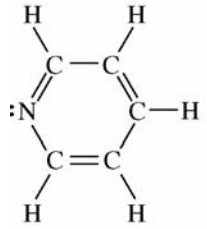
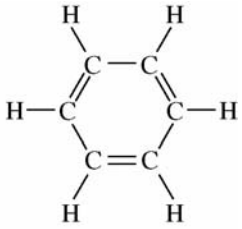
AP® CHEMISTRY
2008 SCORING GUIDELINES

Question 6

(a) Structures of the pyridine molecule and the benzene molecule are shown below. Pyridine is soluble in water, whereas benzene is not soluble in water. Account for the difference in solubility. You must discuss both of the substances in your answer.



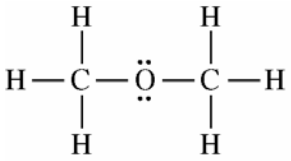
Pyridine



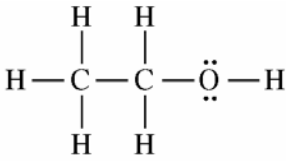
Benzene

Pyridine is polar (and capable of forming hydrogen bonds with water), while the nonpolar benzene is not capable of forming hydrogen bonds. Pyridine will dissolve in water because of the strong hydrogen bonds (or dipole-dipole intermolecular interactions) that exist between the lone pair of electrons on pyridine's nitrogen atom and the solvent water molecules. No such strong intermolecular interaction can exist between benzene and water, so benzene is insoluble in water.	One point is earned for identifying a relevant structural difference between pyridine and benzene. One point is earned for indicating that pyridine is soluble in water because pyridine can form strong dipole-dipole interactions (or hydrogen bonds) with water, while benzene cannot.

(b) Structures of the dimethyl ether molecule and the ethanol molecule are shown below. The normal boiling point of dimethyl ether is 250 K, whereas the normal boiling point of ethanol is 351 K. Account for the difference in boiling points. You must discuss both of the substances in your answer.



Dimethyl Ether



Ethanol

Question 6 (continued)

The intermolecular forces of attraction among molecules of dimethyl ether consist of London (dispersion) forces and weak dipole-dipole interactions. In addition to London forces and dipole-dipole interactions that are comparable in strength to those in dimethyl ether, ethanol can form hydrogen bonds between the H of one molecule and the O of a nearby ethanol molecule. Hydrogen bonds are particularly strong intermolecular forces, so they require more energy to overcome during the boiling process. As a result, a higher temperature is needed to boil ethanol than is needed to boil dimethyl ether.	One point is earned for recognizing that ethanol molecules can form intermolecular hydrogen bonds, whereas dimethyl ether molecules do not form intermolecular hydrogen bonds. One point is earned for recognizing that, compared to the energy required to overcome the weaker intermolecular forces in liquid dimethyl ether, more energy is required to overcome the stronger hydrogen bonds in liquid ethanol, leading to a higher boiling point.

(c) SO_2 melts at 201 K, whereas SiO_2 melts at 1,883 K. Account for the difference in melting points. You must discuss <u>both</u> of the substances in your answer.

In the solid phase, SO_2 consists of discrete molecules with dipole-dipole and London (dispersion) forces among the molecules. These forces are relatively weak and are easily overcome at a relatively low temperature, consistent with the low melting point of SO_2. In solid SiO_2, a network of Si and O atoms, linked by strong covalent bonds, exists. These covalent bonds are much stronger than typical intermolecular interactions, so very high temperatures are needed to overcome the covalent bonds in SiO_2. This is consistent with the very high melting point for SiO_2.	One point is earned for recognizing that SO_2 is a molecular solid with only weak dipole-dipole and London forces among SO_2 molecules. One point is earned for recognizing that SiO_2 is a covalent network solid, and that strong covalent bonds must be broken for SiO_2 to melt.

Question 6 (continued)

(d) The normal boiling point of $Cl_2(l)$ (238 K) is higher than the normal boiling point of $HCl(l)$ (188 K). Account for the difference in normal boiling points based on the types of intermolecular forces in the substances. You must discuss both of the substances in your answer.

The intermolecular forces in liquid Cl_2 are London (dispersion) forces, whereas the intermolecular forces in liquid HCl consist of London forces and dipole-dipole interactions. Since the boiling point of Cl_2 is higher than the boiling point of HCl, the London forces among Cl_2 molecules must be greater than the London and dipole-dipole forces among HCl molecules. The greater strength of the London forces between Cl_2 molecules occurs because Cl_2 has more electrons than HCl, and the strength of the London interaction is proportional to the total number of electrons.	One point is earned for recognizing that the London forces among Cl_2 molecules must be larger than the intermolecular forces (London and dipole-dipole) among HCl molecules. One point is earned for recognizing that the strength of the London forces among molecules is proportional to the total number of electrons in each molecule.

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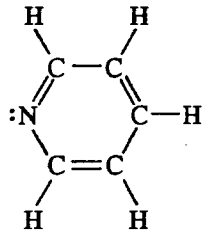
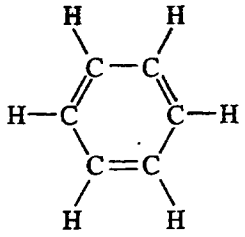
6A.

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

(a) Structures of the pyridine molecule and the benzene molecule are shown below. Pyridine is soluble in water whereas benzene is not soluble in water. Account for the difference in solubility. You must discuss <u>both</u> of the substances in your answer.

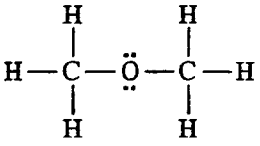


Pyridine

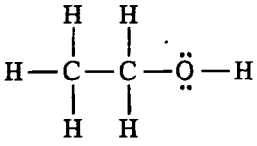


Benzene

(b) Structures of the dimethyl ether molecule and the ethanol molecule are shown below. The normal boiling point of dimethyl ether is 250 K, whereas the normal boiling point of ethanol is 351 K. Account for the difference in boiling points. You must discuss <u>both</u> of the substances in your answer.



Dimethyl Ether



Ethanol

(c) SO_2 melts at 201 K, whereas SiO_2 melts at 1,883 K. Account for the difference in melting points. You must discuss <u>both</u> of the substances in your answer.

(d) The normal boiling point of $Cl_2(l)$ (238 K) is <u>higher</u> than the normal boiling point of $HCl(l)$ (188 K). Account for the difference in normal boiling points based on the types of intermolecular forces in the substances. You must discuss <u>both</u> of the substances in your answer.

6.a) Pyridine is soluble in water because it is polar: the unshared pair of electrons on the Nitrogen atom will attract the positive end of a water molecule. Benzene, however, is a nonpolar atom and will not attract molecules in this way. Although the H-C bond is somewhat polar, the entire molecule is symmetrical, so the molecule as a whole is nonpolar.

GO ON TO THE NEXT PAGE.

6A2

ADDITIONAL PAGE FOR ANSWERING QUESTION 6

b) Ethanol has a higher boiling point because -
- the Ethanol molecule has hydrogen bonding which makes it very polar and more attractive to itself
- the dimethyl Ether molecule exhibits no hydrogen bonding, so its intermolecular forces are weaker, making its boiling point lower

c) SiO_2 has a higher melting point than SO_2 because -
- SiO_2 is a covalent network compound with strong bonds - SiO_2 is glass, rock etc.
- SO_2 forms covalent bonds also but it is a molecular compound attached to itself only through dipole-dipole intermolecular forces rather than through more covalent bonds like SiO_2

d) The boiling point of Cl_2 is higher than HCl because -
- Cl_2's electron cloud is larger than HCl's, making its london dispersion intermolecular forces stronger because the molecule is more polarizable.
- HCl exhibits weak dipole-dipole forces which are not as strong as the London dispersion forces present in Cl_2

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6 B.

ADDITIONAL PAGE FOR ANSWERING QUESTION 6

a) In pyridine, the unshared electron pair on the N allows the pyridine to interact with the water and therefore dissolve. Benzene has no unshared electron pairs anywhere, it does not interact with water and is insoluble

b) In Dimethyl Ether, the only intermolecular forces are dispersion, very weak forces. Ethanol has hydrogen-bond intermolecular forces, which are much stronger. As a result, ethanol holds together better and boils at a higher temperature

c) SiO_2 is a network covalent structure. SiO_2 molecules form a very solid latticework that is very difficult to break. SO_2 is a much simpler compound that does not form this kind of network. It is easier to break the molecules apart, so it has a lower melting point than SiO_2.

d) HCl interacts with other HCl molecules through dipole-dipole forces. These are weak forces and easy to break. As a result, it has a fairly low boiling point. Cl_2 molecules interact with dispersion forces which are also weak, but not as weak as the dipole-dipole forces in HCl. Therefore, Cl_2 has a higher boiling point than HCl.

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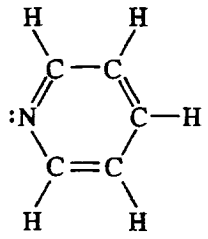
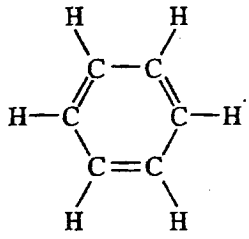
6. Answer the following questions by using principles of molecular structure and intermolecular forces.

6C 1

(a) Structures of the pyridine molecule and the benzene molecule are shown below. Pyridine is soluble in water, whereas benzene is not soluble in water. Account for the difference in solubility. You must discuss both of the substances in your answer.

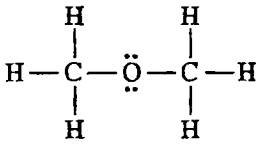


Pyridine

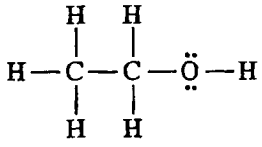


Benzene

(b) Structures of the dimethyl ether molecule and the ethanol molecule are shown below. The normal boiling point of dimethyl ether is 250 K, whereas the normal boiling point of ethanol is 351 K. Account for the difference in boiling points. You must discuss both of the substances in your answer.



Dimethyl Ether



Ethanol

(c) SO_2 melts at 201 K, whereas SiO_2 melts at 1,883 K. Account for the difference in melting points. You must discuss both of the substances in your answer.

(d) The normal boiling point of $Cl_2(l)$ (238 K) is higher than the normal boiling point of $HCl(l)$ (188 K). Account for the difference in normal boiling points based on the types of intermolecular forces in the substances. You must discuss both of the substances in your answer.

a) The reason for pyridine being soluble is because it is polar due to its lone pair on the nitrogen. Also, water is polar, and like dissolves like, which allows for the polar pyridine to dissolve in the polar water. The reason for benzene not being soluble is it is non polar therefore, the non polar benzene cannot dissolve into the polar water

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6C2

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ADDITIONAL PAGE FOR ANSWERING QUESTION 6

b) The dimethyl ether has a lower boiling point because it is nonpolar, which allows for the compound to be broken down more easily. the ethanol molecule has a higher boiling point because it is polar, which caused it to require more energy to seperate

c) SiO_2 melts at a higher temperature because it is the carbon family, which allows it to form covalent network solids, which are very strong. SO_2 melts at a lower temperature because it doesn't have these capabilities.

d) Cl_2 has a higher normal boiling point because it has a dipole - dipole bond. However, HCl only has hydrogen bonding and london dispersion forces which are much weaker and easily broken

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AP® CHEMISTRY
2008 SCORING COMMENTARY

Question 6

Overview

This question explored the importance of intermolecular interactions in phase changes and dissolution. To earn full credit, a student had to identify the relevant forces involved in each process. In part (a) students had to explain that pyridine's ability to hydrogen bond with water distinguishes its aqueous solubility from that of benzene. In part (b) students had to recognize that while ethanol and dimethyl ether (structural isomers) have similar dispersion forces, the hydrogen bonding between ethanol molecules leads to a higher boiling point. Part (c) required students to contrast the melting points of a network covalent solid (in which strong covalent bonds are broken in the melting transition) and a molecular solid (in which only relatively weak intermolecular attractions must be overcome). In part (d) students had to recognize that the London/dispersion interactions between Cl_2 molecules must be greater than the total intermolecular forces between HCl molecules, and then attribute the difference to the larger number of electrons in the Cl_2 molecules.

Sample: 6A
Score: 8

This response earned all 8 points: 2 for part (a), 2 for part (b), 2 for part (c), and 2 for part (d). In part (a) pyridine is shown to be polar, whereas benzene is shown to be nonpolar, and the dipole-dipole interactions between pyridine's lone pair of electrons and the positive end of water's dipole is nicely described. In part (b) the mention of intermolecular hydrogen bonding between ethanol molecules is explicit. The response makes clear that these hydrogen bonds are stronger than the intermolecular interactions between dimethyl ether molecules. It is clear that interactions between molecules are being discussed, and 2 points were earned. In part (c) the difference in the types of intermolecular interactions (covalent network versus dipole-dipole) is clear, as is the fact that the covalent network bonds are stronger than the dipole-dipole forces, which earned 2 points. Part (d) earned 2 points by making clear the relationship between the strength of London/dispersion forces and the size of the electron cloud, as well as stating that the strength of the intermolecular interactions between Cl_2 molecules must be greater than the intermolecular forces between HCl molecules.

Sample: 6B
Score: 6

In part (a) the difference between the two solutes (nonpolar versus polar) is discussed, and the response briefly mentions that the solubility of pyridine is the result of the nature of its interactions with water molecules, so both points were earned. In part (b) the intermolecular hydrogen bonding between ethanol molecules is clearly indicated, as is the fact that weaker dipole-dipole interactions occur between dimethyl ether molecules. No deduction was made for omitting the dipole-dipole forces between dimethyl ether molecules, and both points were earned. In part (c) the SiO_2 is acceptably described ("network covalent structure" with a lattice that is "very difficult to break"), which earned 1 point, but the description of solid SO_2 is inadequate to earn the second point. The answer to part (d) earned 1 point by correctly attributing the higher boiling point for Cl_2 to stronger London/dispersion forces but does not connect the strength of the London force to the total number of electrons, so the second point was not earned.

Question 6 (continued)

Sample: 6C
Score: 2

In part (a) the response includes a discussion of the difference between the two solutes (nonpolar benzene versus polar pyridine) and thus earned 1 point. However, the response does not describe the nature of the interaction between either of the solutes and water, so the second point was not earned. The phrase "like dissolves like" is not a discussion of intermolecular interactions. In part (b) it is not clear whether the student is referring to intra- or intermolecular interactions, and no points were earned. The phrase "which allows for the compound to be broken down" (and many similar constructions by other students) implies that the dimethyl ether molecule breaks apart when heated; no points were earned for this type of response. In part (c) the description of the structure and the relative strength of the interactions in solid SiO_2 earned 1 point, but the response does not adequately deal with SO_2 and thus did not earn the second point. The answer in part (d) did not earn any points for the discussion of dipole-dipole bonds in Cl_2 and the weak hydrogen bonds in HCl.