AP Unit 3: Intermolecular Forces and States of Matter

Test Review Sheet ***KEY***

1. What intermolecular forces would be present in each of the following samples of matter? For each sample, also say which type of intermolecular force is likely to be stronger, or more important.

a. Ammonia gas, NH_3

-H-bonds and LD forces

-H-bonds are stronger, more important

b. Nitrogen gas, N_2

-LD forces only

c. Neon gas, Ne

-LD forces only

d. liquid chlorofluorocarbon, CCl_2F_2

-dipole-dipole forces and LD forces

-dipole-dipole are likely more important

e. formaldehyde, CH_2O

- dipole-dipole forces and LD forces

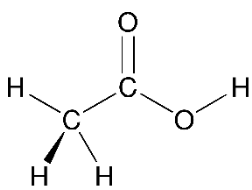
-dipole-dipole are likely more important

f. hydrogen iodide gas, HI

- dipole-dipole forces and LD forces

- dipole-dipole are likely more important

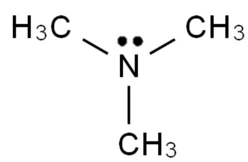
g. acetic acid, CH_3COOH



-LD forces and dipole-dipole (H-bonds)

-H-bonds likely more important

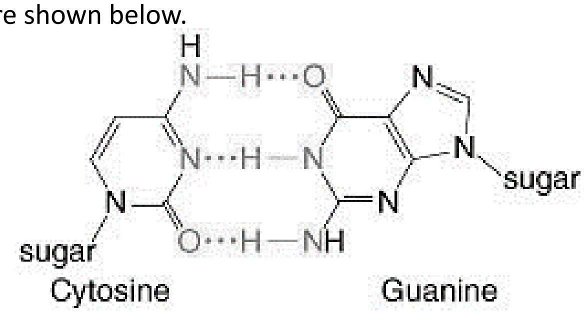
h. trimethyl amine



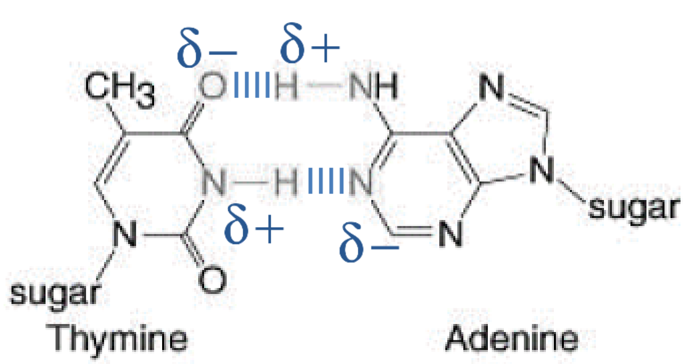
- dipole-dipole forces and LDF's

-dipole-dipole forces are likely more important

2. The base pairs that hold each strand of the DNA double helix together are connected with multiple dipole-dipole attractions between different sections of the molecule. The intermolecular forces that form between the base cytosine and the base guanine are shown below.



a. Lewis structures for the bases thymine and adenine are shown below. Draw in any locations where dipole-dipole forces might form between these two base pairs. Also label the atoms that are experiencing this attraction as either partially negative or partially positive. Would these also classify as Hydrogen bonds?



3. What is the best explanation for the difference in boiling points between HF (19°C) and HCl (-155°C)?

Both molecules are polar, but because F is more electronegative than Cl, HF molecules are more polar. This means that the dipole-dipole forces between HF molecules are stronger (H-bonds) than the dipole-dipole forces between HCl molecules. Therefore, more energy is required to break the H-bonds between HF molecules during the boiling process.

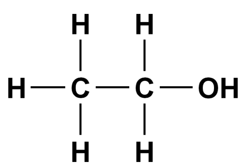
4. What would you expect to have the highest enthalpy of vaporization: CCl_4 or CH_4? Explain.

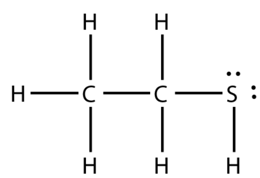
Both molecules are nonpolar, so will only experience LD forces. CCl_4 however has a larger electron cloud than CH_4 and is therefore more polarizable. This results in stronger LD forces between CCl_4 molecules, which require more heat energy to break, so a higher enthalpy of vaporization is expected for CCl_4.

5. What is the best explanation for the fact that Br_2 has a higher boiling point than HBr?

Br_2 is a nonpolar molecule, experiencing only London dispersion forces, while HBr is polar, experiencing dipole-dipole forces. Typically, London dispersion forces are weaker than dipole-dipole forces, but the higher boiling point of Br_2 suggests that in this case, the opposite is true. The LDF's between Br_2 molecules must actually be stronger than the dipole-dipole forces between HBr molecules. This is probably due to the large electron cloud of Br_2, making it highly polarizable and therefore able to form stronger LDF's.

6. Why does ethanol boil at a higher temperature than ethanethiol? Their structures are shown below.





Both molecules are polar, but the very polar O – H bond in ethanol causes stronger dipole-dipole forces (H-bonds) to form between ethanol molecules. Therefore, more heat energy is required to break the H-bonds between ethanol molecules, so it will have a higher boiling point.

7. What explains the fact that liquids will change their shape, but not their volume? Your answer should include references to the particles composing the liquid and the forces between them.

Liquid particles have IM forces that hold strongly enough that there is no space between them, so they can not be compressed, and therefore do not change their volume. They do however, have enough kinetic energy to maintain motion, they will change their shape.

8. What makes a substance behave as a real gas vs. an ideal gas? What conditions can effect this behavior?

Gas laws are based on the assumption that gas particles do not experience any IMF's. When you consider that all gases DO experience some (although usually very weak) IMF's, we call them real gases. These gases are said to "deviate from ideal behavior" because they behave in ways not predicted by the gas law relationships. These deviations will be lower than PV=nRT predicts when gases have stronger IMF's and when gases are at lower temperatures since particles collide less often with the inside walls of their container. The deviations will be higher than PV=nRT predicts when gas particles are larger and are under higher pressures (due to container volume decrease or added particles). This is because the particles have less space to move so will collide with the inside walls of the container more often.

9. Answer the questions concerning the following samples of gases in separate, rigid containers.

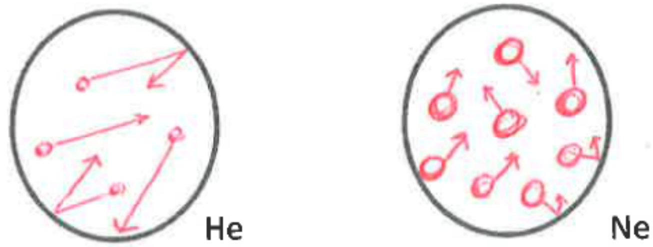
a. Which of the two cylinders contains more moles of gas? Explain.

Ne has more moles of gas particles. It is at the same T and V as the He container, but exerts twice the pressure. It must therefore, have more particles.

b. Which of the two cylinders contains particles with the greater average speed? Explain.

The kinetic energies of the two gases are equal, but since He has a smaller mass, it will be moving faster.

c. In the two circles below, draw representations of the particles in the cylinders above, illustrating the differences in pressure, volume, temperature and moles of gas. Include arrows to show the relative speeds of the particles.



d. Draw a representation of a sample of gas that is colder than both of the samples shown above.

V = 0.5 L
P = 1 atm

decrease the V while keeping the P constant

e. How would the Helium balloon change if it was put in a vacuum chamber and the external pressure was decreased to 0.5 atm at the same temperature? What gas law is this an example of?

In a flexible container, internal and external pressure are always equal, so as the external P drops, so does the internal pressure. Since the internal P is decreasing at a constant temperature, the volume will increase (according to Boyles Law)

10. The following data is gathered for a series of gaseous samples in syringes. 5 moles of each gas is injected into the syringe at 25°C. The syringes are compressed and the pressure and volume changes are recorded. Boyles' Law is then used to calculate a predicted final pressure for comparison purposes.

Gas	Initial Pressure	Initial Volume	Final Volume	Actual Final Pressure	Predicted Final Pressure
He	1.00 atm	50. mL	25 mL	2.00 atm	2.00 atm
Ar	1.00 atm	50. mL	25 mL	1.98 atm	2.00 atm
Xe	1.00 atm	50. mL	25 mL	1.87 atm	2.00 atm

a. What is the best explanation for the greater deviation from the predicted final pressure in Xe?

Xe is a much larger atom than the other two, so will experience stronger London dispersion forces. This will cause the Xe atoms to be slightly more attracted to each other than the Ar and He atoms, causing the Xe to deviate from ideal behavior more than the other two. This means that Xe will not conform to the predictions made using the ideal gas law and it's derivatives, like Boyles' Law used here.

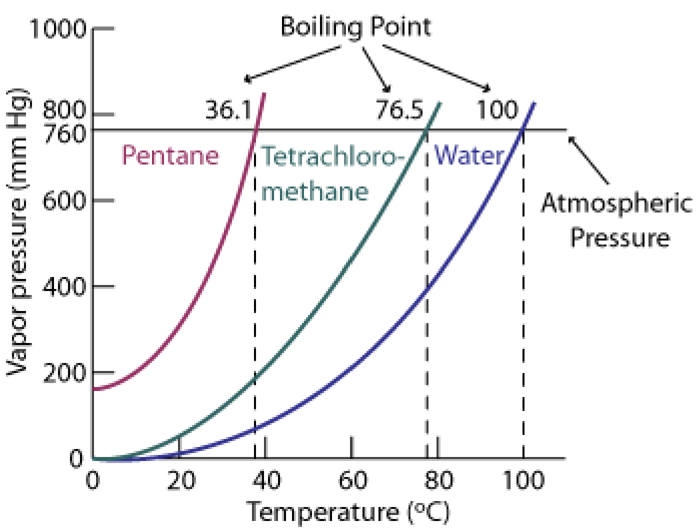
b. If the same test was performed with a sample of krypton, Kr, a deviation from the predicted final pressure is also expected. Will the deviation be less than or greater than that of the other gases? Explain.

Since Krypton's electron cloud is smaller than Xenon's, but larger than Argon's, it will experience London dispersion forces weaker than Xenon's but stronger than Argon's. It will therefore deviate by some amount in between the two, within the range of 1.98 atm and 1.87 atm.

11. When one mole of butane, C_4H_{10}, condenses, 21 kJ of heat energy is released into the surroundings. When one mole of propane, C_3H_8, condenses, 16 kJ of heat energy is released. Account for this difference by discussing intermolecular attractions that occur between propane molecules and between butane molecules.

During the process of condensation, butane and propane molecules will change from gas to liquid. This means that intermolecular attractive forces will form between butane molecules and between propane molecules. Since attractive forces are being formed, energy will be released in the form of heat. Butane releases more energy because it forms stronger intermolecular attractions than propane does. Both substances are non-polar, so will only experience London dispersion forces. Butane's four-carbon chain is longer than propane's and will therefore have more surface area for London dispersion forces to form.

12. The vapor pressure curves for 3 compounds are shown below.



a. Why is water's vapor pressure lower than tetrachloromethane's (CCl_4)?

Water has stronger IMF's (H-bonds) than CCl_4 (LD forces), so it vaporizes less, resulting in lower vapor pressure.

b. What would the boiling point of pentane be at a higher altitude where the atmospheric pressure is only 600 mmHg?

About 35°C

13. The following gases are kept in separate 1 Liter containers: Nitrogen gas, N_2; Chlorine gas, Cl_2; and sulfur hexafluoride gas, SF_6. The initial temperature and pressure inside each container is exactly the same. If the containers are slowly cooled until the gases begin to condense, which gas will do so at the lowest temperature?

All the gases are non-polar, so will experience only LD forces. N_2 has the smallest electron cloud, so is less polarizable than the others, and will therefore experience the weakest LD forces. Since the attractive forces between the N_2 molecules are weakest, they would have to be slowed down the most before they started to stick to each other and condense. For this reason, the N_2 sample would condense at the coldest temperature.

14. Predict which solid would have the higher melting point: C_2H_6 *(s)*, Br_2 *(s)*, Na_2O *(s)*

Higher melting point substances will have stronger interparticle forces. Na_2O is an ionic solid with ions held together with ionic bonds. These are very strong and lots of heat energy will be required to break them during the process of melting. C_2H_6 and Br_2 are both nonpolar molecular solids, held together by only London dispersion forces between molecules. These LDF's will be much weaker and require less energy to break then the ionic bonds, so both will have lower melting points than Na_2O. Br_2 has a larger electron cloud than C_2H_6 however, so it is more polarizable and will experience stronger LDF's. Bromine is predicted to have a higher melting point than C_2H_6.

15. Why do ionic solids conduct electricity in their molten and dissolved states, but not in the solid state?

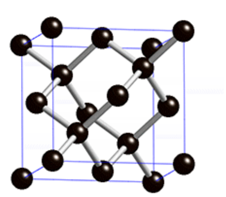
To conduct electricity, a substance must have free-flowing charged particles. Ionic solids have charged particles, but in the solid state they are held in place, so are not free flowing. In the dissolved and molten states those ions are free to move and carry an electric current.

16. Predict the electrical conductivity of each of the following. Justify your response briefly.

a. Ca *(s)* b. SiO_2 *(s)* c. $MgCl_2$ *(liquid)*

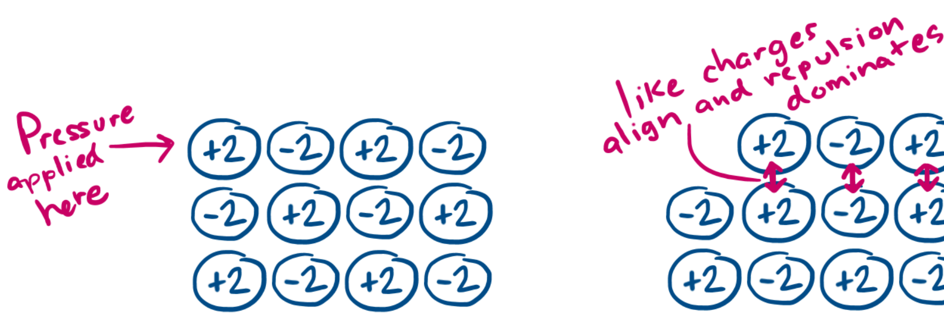
Ca is a metal, so in the solid state it has free-flowing electrons that allow it to conduct electricity.
SiO_2 is a covalent network solid that does not have any free-flowing charged particles.
$MgCl_2$ is an ionic solid, so in the liquid state, the cations and anions are free to flow and conduct an electric current.

17. Why is diamond one of the hardest substances known to man? Reference the diagram below in your answer.



Within the crystal structure of diamond it be seen that every individual atom is covalently bonded to 4 other carbon atoms. The strength and quantity of these bonds makes it extremely hard to break the C's apart from one another, making diamond one of the hardest known substances.

18. Draw a model of magnesium sulfide that illustrates why it is so brittle.



The model above shows how when rows of ions are realigned, the like charged ions will end up adjacent to one another. This means that repulsive forces now dominate and that row of ions will be broken off. This explains why ionic substances, like MgS, would be brittle and break easily.

19. Which ionic solid is likely to have the higher melting point: LiCl or LiBr?

Cl is smaller than Br, so the Li and Cl ions are closer to one another and therefore more strongly attracted. More heat is required to break the stronger ionic bonds between Li and Cl, so it will have a higher melting point.

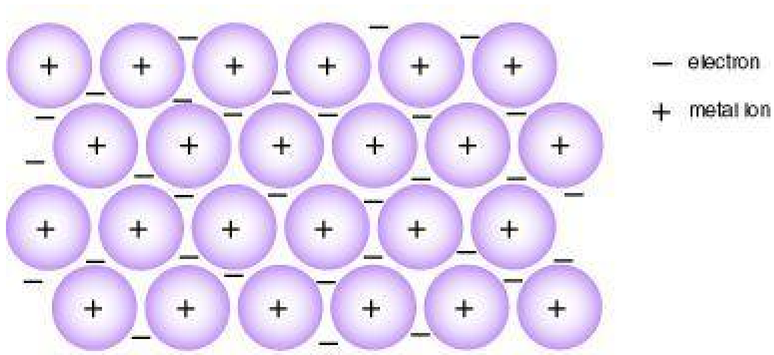
Which ionic solid is likely to have the higher melting point: MgS or MgO?

O is smaller than S, so the Mg and O ions are closer to one another and therefore more strongly attracted. More heat is required to break the stronger ionic bonds between Mg and O, so it will have a higher melting point.

Which ionic solid is likely to have the higher melting point: NaCl or CaO?

Ca and O have a magnitude of +2 and -2, respectively, while Na and Cl have a magnitude of +1 and -1, respectively. Ca and O will therefore be more strongly attracted to one another, so more heat will be needed to break that attraction during the process of melting.

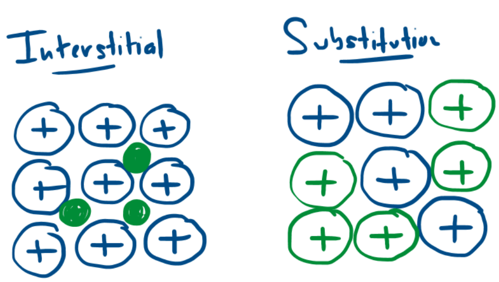
20. The model below represents the bonding in a sample of Copper. Why is copper electrically and thermally conductive? Reference the model in your response.



The electrons are free to flow through the sample, making electrical conduction possible.

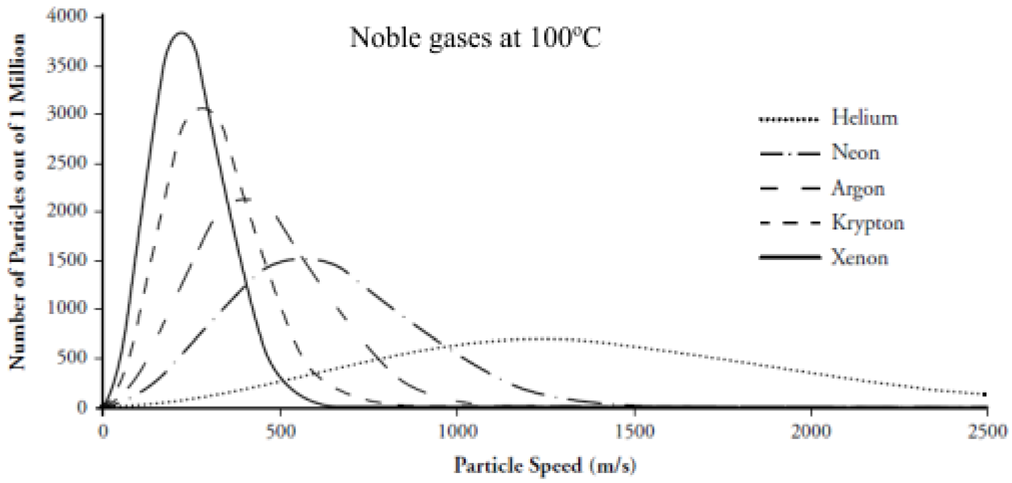
The movement of electrons also allows for the transfer of kinetic energy, making the Copper very thermally conductive as well.

21. What is the difference between interstitial alloys and substitutional alloys? What effect does these differences have on the properties? ***Interstitial alloys are made of a mixture of metallic atoms where one is larger in size (radius) than the other. In the model below, the blue atom is the larger metallic element and the green atom is the smaller. The smaller atom can fit into the spaces between the larger atoms, called interstices. These alloys tend to be harder than just the metal alone because the smaller atoms make it harder to re-align the rows of atoms.***



Substitution alloys are made of a mixture of metallic atoms that are similar in size (radius). The properties of these will be a combination of the two metals being mixed together.

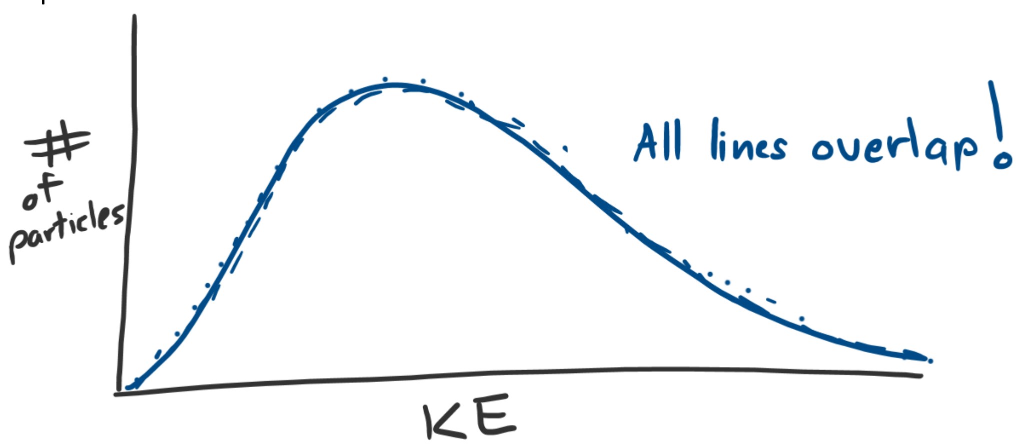
22. Refer to the graph below when answering parts a and b.



a ... e speed?

...ge kinetic energy. Helium atoms have the smallest mass, so will therefore have the greatest velocity in order to have an equal kinetic energy to the other atoms.

b. Sketch a how these 5 lines might look if the x-axis was representing the kinetic energies of the noble gas samples.



One of the components of the kinetic theory of gases states that any two gases at the same temperature will have equal average kinetic energy values. Since all of these gases are at 100 degrees C, their kinetic energy values will be roughly the same and the lines overlap.

23. Refer to the information in the table.

Process	ΔH
$HBr(l) \rightarrow HBr(g)$	7.95 kJ/mol
$HBr(g) \rightarrow H^+(g) + Br^-(g)$	370 kJ/mol

a. Which process represents the breaking of intermolecular forces and which represents the breaking of intramolecular forces?

The first process represents the vaporization of HBr. The molecules stay intact, they are simply separated from one another, so IMF's are broken. In the second process, the H and Br atoms are separated from one another by breaking the covalent bond holding the molecule together, so intramolecular forces are broken.

b. Why are both enthalpy values endothermic?

Both values are endothermic because both are the energy requirements for breaking bonds. Breaking bonds always requires energy to be absorbed from the surroundings.

c. Using principles of Coulomb's law, explain why the enthalpy for the second process is so much greater.

Coulomb's Law states that attractive forces between opposite charges will be stronger when the charges have greater magnitudes and are closer together. The dipole-dipole forces forming between HBr molecules are the result of attractions between partial charges on the H and Br atoms, with very low magnitudes. This attraction will therefore be very weak and relatively easy to break.

The covalent bond however, results from the attraction between the nuclei of each atom to the area of high electron density between them. The magnitudes of the charges of these nuclei and the electrons are much higher, so the attraction will be much stronger.

24. The table below displays information related to the metallic bonding in the two metals shown.

Element	Electrical Conductivity (relative to Cu)	Atomic Radius (pm)	Melting Point (K)
K	0.229	200	337
Ca	0.506	174	1115

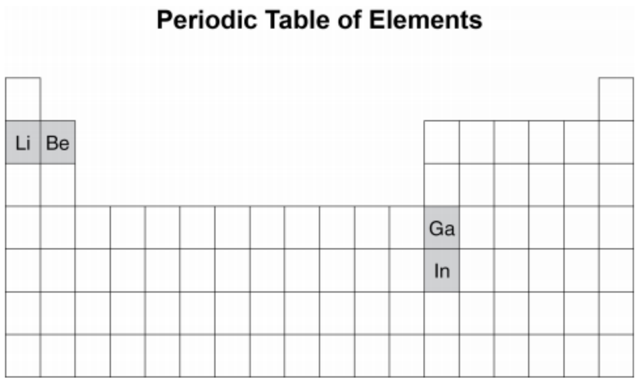
a. What is the best explanation for the difference in conductivity between Ca and K?

Conductivity is dependent on the charged particles that are available to move freely within the structure of a substance. Calcium has two valence electrons, compared to potassium's one, that become delocalized when forming metallic bonds to other calcium atoms. A sample of Ca will therefore have twice as many delocalized electrons that are free to move around, so will be roughly twice as conductive.

b. What is the best explanation for the difference in melting point between Ca and K?

Melting point is determined by the strengths of the attractive forces between the neighboring particles within the lattice structure of a solid. Calcium ions will experience much stronger metallic bonding than potassium ions due to 2 factors: charge magnitude and ionic radius. Calcium loses two valence electrons, while potassium only loses one, so it's charge will be +2 compared to potassium's +1. This means that that the Ca atoms will be more strongly attracted to the delocalized electrons that surround them. Calcium is also smaller potassium, so the distance between calcium ions and the delocalized electrons is smaller, causing a greater attraction. Since calcium ions experience the stronger metallic bonds, more energy is required to break those bonds, so Ca has a much higher melting point.

25. Which of the four elements shown would have the highest melting point and why?

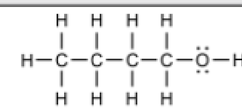
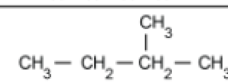
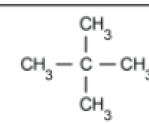


All of the atoms shown are metallic elements, so will experience metallic bonds. The element with the highest melting point will be Beryllium because it will experience the strongest metallic bonds, and therefore more heat will be required to break those bonds during the process of melting.

Indium and gallium will both form +3 ions, but are also very large, meaning that the distances between ions and the delocalized is greater, leading to weaker metallic bonds.

Beryllium is smaller than lithium, and also forms an ion of greater magnitude (+2 vs. +1), so it will experience the strongest metallic bonds, and therefore have the highest melting point.

26. The Lewis structures for several organic molecules are shown to the right.

Compound	Lewis Structure
C_4H_9OH (1-butanol)	
C_5H_{12} (2-methylbutane)	
C_5H_{12} (2,2-dimethylpropane)	
C_6H_{14} (hexane)	$CH_3-CH_2-CH_2-CH_2-CH_2-CH_3$

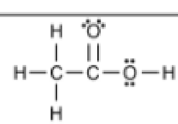
a. Rank the four molecules in terms of their comparative boiling points, from lowest to highest. Explain.

1-butanol will have the highest boiling point. It will experience strong hydrogen bonds, as well as significantly strong LDF's due it's straight chain of carbon atoms. Both of these forces will require more heat in order to break, and give it the highest boiling point.

The other 3 molecules are all non-polar, and will therefore only experience LDF's. Hexane, with a long, straight chain, will experience the strongest LDF's. It will therefore have the highest boiling point of the three, and the second highest overall.

2,2-dimethyl propane will have the lowest boiling point because it's LDF's will be weakest. The molecule is very compact with very little surface area where it could contact other molecules and form LDF's.

27. Octane is a important component of gasoline, and ethanoic acid provides most of the sour, acidic taste in vinegar. The structure of each molecule is shown below.

C_8H_{18} (octane)	$CH_3-CH_2-CH_2-CH_2-CH_2-CH_2-CH_2-CH_3$
CH_3COOH (ethanoic acid)	

a. Why is the boiling point of octane about 7°C higher than that of ethanoic acid? Explain in terms of the intermolecular forces present for each molecule.

Normally, a polar molecule with hydrogen bonds, like ethanoic acid, would have the higher boiling point when compared to a non-polar molecule that only has LDF's (like octane). This is because hydrogen bonds are typically very strong, and would require more energy to break than LDF's. In this case however, since we are told that the boiling point of octane is greater, it must mean that the LDF's in octane are actually stronger than the hydrogen bonding between ethanoic acid molecules. This is likely due to the length of the chain in octane, which greatly increases its surface area, leading to considerably strong LDF's.

28. Each of the following statements contains a portion that is incorrect or inaccurate. Identify the inaccuracy in each and offer a corrected version.

a. Lithium fluoride is more polar than lithium oxide, so will experience stronger intermolecular attractions.
Lithium fluoride is ionic and is made of ions, so the term polar does not apply. Polarity requires there to be unequally shared electrons in COVALENT bonds. Since covalent bonds do not exist in either of these substances, they can't be classified as polar or non-polar.

A more accurate statement would be: Lithium and fluoride ions will be more strongly attracted to one another than lithium and oxide ions.

b. Water has a hydrogen bond while phosphine, PH_3, only has a dipole-dipole attraction.
Stating that water has "a" hydrogen bond and that phosphine has "a" dipole-dipole attraction implies that there is one hydrogen bond and one dipole-dipole attraction present. This is inaccurate because even a small sample of water or phosphine would contain many trillions of molecules, experience many trillions of attractions between molecules.

A more accurate statement would be: Water molecules experience hydrogen bonds between molecules while phosphine experiences only dipole-dipole forces between molecules.

c. When ethanol, C_2H_5OH, boils bonds between oxygen atoms and hydrogen atoms are broken.
Boiling is a physical change, so the C_2H_5OH molecules will stay intact. The molecules separate from each other, breaking intermolecular attractions, but the individual molecules remain whole.

A more accurate statement would be: When ethanol boils, intermolecular attractions between molecules are broken.

d. Hydrogen fluoride, HF, has a stronger bond than hydrogen chloride, HCl.
The term "bond" usually is meant to imply intramolecular attractive forces (covalent, ionic, metallic). Since the statement is probably trying to compare intermolecular attractions between molecules, simply using the word "bond" is an odd choice.

A more accurate statement would be: Hydrogen fluoride, HF, will experience stronger hydrogen bonds between molecules while hydrogen chloride, HCl, will experience weaker dipole-dipole forces between molecules.

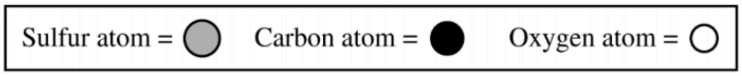
e. Water molecules will experience hydrogen bonds, dipole-dipole interactions, and London dispersion forces.
Water only experiences two attractive forces between molecules: dipole-dipole forces and LDF's. The dipole-dipole forces that it experiences are also classified as H-bonds, so the two should not be listed as if they were separate things.

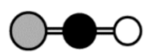
A more accurate statement would be: Water molecules will experience dipole-dipole forces that are Hydrogen bonds and London dispersion forces.

f. London dispersion forces are weaker than dipole-dipole forces.
London dispersion forces are only weak when electron clouds are very small. They can actually be quite strong when the electron cloud is large and polarizable.

A more accurate statement would be: London dispersion forces are usually weaker than dipole-dipole forces, but can be equally as strong or stronger, if the electron cloud is large and polarizable enough.

29. The table below shows the molecular structures and corresponding boiling points of two molecular compounds.

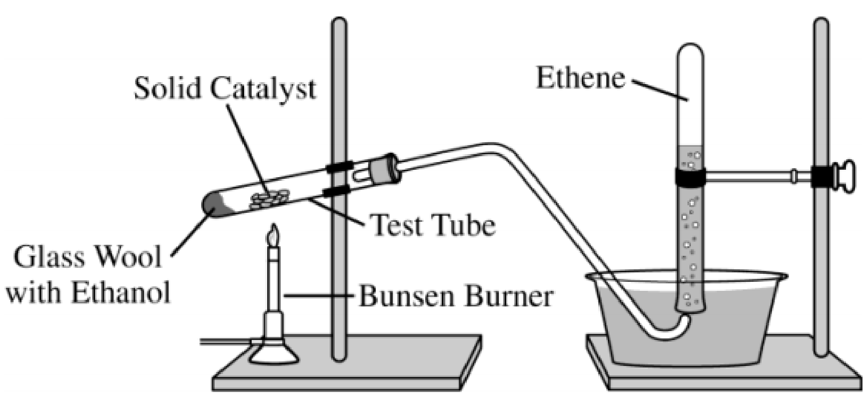


Compound	Molecular Structure	Boiling Point at 1 atm (K)
CS_2		319
COS		223

In terms of the relative strengths of ALL the intermolecular forces in each compound, explain why the boiling point of CS_2 is higher than the boiling point of COS.

CS2 is nonpolar, so will only experience London dispersion forces. COS is polar, so will experience dipole-dipole forces in addition to London dispersion forces. Since CS2 has the higher boiling point, the London dispersion forces between CS2 molecules must be stronger than the London dispersion forces AND the dipole-dipole forces of COS.

30. Some glass wool is soaked in ethanol and heated in the presence of a solid catalyst. The ethanol decomposes, producing ethane gas. The diagram below shows the apparatus used to conduct this experiment, collecting the ethane gas as it bubbles into an inverted test tube. Prior to the start of the reaction, the test tube was completely full of water.



The equation for the reaction is shown below.

$$C_2H_5OH(l) \rightarrow C_2H_4(g) + H_2O(g)$$

When the reaction was stopped, 0.0854 Liters of gas was collected under a pressure of 0.822 atm and a water temperature of 305 K. At 305 K, the vapor pressure of water is 35.7 Torr.

a. What gases are present in the collection tube?
The ethane that was produced is collected in the tube, along with water vapor from the evaporation of liquid water in tube.

b. Calculate the partial pressure of each gas in atm.

$$P_{total} = P_{C_2H_4} + P_{H_2O}$$

$$35.7\ Torr\ x \frac{1\ atm}{760\ Torr} = 0.0470\ atm\ H_2O(g)$$

$$0.822\ atm = P_{C_2H_4} + 0.0470\ atm$$

$$P_{C_2H_4} = 0.775\ atm\ C_2H_4\ (g)$$

c. How many moles of each gas is in the test tube?

$$PV = nRT$$

$$(0.0470\ atm)(0.0854\ L) = n(0.082)(305)$$

$$n = 1.60x10^{-4}\ moles\ of\ H_2O$$

$$PV = nRT$$

$$(0.775\ atm)(0.0854\ L) = n(0.082)(305)$$

$$n = 2.65x10^{-3}\ moles\ of\ C_2H_4$$

d. The experiment produces equal moles of ethane gas and water vapor. Explain why the collection tube doesn't contain equal moles of each gas? Answer in terms of intermolecular forces experienced between the gaseous products and the liquid water used to collect the gases.
The collection tube contains much less water vapor and much more ethane gas. This is because ethane gas is nonpolar, while the produced water vapor is polar. Since ethane is nonpolar, as it bubbles through the liquid water, the only attractive force it will experience with the water molecules is weak London dispersion forces. This means most of the ethane gas will pass right through the liquid water.

As water vapor is produced and bubbled through the liquid water however, hydrogen bonds will form between the gaseous water molecule products and the liquid water molecules. Since these hydrogen bonds are so strong, the water vapor molecules will be attracted to the liquid water molecules and remain within the liquid.

31. Describe how each of the following pairs of substances dissolve/mix in one another. Be sure to mention the series of bond making and bond breaking steps involved in each process.

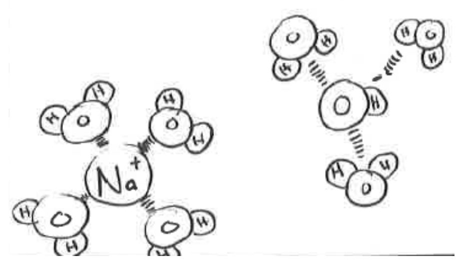
Also, in the box provided, draw a model to represent what the particles might look like when dissolved / mixed.

a. NaOH(*s*) in H_2O(*l*)

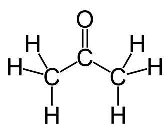
Bonds broken: 1. Ionic bond between Na^+ and OH^-
2. H-bonds between H_2O molecules

Bonds formed: 1. Ion-dipole interactions between H_2O and Na^+ and OH^- ions.

Solution Particulate Model:



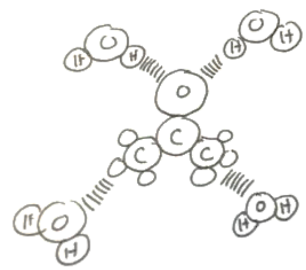
b. Acetone(*l*) in water(*l*)



Bonds broken: 1. Dipole-dipole bonds between acetone molecules
2. H-bonds between H_2O

Bonds formed: 1. Dipole-dipole bonds between H_2O and acetone

Solution Particulate Model:



c. Quartz, SiO_2(*l*) in H_2O(*l*)

Quartz is a covalent network solid, so is not soluble in any common solvent. The forces between Si and O atoms are covalent bonds which are too strong to be broken by any attractive force that the atoms might form with another solvent particle.

Solution Particulate Model:

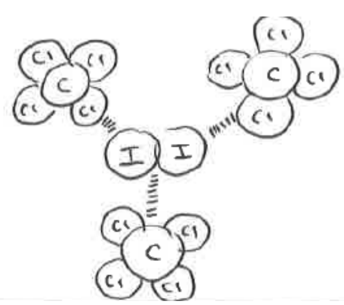
No solution will exist so no solution model can be made!

d. I_2 (s) in CCl_4 (*l*)

Bonds broken: 1. LD Forces between I_2 molecules
2. LD Forces between CCl_4 molecules

Bonds formed: 1. LD forces between I_2 and CCl_4 molecules

Solution Particulate Model:



32. Why is NH_3 more soluble in water than PH_3?

Both molecules are polar, so both molecules will be soluble in water, which is also polar. NH_3 however, is more polar than PH_3, so stronger H-bonds will form between NH_3 molecules and water molecules. Only dipole-dipole forces will be able to form between PH_3 and water molecules, which are weaker. A stronger attractive force between solute and solvent particles will typically lead to a greater solubility.

33. Why is SF_6 more soluble in liquid hexane (nonpolar solvent) than nitrogen gas?

Both molecules are non-polar, so both molecules will be soluble in hexane which is also non-polar. SF_6 however, has a larger electron cloud and is more polarizable than N_2, so stronger LD Forces will form between SF_6 molecules and hexane molecules. LD forces will be able to form between N_2 and hexane molecules as well, but they will be weaker. A stronger attractive force between solute and solvent particles will typically lead to a greater solubility.

34. While the following non-polar gases are largely insoluble in water, they are all actually soluble, just in very small quantities.

The Solubility of Some Gases in Water

Gas	Molar Mass	Solubility @ 20°C
	g/mol	g/100g Water
H_2	2.01	0.000160
N_2	28.0	0.000190
O_2	32.0	0.000434
Cl_2	70.9	0.729

a. Why is the solubility of Cl_2 greater than the solubility of H_2?

Cl_2 has a larger electron cloud and is more polarizable than H_2, so stronger LD forces will be able to form between Cl_2 and H_2O. A stronger attractive force will typically lead to greater solubility.

35. Describe the series of bond making and bond-break steps that take place during the dissolution of the following substances:

a. Lithium bromide in water

Bonds Broken: 1. Ionic bonds between Li^+ and Br^-
2. H-bonds between H_2O molecules

Bonds formed: 1. Ion-dipole forces between the ions and water molecules.

b. methanal, CH_2O, in water

Bonds broken: 1. Dipole-dipole forces between methanal molecules
2. H-bonds between H_2O molecules

Bonds formed: 1. Dipole-dipole forces between methanal and water molecules.

36. Which of the bond-making and bond-breaking steps in question 6 require energy? Which are endothermic and which are exothermic?

All bond-breaking steps require energy, so are endothermic. All bond-forming steps, are the reverse process, so energy is released, making them exothermic. Since the ionic bonds are likely to be the strongest out of both lists, they will be the hardest to break, requiring the most energy.

37. What is the molarity of the sulfate ion in each of the following solutions?

a. 1.00 M Na_2SO_4 **$Na_2SO_4 \rightarrow 2Na^+ + SO_4^{2-}$ $[SO_4^{-2}] = 1.00$ M**
b. 2.00 M $MgSO_4$ **$MgSO_4 \rightarrow Mg^{+2} + SO_4^{2-}$ $[SO_4^{-2}] = 2.00$ M**
c. 2.00 M $Al_2(SO_4)_3$ **$Al_2(SO_4)_3 \rightarrow 2\,Al^{+3} + 3\,SO_4^{2-}$ $[SO_4^{-2}] = 6.00$ M**

38. What mass of LiCl must be dissolved in water to give a chloride ion concentration of 5×10^{-3} M?

$LiCl \rightarrow Li^+ + Cl^-$

5×10^{-3} M $\quad$ 5×10^{-3} M

$M = \frac{mol}{L}$ $\quad$ $5\times10^{-3}\,M\ LiCl = \frac{mol}{1\,L}$ $\quad$ $5\times10^{-3}\,mol\ LiCl \times \frac{42.5\,g}{1\,mol} = \boxed{0.213\,g}$

39. The absorptivity of a particular chemical is 1.5/M·cm. What is the concentration of a solution made from this chemical if a 2.0 cm sample has an absorbance of 1.20?

$A = a\,b\,c$

$1.20 = (1.5\ M^{-1}cm^{-1})(2\ cm)\ c$

$c = 0.4\ M$

40. If the chemical described in the previous problem is reddish/purple in color, what wavelength should be used to measure the absorbance of the solution with a spectrometer?

Green/blue
More detail: Since the solution is reddish/purple, it DOESN'T absorb red and purple. That means we could choose any other color light as something would actually be absorbed. Hence, green/blue is a good choice

41. Which of the following solutions contains the largest number of moles of chloride ions

a. 100 mL of 0.30 M $AlCl_3$

$AlCl_3$ *produces 3 times as many* Cl^{-1} *ions, so the M of* Cl^{-} *is* $0.90\ M$

$M = \frac{mol}{L}$ so… $0.90\ M = \frac{x\ mol\ Cl^{-}}{0.1\ L}$ $x = 0.09\ mol\ of\ Cl^{-}$

b. 50.0 mL of 0.60 M $MgCl_2$

$MgCl_2$ *produces 2 times as many* Cl^{-1} *ions, so the M of* Cl^{-} *is* $1.2\ M$

$M = \frac{mol}{L}$ so… $1.2\ M = \frac{x\ mol\ Cl^{-}}{0.05\ L}$ $x = 0.06\ mol\ of\ Cl^{-}$

c. 200.0 mL of 0.40 M NaCl

NaCl produces an equal number of moles of Cl^{-1} *ions, so the M of* Cl^{-} *is* $0.40\ M$

$M = \frac{mol}{L}$ so… $0.40\ M = \frac{x\ mol\ Cl^{-}}{0.2\ L}$ $x = 0.08\ mol\ of\ Cl^{-}$

42. Determine which of the following compounds are soluble or insoluble in water using the solubility rules.

a. Lithium hydroxide ***(soluble)***
b. Calcium sulfate ***(insoluble)***
c. Potassium phosphate ***(soluble)***
d. Ammonium acetate ***(soluble)***
e. Lead(II) chloride ***(insoluble)***
f. Strontium sulfide ***(insoluble)***

****Note: For any AP Chem test, you would only be responsible for being able to answer a, c, and d. The others require a reference sheet for solubility rules.***

43. Write a balanced equation for the following substances dissolving in water.

a. Na_2SO_4 (s) → $2Na^{+}(aq) + SO_4^{-2}(aq)$

d. CH_2O (l) → $CH_2O(aq)$

b. H_2O_2 (l) ⍰ $H_2O_2\ (aq)$

e. $Al(C_2H_3O_2)_3$ ⍰ $Al^{+3}\ (aq)\ +\ 3\ C_2H_3O_2^{-1}\ (aq)$

c. HBr (s) ⍰ $H^{+}(aq) + Br^{-}(aq)$

44. Calculate the concentration of **all ions** present in each of the following solutions

a. 0.100 mol of $Ca(NO_3)_2$ in 100.0 mL of solution

$$M = \frac{mol}{L} \qquad so.... \qquad M\ of\ Ca(NO_3)_2 = \frac{0.1\ mol}{0.1\ L} = 1\ M\ Ca(NO_3)_2$$

$$This\ will\ produce\ a\ solution\ with\ 1\ M\ Ca^{+2}\ and\ 2\ M\ NO_3^{-1}$$

b. 2.5 mol of sodium sulfate in 1.25 L of solution

$$M = \frac{mol}{L} \qquad so.... \qquad M\ of\ Na_2SO_4 = \frac{2.5\ mol}{1.25\ L} = 2\ M\ Na_2SO_4$$

$$This\ will\ produce\ a\ solution\ with\ 4\ M\ Na^{+}\ and\ 2\ M\ SO_4^{-2}$$

c. 5.00 g of ammonium chloride in 500.0 mL of solution

$$5\ g\ NH_4Cl\ x \frac{1\ mol}{53.5\ g} = 0.0934\ mol\ NH_4Cl$$

$$M = \frac{mol}{L} \qquad so.... \qquad M\ of\ NH_4Cl = \frac{0.0934\ mol}{0.5\ L} = 0.187\ M\ NH_4Cl$$

$$This\ will\ produce\ a\ solution\ with\ 0.187\ M\ NH_4^{+}\ and\ 0.187\ M\ Cl^{-1}$$

d. 1.00 g of potassium phosphate in 250.0 mL of solution

$$1.00\ g\ K_3PO_4\ x \frac{1\ mol}{212.27\ g} = 0.0047\ mol\ K_3PO_4$$

$$M = \frac{mol}{L} \qquad so.... \qquad M\ of\ K_3PO_4 = \frac{0.0047\ mol}{0.25\ L} = 0.0188\ M\ K_3PO_4$$

$$This\ will\ produce\ a\ solution\ with\ 0.057\ M\ K^{+}\ and\ 0.0188\ M\ PO_4^{-3}$$

45. In solution A, 4.00 grams of calcium bromide is dissolved in 400 mL of solution. In solution B, 2.00 grams of aluminum bromide is dissolved in 500 mL of solution. Solution A and solution B are mixed. What is the bromide ion concentration in the resulting solution?

$$Solution\ A:\ \ 4.00\ g\ CaBr_2\ x \frac{1\ mol}{199.89\ g} = 0.020\ mol\ CaBr_2$$

$$0.02 \text{ moles of } CaBr_2 \text{ will produce a solution with } 0.04 \text{ moles of } Br^-$$

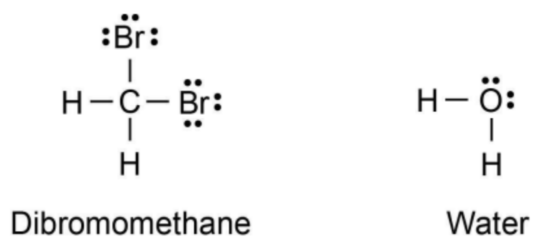
$$\text{Solution B: } 2.00\ g\ AlBr_3\ x \frac{1\ mol}{266.69\ g} = 0.0075\ mol\ AlBr_3$$

$$0.0075 \text{ moles of } AlBr_3 \text{ will produce a solution with } 0.0225 \text{ moles of } Br^-$$

$$\text{Both solutions are combined, so simply add the moles of } Br^- \text{ and divide by the new total volume}$$

$$M = \frac{mol}{L} = \frac{0.04\ moles\ Br^- + 0.0225\ moles\ Br^-}{0.9\ L} = 0.069\ M\ Br^-$$

46. Dibromomethane (CH_2Br_2) and water (H_2O) are both liquids at room temperature and have very nearly the same boiling point. The Lewis structures for these substances are shown below.



a. Compare the overall attraction between molecules in each substance. Explain your reasoning.

Since the molecules have nearly the same boiling point, they are expected to have attractive forces between molecules that are similar in strength.

b. Compare the types of IMFs in each substance, and compare the relative strengths of each type. Explain your reasoning.

Dibromomethane is polar, so will experience dipole-dipole forces. It will also experience London dispersion forces.

Water is polar, but contains an O – H bond, so will experience Hydrogen bonds between molecules. It will also experience London dispersion forces.

The dipole-dipole forces between dibromomethane molecules must be weaker than the hydrogen bonds between water molecules since dibromomethane is much less polar than water. This also implies that the London dispersion forces between dibromomethane molecules are similar in strength to the hydrogen bonds between water molecules. This is possible because of the large electron clouds on the Br atoms, making the molecular very polarizable.

c. NaBr is more soluble in one of these two liquids. Identify which of the two is the better solvent for NaBr, and explain your reasoning.

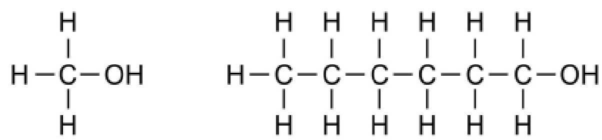
NaBr is an ionic solid, and it's ions will experience ion-dipole attractions with both dibromomethane and water molecules. Since water is more polar than dibromomethane, the ion-dipole attractions with the water molecules will be stronger, making it more soluble in water than in dibromomethane. Water is therefore the better solvent.

d. When CH_2Br_2 and H_2O are mixed, they form distinct layers. Explain why this occurs. In your explanation, use CH_2Br_2 as the solute and answer in terms of solute-solute, solvent-solvent, and solute-solvent interactions.

The formation of two separate layers indicates that dibromomethane is not soluble in water, despite the fact that they are both polar.

Solubility requires that solute-solvent interactions be stronger than the attractive forces within the solute and the solvent. Since these two liquids are not soluble, the dipole-dipole forces that would form between them are not stronger than the hydrogen bonds between water molecules.

47.



Methanol 1-hexanol

A student tests the ability of methanol and 1-hexanol to be dissolved in the solvents water and hexane (C_6H_{14}).

a. The student finds that methanol is completely soluble in water, whereas 1-hexanol is only slightly soluble in water. Explain these results in terms of intermolecular forces (IMFs), such as London dispersion forces (LDFs), dipole-dipole interactions, or hydrogen bonding.

The long carbon chain of 1-hexanol makes the majority of the molecular non-polar, despite the very polar O – H bond on the end. Since most of the molecule is non-polar, it will not form enough significantly strong intermolecular forces with water molecules, making it less soluble.

Methanol however has a much smaller carbon chain, so it is much more polar than 1-hexanol. This will allow hydrogen bonds to form between water molecules and methanol molecules, making it very soluble.

b. The student also observes that 1-hexanol is soluble in hexane, whereas methanol is only slightly soluble in hexane. Explain these results in terms of IMFs.

1-hexanol is soluble in hexane because hexane is non-polar, and the majority of the 1-hexanol molecule is non-polar as well. This means that London dispersion forces will be able to form between the two molecules, allowing them to mix. Methanol however, is a largely polar molecule. This means that no significantly strong intermolecular force will be able to form between methanol and hexane molecules.

The student notices that 2-methylheptane (C_8H_{18}, commonly known as isooctane), a hydrocarbon used in gasoline, is described in a reference book as hydrophobic and thus insoluble in water. The student concludes that isooctane and water molecules repel each other.

c. Identify all of the types, and describe the relative strengths, of the intermolecular forces that occur between water molecules, between isooctane molecules, and between water and isooctane molecules, and use that information to explain the error in the student's conclusion.

Water molecules are polar and would be attracted to each other primarily with strong hydrogen bonds.

Isooctane molecules are non-polar and would be attracted to each other primarily with London dispersion forces.

Isooctane molecules and water molecules would be attracted to one another by only very weak London dispersion forces. These forces are not strong enough to break the much stronger hydrogen bonds between water molecules, which explains why the two liquids are insoluble. This explains why the student's conclusion was incorrect. Water molecules do not repel isooctane molecules, they are attracted too weakly for a solution to form.

48. Each example below provides a correct, real-life observation. The statement that follows is an attempt at explaining or describing some aspect of the observation, and is incorrect in at least one way. Correct each statement by rewriting the statement OR by explaining why it is wrong.

Observation: Ammonia, NH_3, is more soluble in water than phosphorus trihydride.

a. Statement: Ammonia, NH_3, is more soluble in water than phosphorus trihydride because it will experience stronger dipole-dipole attractions with water molecules.

b. Correction / explanation:

Ammonia IS more soluble in water than phosphorus trihydride because it experiences stronger dipole-dipole attractions with water molecules. What is missing is the name of those stronger attractions: hydrogen bonds!

Corrected statement should read: "Ammonia, NH_3, is more soluble in water than phosphorus trihydride because it will experience hydrogen bonds with water molecules, while phosphorus trihydride will only experience very weak dipole-dipole forces with water molecules."

Observation: Potassium oxide is soluble in water.

c. Statement: The ionic bonds between between K and O ions are much stronger than the ion-dipole forces between those same ions and water molecules.

d. Correction / explanation:

Since potassium oxide is soluble in water, that means that the ion-dipole forces between K and O ions must be stronger than the ionic bonds and the hydrogen bonds between water molecules.

Corrected statement should read: "The ionic bonds between between K and O ions are weaker than the ion-dipole forces between those same ions and water molecules."

Observation: A 1.0 M solution of aluminum chloride is a better conductor of electricity than a 1.0 M solution of sodium chloride.

e. Statement: When sodium chloride dissolves in water it forms a greater number of ions than aluminum chloride. Specifically, sodium chloride will produce more moles of sodium ions than aluminum chloride will produce of aluminum ions.

f. Correction / explanation:

The formula of sodium chloride is NaCl. When it dissolves, it will produce two ions, Na^+ and Cl^{-1}. The formula of aluminum chloride is $AlCl_3$. When it dissolves, it will produce four ions, 1 Al^{+3} and 3 Cl^{-1} ions. The increased number of moles of ions present in the aluminum chloride solution will make it the better conductor of electricity.

Corrected statement should read: "When aluminum chloride dissolves in water it forms a greater number of ions than sodium chloride. Specifically, aluminum chloride will produce more moles of chloride ions than sodium chloride."

Observation: Methanal, CH_2O, is soluble in water.

g. Statement: As methanal dissolves, the carbon atoms dissociate from the hydrogen and oxygen atoms. Strong London dispersion forces are experienced between these atoms and water molecules, allowing them to remain in solution.

h. Correction / explanation:

Methanal is a molecule, so it is held together with extremely strong covalent bonds. For this reason, when molecules dissolve, they do not break apart into separate atoms. Instead, the methanol molecules will simply be separated from one another, breaking whatever intermolecular force holds them together.

Corrected statement: "As methanal dissolves, the dipole-dipole forces between methanal molecules are broken. Strong dipole-dipole forces are experienced between methanal molecules and water molecules, allowing them to remain in solution."

Observation: Liquid fluoromethane, CH_3F, will form two separate layers when added to water.

i. Statement: The London dispersion forces that form between water and fluoromethane molecules are stronger than the dipole-dipole forces between fluoromethane molecules and stronger than the Hydrogen bonds between water molecules.

j. Correction / explanation:

The observation that the two substances don't mix indicates that the attractive forces formed between them is not strong enough. This is not normal, since usually two polar molecules will be soluble in one another, but in this instance that appears to not be the case.

Corrected statement: "The dipole-dipole forces that form between fluoromethane and water are weaker than the dipole-dipole forces between fluoromethane molecules and weaker than the hydrogen bonds between water molecules."

Observation: A 50.0 mL $CaBr_2$ solution has a molarity of 0.05 M. A different 50.0 mL solution of $AlBr_3$ has a molarity of 0.025 M. The two solutions are mixed and both salts remain fully dissolved.

k. Statement: The bromide ion concentration in the resulting solution is higher than the bromide ion concentration in both original solutions.

l. Correction / explanation:

$$Br^{-1}\ concentration\ in\ CaBr_2\ solution:$$

$$CaBr_2 \rightarrow Ca^{+2} + 2Br^-$$

$$A\ 0.05\ M\ CaBr_2\ solution\ will\ produce\ a\ 0.1\ M\ Br^-\ solution$$

$$Br^{-1}\ concentration\ in\ AlBr_3\ solution:$$

$$AlBr_3 \rightarrow Al^{+3} + 3Br^-$$

$$A\ 0.025\ M\ AlBr_3\ solution\ will\ produce\ a\ 0.075\ M\ Br^-\ solution$$

$$Combined\ solution:$$

$$0.1\ M\ Br^- = \frac{x\ mol}{0.05\ L} \qquad x = 0.005\ mol\ Br^-\ from\ CaBr_2$$

$$0.075\ M\ Br^- = \frac{x\ mol}{0.05\ L} \qquad x = 0.00375\ mol\ Br^-\ from\ AlBr_3$$

$$M = \frac{0.005\ mol + 0.00375\ mol}{0.1\ L} = 0.088\ M\ Br^-$$

The calcium bromide solution had the highest bromide ion concentration.

Observation: A 0.05 solution of $FeCl_2$ is created and added to a 1 cm long cuvette. Red light is directed through the solution and an absorbance of 0.01 is recorded. Blue light is passed through the solution and an absorbance of 3.35 is recorded.

m. Statement: $FeCl_2$(aq) is likely to be blue in color.

n. Correction / explanation:

Since the absorbance with red light is the lowest number, the solution does not absorb red light, so any red light will pass directly through the solution. Since the absorbance with blue light is the highest number, the solution absorbs most of the blue light that passes through. For this reason, the solution is likely to be red.

Corrected statement: "$FeCl_2$(aq) is likely to be red in color."

Observation: A 0.05 solution of $FeCl_2$ is created and added to a 1 cm long cuvette. Blue light is passed through the solution and an absorbance of 3.35 is recorded. The same solution is added to a 2 cm cuvette and an absorbance of 6.67 is recorded.

o. Statement: The $FeCl_2$ molecules in solution absorb more light when the path length is longer because the molecules have increased motion in the greater volume of space. The more they can move, the more light they will absorb.

p. Correction / explanation:

When light has a longer path length, it will interact with a greater number of molecules. In this specific examples, since the light travels twice as far, it will interact with twice as many molecules, so will absorb roughly twice the amount of light. The movement of the particles is not a factor.

Corrected statement: "The $FeCl_2$ molecules in solution absorb more light when the path length is longer because the light will interact with twice as many molecules, absorbing twice as much light."