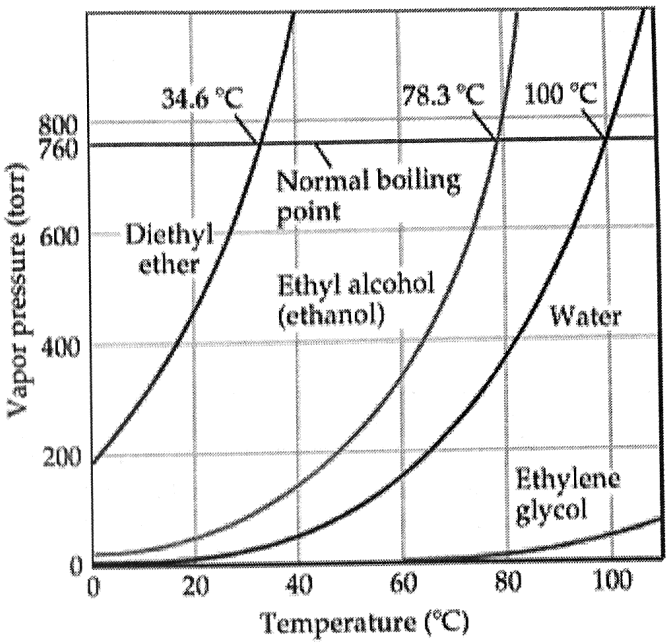
c. smallest vapor pressure at 25°C: CH_3OCH_3, CH_3CH_2OH, $CH_3CH_2CH_3$

d. greatest viscosity: H_2S, HF, H_2O_2

e. greatest heat of vaporization: H_2CO, CH_3CH_3, CH_4

f. smallest enthalpy of fusion: I_2, CsBr, CaO

9	10
11.85 Ethylene glycol [$CH_2(OH)CH_2(OH)$] is the major component of antifreeze. It is a slightly viscous liquid, not very volatile at room temperature, with a boiling point of 198 °C. Pentane (C_5H_{12}), which has about the same molecular weight, is a nonviscous liquid that is highly volatile at room temperature and whose boiling point is 36.1 °C. Explain the differences in the physical properties of the two substances.	**11.49** Using the vapor-pressure curves in Figure 11.24, **(a)** estimate the boiling point of ethanol at an external pressure of 200 torr; **(b)** estimate the external pressure at which ethanol will boil at 60 °C; **(c)** estimate the boiling point of diethyl ether at 400 torr; **(d)** estimate the external pressure at which diethyl ether will boil at 40 °C.



▲ Figure 11.24 **Vapor pressure for four common liquids as a function of temperature.** The temperature at which the vapor pressure is 760 torr is the normal boiling point of each liquid.

Problem Set 3: Solids – Types and Properties

1	2
11.71 What kinds of attractive forces exist between particles in **(a)** molecular crystals, **(b)** covalent-network crystals, **(c)** ionic crystals, **(d)** metallic crystals?	**11.74** Which type (or types) of crystalline solid is characterized by each of the following: **(a)** high mobility of electrons throughout the solid; **(b)** softness, relatively low melting point; **(c)** high melting point and poor electrical conductivity; **(d)** network of covalent bonds; **(e)** charged particles throughout the solid.
3	**4**
11.75 A white substance melts with some decomposition at 730 °C. As a solid, it does not conduct electricity, but it dissolves in water to form a conducting solution. Which type of solid (Table 11.7) might the substance be?	**11.76** You are given a white substance that sublimes at 3000 °C; the solid is a nonconductor of electricity and is insoluble in water. Which type of solid (Table 11.7) might this substance be?
5	**6**
11.72 Indicate the type of crystal (molecular, metallic, covalent-network, or ionic) each of the following would form upon solidification: **(a)** $CaCO_3$, **(b)** Pt, **(c)** ZrO_2 (melting point, 2677 °C), **(d)** table sugar ($C_{12}H_{22}O_{11}$), **(e)** benzene, **(f)** I_2.	**11.78** For each of the following pairs of substances, predict which will have the higher melting point, and indicate why: **(a)** HF, HCl; **(b)** C (graphite), CH_4; **(c)** KCl, Cl_2; **(d)** LiF, MgF_2.

7

63. Explain how doping silicon with either phosphorus or gallium increases the electrical conductivity over that of pure silicon. Specify the type of doping involved (n or p) in each case.

8

82. What type of solid will each of the following substances form?

a. diamond
b. PH_3
c. H_2
d. Mg
e. KCl
f. quartz
g. NH_4NO_3
h. SF_2
i. Ar
j. Cu
k. $C_6H_{12}O_6$

9

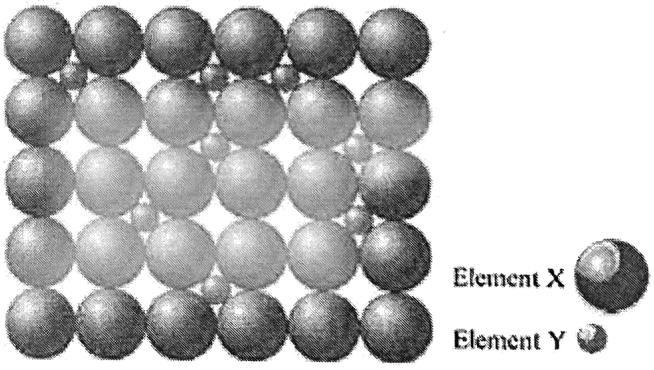
Consider the following data concerning four different substances. SiO_2 B_2H_6 W CsI

Compound	Conducts Electricity as a Solid	Other Properties	Type of Solid
	no	gas at 25°C	
	no	high mp	
	no	aqueous solution conducts electricity	
	yes	high mp	

a) Place each substance formula in the correct box.
b) Label the type of solid in each cased based on the properties (ionic, metallic, molecular, network covalent)

10

An example of an alloy is shown in the diagram below. Compared with the pure metal X, how would you expect the properties of the alloy to vary?



(A) The alloy has higher malleability and higher density.

(B) The alloy has lower malleability and lower density.

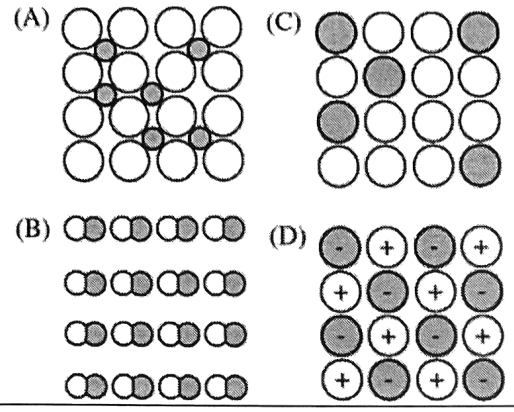
(C) The alloy has higher malleability and lower density

(D) The alloy has lower malleability and higher density.

Explain your choice.

11

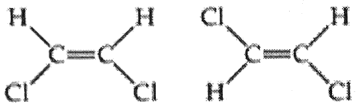
Label each type of solid based on its structure.



Problem Set 4: Additional Exercises

1

11.81 Two isomers of the planar compound 1,2-dichloroethylene are shown here, along with their melting and boiling points.



cis isomer trans isomer

	cis isomer	trans isomer
Melting point (°C)	−80.5	−49.8
Boiling point (°C)	60.3	47.5

(a) Which of the two isomers will have the stronger dipole–dipole forces? Is this prediction borne out by the data presented here? **(b)** Based on the data presented here, which isomer packs more efficiently in the solid phase?

2

A certain compound contains only C, H, and N. Combustion of 0.125 g of this compound produces 0.172 g of H_2O and 0.279 g of CO_2.

a. Calculate the number of moles of CO_2 and H_2O.

b. Find the mass percentages of C, H, and N and the empirical formula of this compound.

c. Assume the empirical formula is also the molecular formula. Draw structural formulas for the four different isomers that are possible for a compound with this formula.

d. The four compounds have boiling points that range from 3 °C to 48 °C. Identify the isomers that you would expect to exhibit the lowest and highest boiling points. Explain your reasoning in terms of the intermolecular forces involved.

AP Chemistry Name.....

States of matter & properties of solutions #4 Hour.....

Directions: Complete the following problems.

1. Which solvent, water or carbon tetrachloride (CCl_4), would you chose to dissolve in each of the following?
   a. KrF_2 b. SF_2 c. SO2 d. CO_2 e. MgF_2 f. CH_2O g. $CH_2{=}CH_2$

2. Explain why NH_3 has a higher solubility in water than BF_3.

3. Explain why CH_3OH is miscible in water whereas $CH_3(CH_2)_6OH$ is not.

4. Potassium bromide is *least* soluble in which of the two liquids from each set below? Briefly explain.
   a. H_2O and CH_4
   b. CH_3OH or CH_3CH_2OH
   c. NH_3 or Br_2

5. The solubility of $MnSO_4{\times}H_2O$ in water at 20°C is 70 g per 100 mL of water.
   a. Is a 1.22 M solution of $MnSO_4{\times}H_2O$ in water at 20°C saturated, supersaturated or unsaturated?
   b. Given a solution of $MnSO_4{\times}H_2O$ of unknown concentration, what experiment could you perform to determine whether the new solution is saturated, supersaturated, or unsaturated?

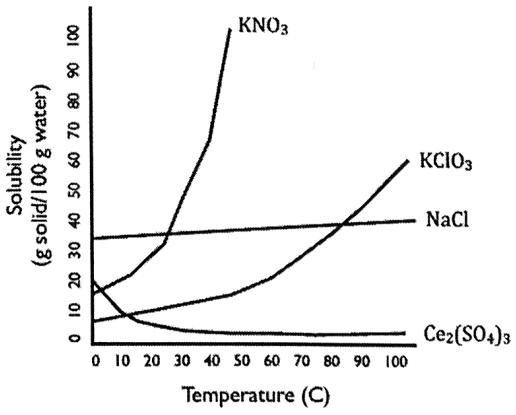
Questions 6-9 refer to the solubility curves shown below. Suppose you have four beakers containing equal volumes of water. You then add one type of salt to each beaker until the solutions become saturated.

6. Which of the four saturated solutions would produce the greatest mass of precipitate when cooled from 90°C to 60°C?

7. The molality of which solution would increase the largest when it is cooled from 20°C to 0°C?

8. Which saturated solution has the highest molality at 40°C?

9. You are given a dry mixture containing 60 g of KNO_3 and 60 g of $KClO_3$ and you are asked to produce as much pure $KClO_3$ as possible. Describe your procedure.



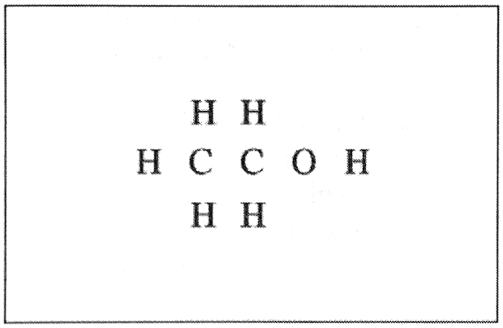
10. (AP) Answer the following questions using principles of molecular structure and intermolecular forces.

Compound	Empirical Formula	Solubility in Water	Boiling Point (°C)
1	C_2H_6O	Slightly soluble	−24
2	C_2H_6O	Soluble	78

Compounds 1 and 2 in the data table above have the same empirical formula, but the have different physical properties.

a. The skeletal structure for one of the two compounds is shown below in Box X.

   i. Complete the Lewis electron-dot diagram of the molecule in Box X. Include any lone (nonbonding) pairs of electrons.



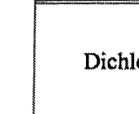
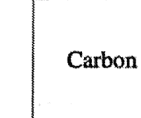
Box X

Box Y

   ii. In Box Y above, draw the complete Lewis electron-dot diagram for the other compound, which is a structural isomer of the compound represented in Box X. Include any lone (nonbonding) pairs of electrons.

b. On the basis of the complete Lewis electron-dot diagrams you drew in part (a) and the information in the data table above, identify which compound, 1 or 2, has the structure represented in Box X. Justify your answer in terms of the intermolecular forces present in each compound.

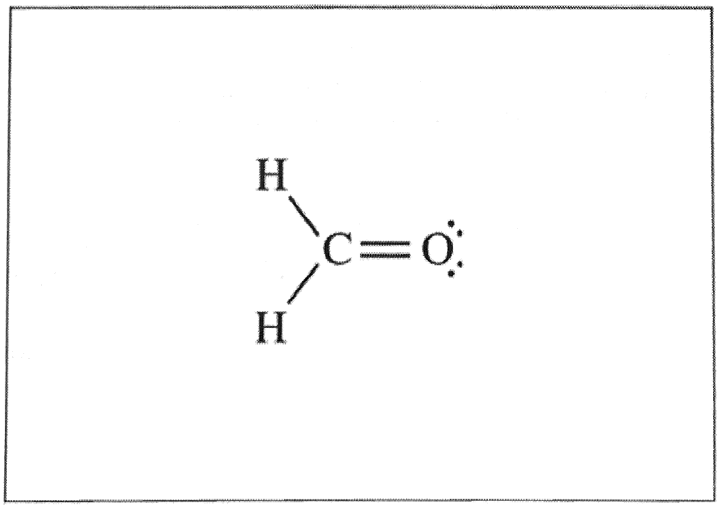
Use the information in the following table to answer parts (c) and (d).

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

c. 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.

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

e. The complete Lewis electron-dot diagram of methanal (formaldehyde) is shown in the box below. Molecules of methanal can form hydrogen bonds with water. In the box below, draw a water molecule in a correct orientation to illustrate a hydrogen bond between a molecule of water and a molecule of methanal. Use a dashed line to represent the hydrogen bond.



11. (AP) At 298 K and 1 atm, the standard state of Br_2 is a liquid, whereas the standard state of I_2 is a solid. The enthalpy changes for the formation of $Br_2(g)$ and $I_2(g)$ from these elemental forms at 298 K and 1 atm are given in the table below.

Process	$\Delta H°$ (kJ/mol_{rxn})
$Br_2(l) \rightarrow Br_2(g)$	30.91
$I_2(s) \rightarrow I_2(g)$	62.44

a. Explain why $\Delta H°$ for the formation of $I_2(g)$ and $I_2(s)$ is larger than $\Delta H°$ for the formation of $Br_2(g)$ from $Br_2(l)$. In your explanation identify the type of particle interactions involved and a reason for the difference in magnitude of those interactions.

b. Predict which of the two processes shown in the table has a greater change in entropy. Justify your prediction.

c. $I_2(s)$ and $Br_2(l)$ can react to form the compound IBr(l). Predict which would have a greater molar enthalpy of vaporization, IBr(l) or $Br_2(l)$. Justify your prediction.

An experiment is performed to compare the solubilities of $I_2(s)$ in different solvents, water and hexane (C_6H_{14}). A student adds 2 mL of H_2O and 2 mL of C_6H_{14} to a test tube. Because H_2O and C_6H_{14} are immiscible, two layers are observed in the test tube. The student drops a small, purple crystal of $I_2(s)$ into the test tube, which is then corked and inverted several times. The C_6H_{14} layer becomes light purple, while the H_2O layer remains virtually colorless.

d. Explain why the hexane layer is light purple while the water layer is virtually colorless. Your explanation should reference the relative strengths of interactions between molecules of I_2 and the solvents H_2O and C_6H_{14}, and the reasons for the differences.

e. The student then adds a small crystal of KI(s) to the test tube. The test tube is corked and inverted several times. The I^- ion reacts with I_2 to form the I_3^- ion, a linear species.

   i. In the box below, draw the complete Lewis electron-dot diagram for the I_3^- ion.