AP® CHEMISTRY
2013 SCORING GUIDELINES

Question 6
(9 points)

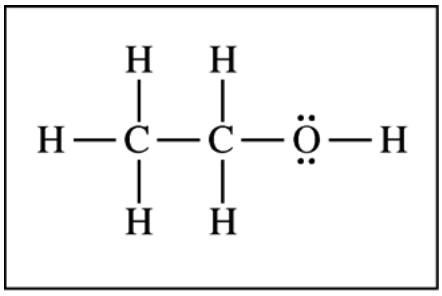
Answer the following questions using principles of molecular structure and intermolecular forces.

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 they have different physical properties.

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

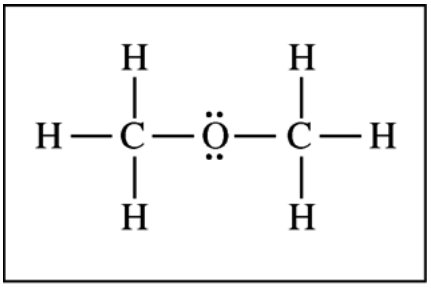
(i) Complete the Lewis electron-dot diagram of the molecule in Box X. Include any lone (nonbonding) pairs of electrons.



Box X

1 point is earned for a correct Lewis diagram.

(ii) In Box Y below, 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.



Box Y

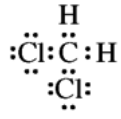
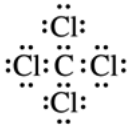
1 point is earned for a correct Lewis diagram.

Question 6 (continued)

(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.

Compound 2 is in Box X. Compound 2 (X) would have intermolecular hydrogen bonding. Compound 1 (Y) would have weaker dipole-dipole and London dispersion forces (LDFs). Because compound 2 has stronger intermolecular forces (IMFs) it has a higher boiling point. Also, compound 2 is capable of forming more hydrogen bonds with H_2O than compound 1 is, causing the solubility difference noted in the table.	2 points are earned for identification of compound 2 and a rationale that references the types of IMFs in each compound while explaining relative boiling points and/or solubilities.

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.

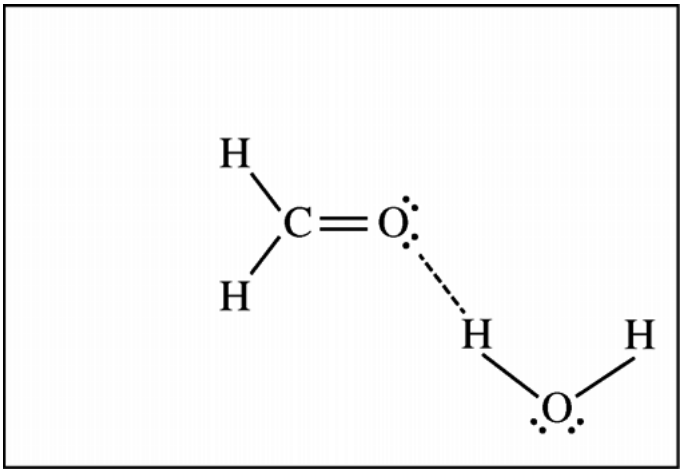
CH_2Cl_2 is polar, whereas CCl_4 is not. Therefore, CH_2Cl_2 interacts with H_2O via dipole-dipole forces, while CCl_4 only interacts with water via dipole/induced dipole forces or LDFs, which would be weaker. As a result, CH_2Cl_2 has a greater solubility.	2 points are earned for a rationale that references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

(d) 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).

Question 6 (continued)

(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 the molecule of methanal. Use a dashed line to represent the hydrogen bond.



See diagram above.	1 point is earned for a correct diagram.

6A

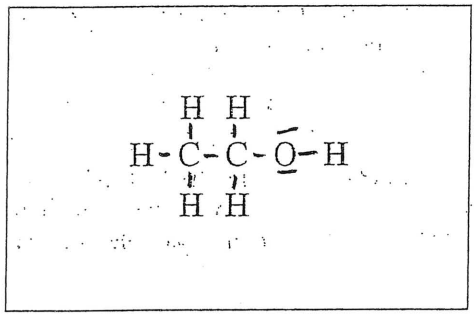
6. Answer the following questions using principles of molecular structure and intermolecular forces.

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

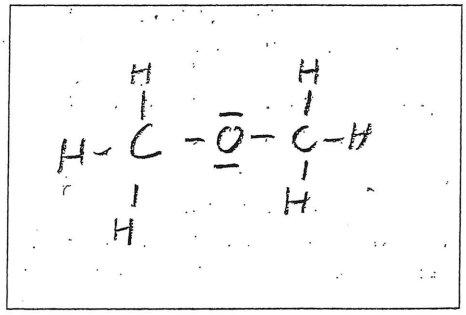
Compounds 1 and 2 in the data table above have the same empirical formula, but they have different physical properties.

(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



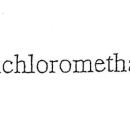
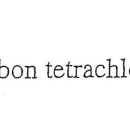
Box Y

(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.

B B B B B B B B B B B B B B 6A2

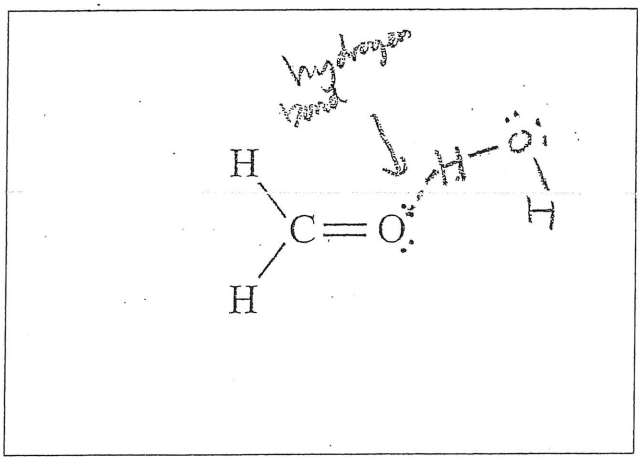
Use the information in the following table to answer parts (c) and (d).

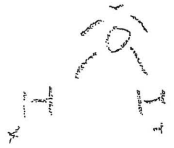
Name	Lewis Electron-Dot Diagram	Boiling Point (°C)	Vapor Pressure at 20°C (mm Hg)
Dichloromethane		39.6	353
Carbon tetrachloride		76.7	89

(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 the molecule of methanal. Use a dashed line to represent the hydrogen bond.





a Drawn in

b Compound 2 has the structure shown in box X. This is because the structure in box X exhibits

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ADDITIONAL PAGE FOR ANSWERING QUESTION 6

London forces, dispersion forces, and hydrogen bonding. These forces are greater than the molecule in box Y which does not have the potential to form hydrogen bonds, and account for its increased boiling point as there is a greater attraction between the different particles. The hydrogen bond also could form with water molecules, which accounts for its increased solubility in water.

c Dichloromethane is more soluble in water because it has land dispersion forces and dipole-dipole movements. the dipole-dipole movement makes it polar, which allows it to be more readily soluble in water, which is itself a polar compound. the CCl_4 however only has london dispersion forces, and its tetrahedral shape makes it non polar, which prevents its attraction to, and dissolving in water.

d In terms of intermolecular forces, the CCl_4 has a lower vapor pressure because it has greater intermolecular forces. Due to its 4 Chloride atoms the CCl_4 has more electrons, and as such experiences greater london forces than the CCl_2H_2. Even though CCl_2H_2 has some dipole dipole movements, it is apparently insufficient to account for the extra electrons in CCl_4. Because of this greater force

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the CCl_4 is more attracted to itself, and will remain more liquid than the CCl_2H_2, which is why it has a lower vapor pressure and CCl_2H_2 has a higher one.

6. 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
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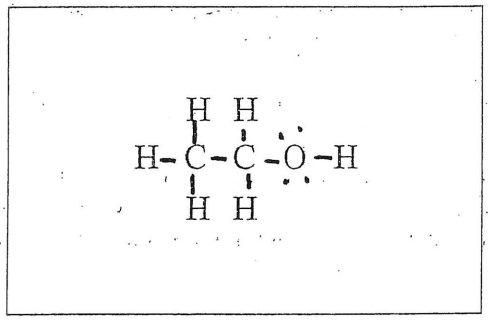
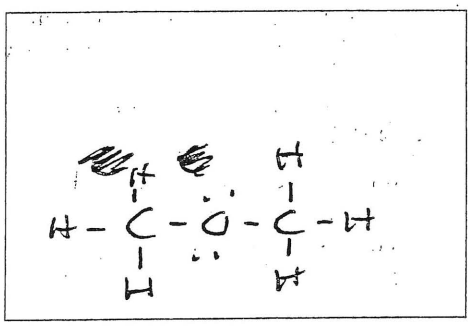
(i) Complete the Lewis electron-dot diagram of the molecule in Box X. Include any lone (nonbonding) pairs of electrons.



Box X



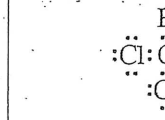
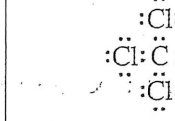
Box Y

(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.

B B B B B B B B B B B B B 6Ba

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.

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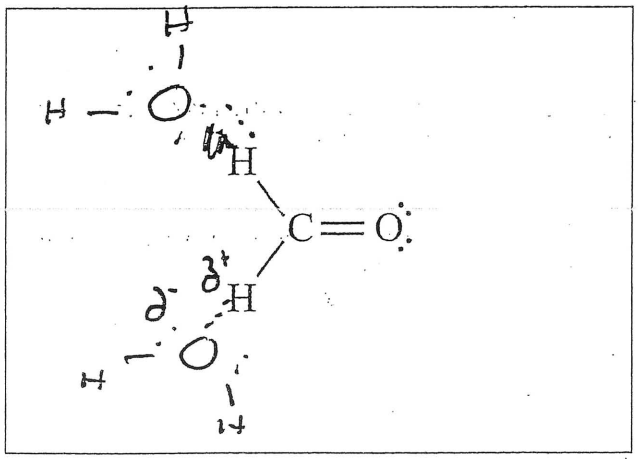
(e) The complete Lewis electron-dot diagram of methanal (formaldehyde) is shown in the box below. Molecules of methanal can form hydrogen bonds with water. In the box below, draw a water molecule in a correct orientation to illustrate a hydrogen bond between a molecule of water and the molecule of methanal.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



b. Box X represents compound 2, since it has a charged OH group attached to it, which facilitates strong intermolecular hydrogen bonds, causing it to have

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a higher boiling point. Also, since it has the charged OH, it is soluble, as H_2O can bind to the charged area, as opposed to the non-charged compound 1.

C. Chlorine is a highly electronegative atom, meaning it attracts electrons in a molecule. In Carbon tetrachloride, there are four Cl atoms arranged in a tetrahedron around the central carbon. Even though each Cl is highly electronegative, they each attract electrons equally, meaning the molecule as a whole is nonpolar. Therefore its only bond with water is weak London forces, making it very insoluble. Dichloromethane, on the other hand, has 2 Cl atoms on one side of the molecule. They pull electrons to that end of the molecule, creating a dipole. ~~Charged~~ water molecules, which also have a dipole, can bind to dichloromethane, making it soluble.

D. Dichloromethane has a lot less electrons than Carbon tetrachloride, due to having a lot less electrons. Therefore the intermolecular London forces between CCl_4 molecules are

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6B4

ADDITIONAL PAGE FOR ANSWERING QUESTION 6

much stronger than those between CCl_2H_2 molecules. Since the forces between CCl_2H_2 molecules are much weaker than those between CCl_4 molecules, it has a higher vapor pressure and therefore a lower boiling point.

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6. Answer the following questions using principles of molecular structure and intermolecular forces.

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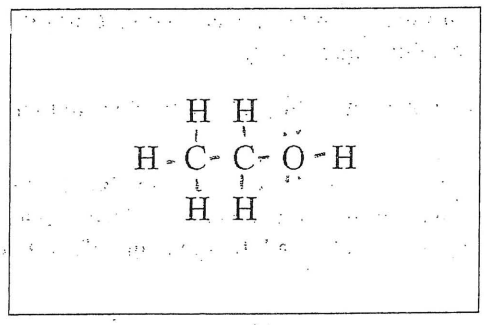
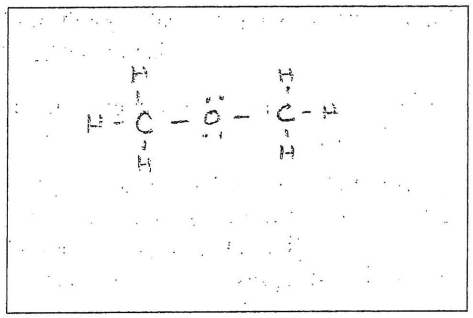


Box X



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.

B B B B B B B B B B B B B B 6C2

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

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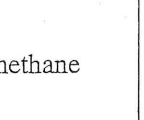
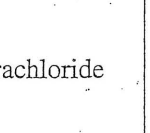
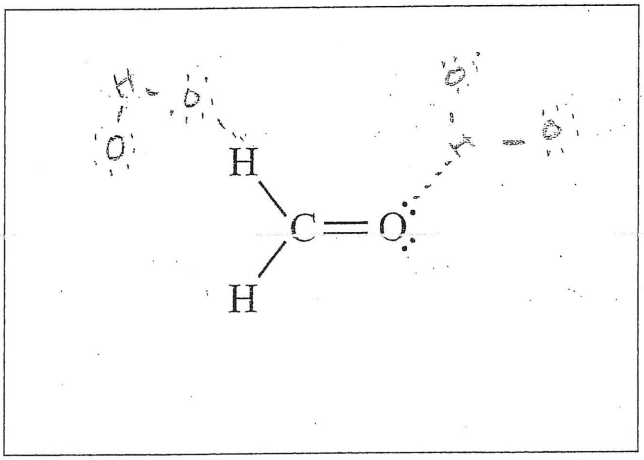
Dichloromethane		39.6	353
Carbon tetrachloride		76.7	89

(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 the molecule of methanal. Use a dashed line to represent the hydrogen bond.



B) Box X

- POLAR MOLECULE
- LONDON FORCES + DIPOLE
- BECAUSE THIS MOLECULE

Box Y

- NON POLAR MOLECULE
- LONDON FORCES
- BECAUSE THIS MOLECULE

(6C3)

ADDITIONAL PAGE FOR ANSWERING QUESTION 6

BOX X (CONT.)

IS MORE POLAR AND LIKE DISSOLVES LIKE, IT WILL BE MORE SOLUBLE IN H_2O

• MORE SOLUBLE = COMPOUND 2

BOX Y (CONT.)

• IS LESS POLAR, AND LIKE DISSOLVES LIKE, IT WILL BE LESS SOLUBLE IN H_2O

• LESS SOLUBLE = COMPOUND 1

c)

DICHLOROMETHANE

• POLAR MOLECULE
• DIPOLE + LONDON FORCES
• LIKE DISSOLVES LIKE, H_2O IS POLAR AND SO IS DICHLOROMETHANE, SO HIGHER SOLUBILITY

CARBON TETRACHLORIDE

• NON POLAR MOLECULE
• LONDON FORCES
• LIKE DISSOLVES LIKE, H_2O IS POLAR AND CARBON TETRACHLORIDE IS NOT, SO LESS SOLUBILITY

D)

DICHLOROMETHANE

• POLAR MOLECULE
• DIPOLE + LONDON FORCES
• EACH MOLECULE IS ATTRACTED TO ANOTHER THROUGH DIPOLE INTERACTION WHICH IS STRONGER THAN LONDON, SO LESS MOLECULES

CARBON TETRACHLORIDE

• NON POLAR MOLECULE
• LONDON FORCES
• LONDON FORCES ARE WEAKER THAN THE OTHERS SO IT IS EASIER TO SEPARATE EACH MOLECULE WHEN LESS IS HOLDING THEM TOGETHER

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B B B B B B B B B B B B B B GC4

ADDITIONAL PAGE FOR ANSWERING QUESTION 6

DICHLOROMETHANE ARE ABLE TO ESCAPE ON TOP OF THE LIQUID, SO IT HAS A HIGHER VAPOR PRESSURE

CARBON TETRACHLORIDE • MORE MOLECULES CAN SEPARATE = LOWER VAPOR PRESSURE

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2013 SCORING COMMENTARY

Question 6

Overview

This question provided students with data to draw Lewis electron-dot diagrams and to use the concept of intermolecular forces to explain observations about solubility and vapor pressure. Part (a)(i) asked students to complete a Lewis electron-dot diagram, including any lone (non-bonding) pairs of electrons when given an array of atoms arranged to represent ethanol. Part (a)(ii) assessed knowledge of structural isomers by asking students to draw a complete Lewis electron-dot diagram for the isomer of the compound drawn in part (a)(i). In part (b) students used the information in the data table to determine which of the two compounds was represented by the Lewis electron-dot structure in part (a)(i), justifying answers in terms of the intermolecular forces present in each compound. Part (c) asked students to examine the Lewis electron-dot diagrams of dichloromethane and carbon tetrachloride and to use intermolecular forces to explain why dichloromethane is more soluble than carbon tetrachloride. In part (d) students explained why dichloromethane has a higher vapor pressure than carbon tetrachloride in terms of intermolecular forces. Part (e) asked students to draw a correctly oriented water molecule to illustrate a hydrogen bond formed between a molecule of water and a molecule of methanal.

Sample: 6A
Score: 9

This response earned 9 points. Part (a) earned 2 points for correct structures. Lone pairs of electrons represented by line segments were accepted. Part (b) earned 2 points for correct identification of compound 2 as the structure represented in Box X and a correct description of all three of the intermolecular forces that exist between particles of ethanol and by implication, between particles of the ether. Also, the forces are correctly related to the data in the table. Part (c) earned 2 points for a correct description of both types of intermolecular forces that exist between particles of dichloromethane and the London dispersion forces (LDFs) that exist between particles of carbon tetrachloride. Additionally there is a correct relationship drawn between these forces and the relative solubility of the compounds in water. Part (d) earned 2 points for a correct description of both of the intermolecular forces that exist between particles of dichloromethane and the LDFs that exist between molecules of carbon tetrachloride. Finally, the forces are correctly connected to the relative vapor pressures of the substances. Part (e) earned 1 point for a correct representation of a hydrogen bond between methanal and water.

Sample: 6B
Score: 7

This response earned 7 points. Two points were earned in part (a). In part (b) the specific intermolecular forces for compound 1 in Box Y are not discussed, so only 1 of the 2 possible points was earned. Two points were earned in part (c). In part (d) 2 points were earned for a good comparison of the significant intermolecular force (LDF) responsible for the vapor pressure difference listed in the data table. No point was earned in part (e) as the depiction of a hydrogen bond is not correct.

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Question 6 (continued)

Sample: 6C
Score: 5

This response earned 5 points. In part (a) 2 points were earned. Neither point was earned in part (b) because there is no mention of hydrogen bonds either between the molecules of compound 2 or between the molecules of either compound and water. Additionally, there is no mention of the dipole-dipole forces that exist between molecules of compound 1. Two points were earned in part (c). Part (d) earned only 1 of 2 possible points due to the incorrect statement that stronger intermolecular forces lead to a high vapor pressure. No point was earned in part (e) because both the depictions of water molecules and hydrogen bonds are incorrect.