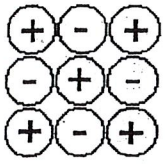
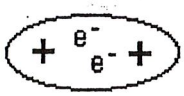
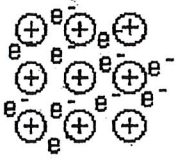
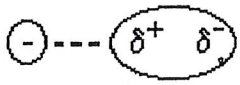
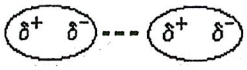
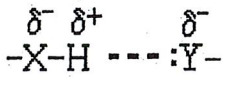
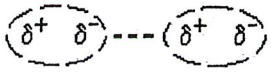
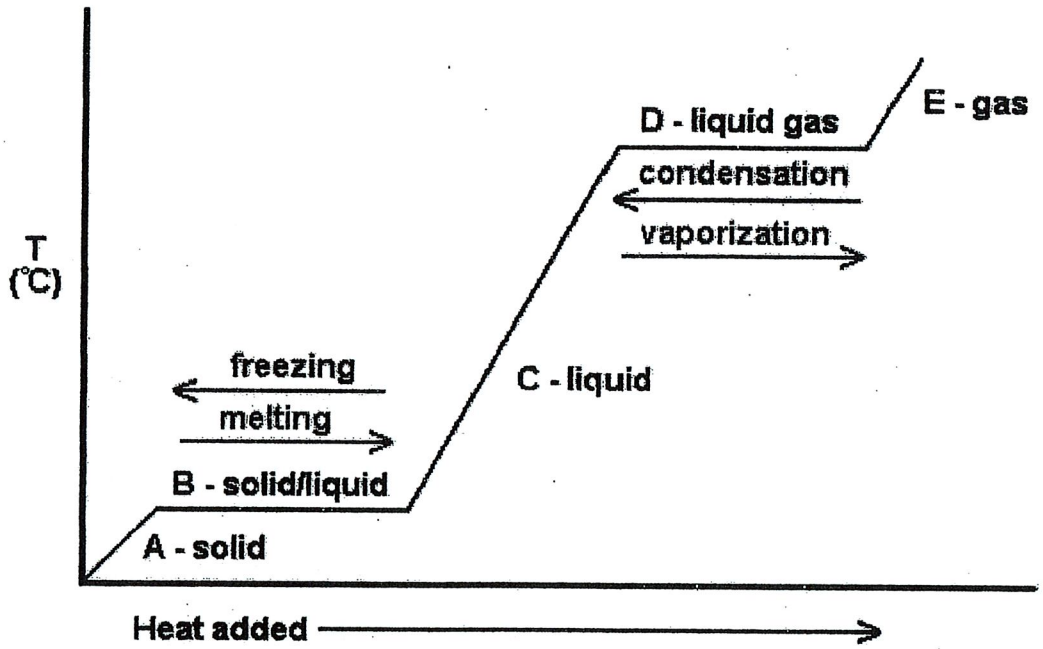
Chapter 10

Liquids + Solids

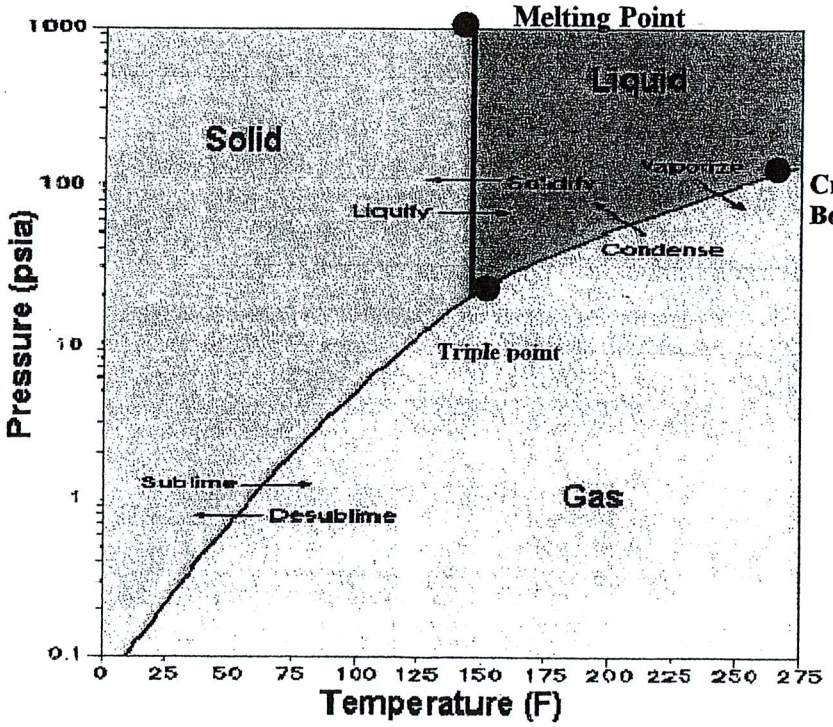
Intermolecular and Intramolecular Forces

Force	Model	Basis of Attraction	Energy (kJ/mol)	Example
Intramolecular				
Ionic		Opposite charges	4000 – 400	NaCl
Covalent		Nuclei – shared e^- pair	1100 – 150	H - H
Metallic		Metal cations and delocalized electrons	1000 – 75	Au
Intermolecular				
Ion-dipole		Ion and polar molecule	600 – 40	Na^+ & H_2O
Dipole-dipole		Partial charges of polar molcules	25 – 5	HCl & HCl
Hydrogen bond		H bonded to N, O, or F, and another N, O, or F	40 – 10	H_2O & NH_3
London dispersion		Induced dipoles of polarizable molecules	40 – 0.05	Xe & Xe

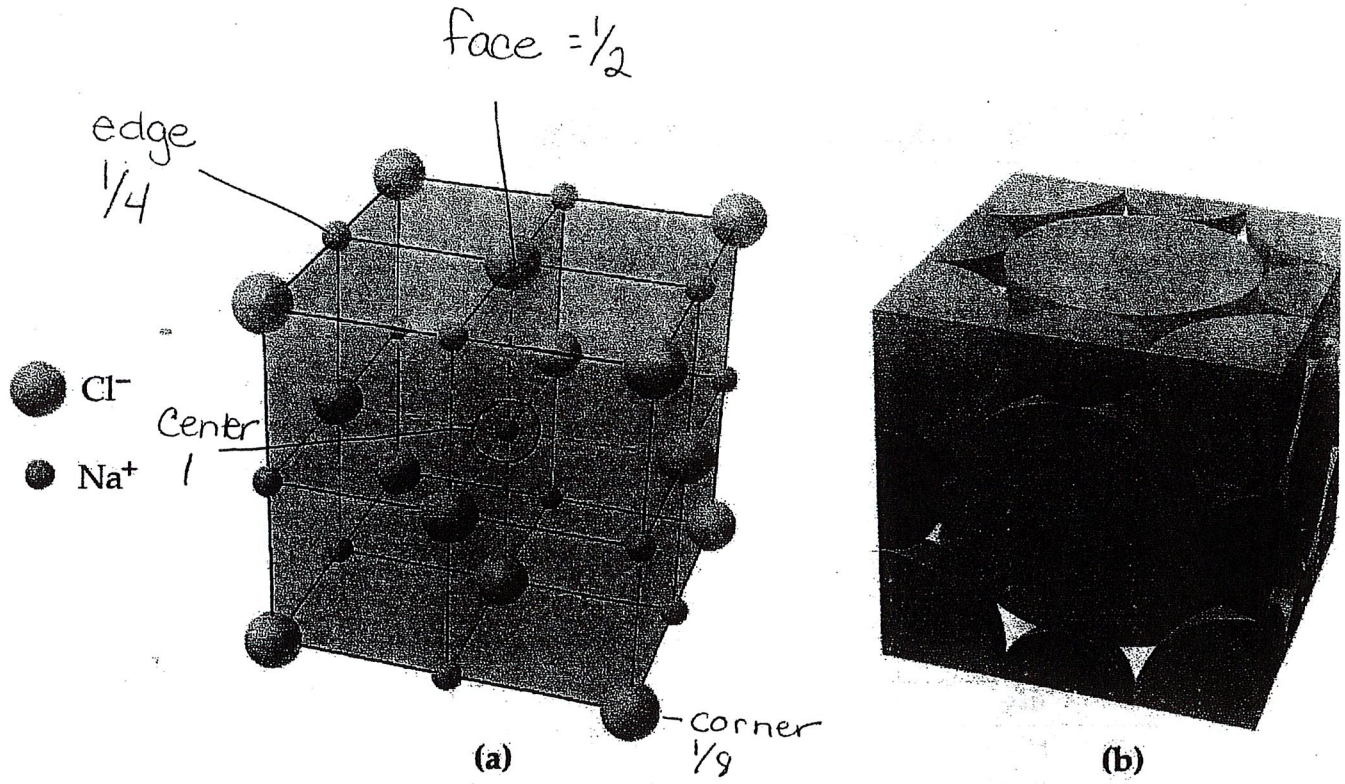
Heating Curve



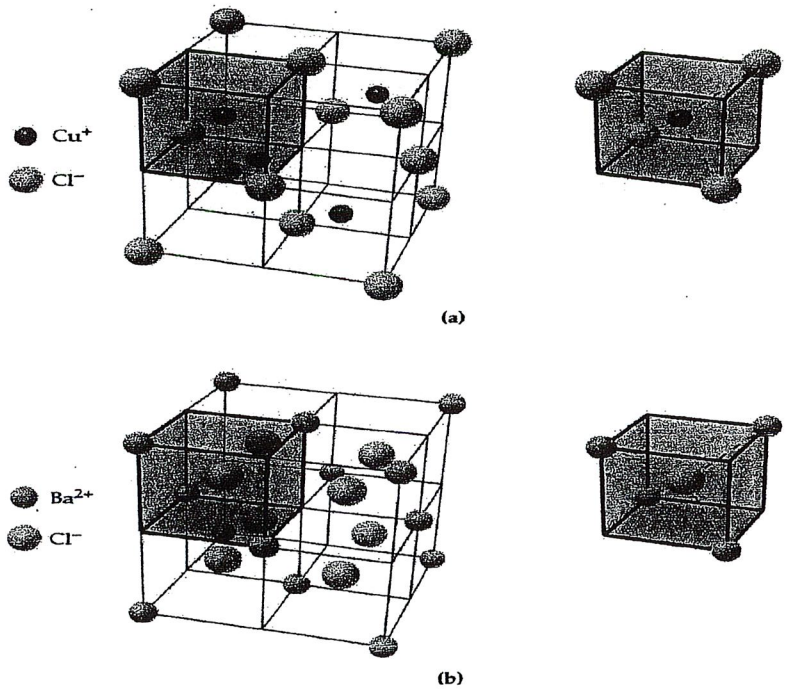
Phase Diagram



Triple point



The unit cell of NaCl in both (a) a skeletal view and (b) a space-filling view in which one face of the unit cell is viewed head-on. The larger chloride anions adopt a face-centered cubic unit cell, with the smaller sodium cations fitting into the holes between adjacent anions.



Unit cells of (a) CuCl and (b) $BaCl_2$. Both are based on a face-centered cubic arrangement of one ion, with the other ion tetrahedrally surrounded in holes. In CuCl, only alternating holes are filled, while in $BaCl_2$, all holes are filled.

• AP Chemistry IMF WKS I

Name _____
Period ___ Date ___/___/___

10 • IMF's, Liquids, & Solids

IMF'S IN SOLIDS

Indicate the **strongest** IMF holding together crystals of the following:

		Molecular Crystal			Metal	Ionic Crystal	Network Solid
		London forces	Dipole-dipole attractions	Hydrogen Bonds	Metallic Bonds	Ionic Bonds	Covalent Bonds
1.	NH_3						
2.	Kr						
3.	HCl						
4.	F_2						
5.	$KMnO_4$						
6.	NaCl						
7.	SO_2						
8.	CO_2						
9.	C_3H_8						
10.	CH_4						
11.	CH_3Cl						
12.	HF						
13.	C_6H_6						
14.	NO						
15.	H_2SO_4						
16.	WC						
17.	Si						
18.	SiO_2						
19.	$C_{(graphite)}$						
20.	N_2						
21.	CH_3OH						
22.	Ag						
23.	$(C_2H_5)_2NH$						
24.	NaOH						
25.	Al						
26.	PCl_3						
27.	XeF_4						

NOTES:

more on the back...

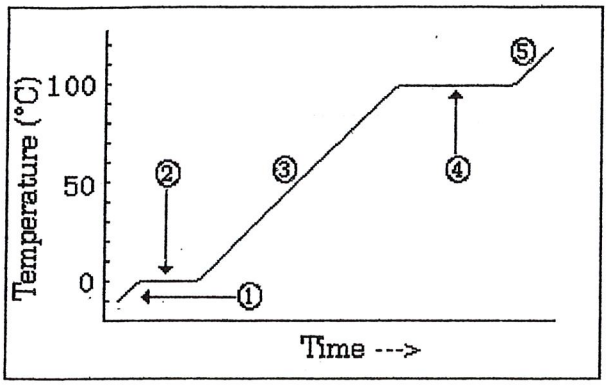
South Pasadena • AP Chemistry

Name _____

Period __ Date ___/___/___

6 • Energy and Chemical Reactions

HEATING CURVE CALCULATIONS



In the heating and cooling curves tutorial we learned that energy is **absorbed** by a substance as it **warms up**, **melts** (fusion) or **boils** (vaporization) and energy is **released** from a substance as it **cools down**, **condenses**, or **freezes**.

Calorimetry ($q=mC\Delta T$) allows us to calculate the energy changes as a substance **warms or cools**. (1, 3, & 5)

The energies involved in **phase changes** (areas 2 & 4) are the **Heat of Vaporization** (liquid → gas) and the **Heat of Fusion** (solid → liquid). These energies will be used as conversion factors.

Heat of Vaporization or Heat of Condensation of water	**Heat of Fusion (melting) or Heat of Solidification of water**
$H_{vap} = \frac{2330\ J}{gram}$	$H_{fus} = \frac{335\ J}{gram}$

Joules (J) are energy units. It takes 4.184 Joules of energy to heat 1 gram of water by 1 °C.

Examples:

Calculate the energy needed to vaporize 10.0 g of water.

$$10.0\ g\ H_2O \times \frac{2330\ J}{gram} = 23{,}000\ J = 23.0\ kJ$$

Calculate the energy released when 10.0 kg of water melts.

$$10.0\ kg\ H_2O \times \frac{1000\ g}{1\ kg} \times \frac{335\ J}{gram} = 3{,}350{,}000\ J = 3{,}350\ kJ$$

Do the following calculations. Show your equation for each problem. Box your answers.

1. Calculate the energy needed to vaporize…

   a) 15.0 g of water

   b) 5.75 kg of water

   c) 3.88 moles of water

   This is represented on the Heating Curve as Section ____.

(5)

2. Calculate the mass of water (in grams) that will be vaporized by…

   a) 20.0 kJ of energy

   b) 175 kJ of energy

   c) 135 J of energy

3. Calculate the energy needed to melt…

   a) 23.0 g of water

   b) 8.75 kg of water

   c) 3.25 moles of water

   This is represented on the Heating Curve as Section ____.

4. Calculate the mass of water (in grams) that will be melted by…

   a) 30.0 kJ of energy

   b) 7.60 kJ of energy

   c) 133 J of energy

5. Calculate the energy…

   a) absorbed by 35.8 g of ice melting

   b) released as 88.5 g of water vapor condenses

   c) released as 92.2 g of water freezes

   d) absorbed as 13.6 g of water vaporizes

   e) absorbed when 2.25 moles of ice melts

   f) absorbed when 2.25 moles of water vaporizes

6. A 25.00 gram sample of ice at 0.0°C melts and then warms up to 20.0°C. How much energy is absorbed?

   This problem is represented on the Heating Curve as Sections ____ & ____.

Phase Change Worksheet

1) A 12 oz. can of soda weighs about 450 grams. How many joules are released when a can of soda is cooled from 25 degrees Celsius (room temperature) to 4 degrees Celsius (the temperature of a refrigerator). **The heat capacity of liquid water is 4.18 J / gram x °C.** (AKA Specific heat)

2) How many joules are required to heat 250 grams of liquid water from 0^0 to 100^0 C ?

3) How many joules are required to melt 100 grams of water? **The heat of fusion of water is 6.01 kJ / mole.**

4) How many joules are required to boil 150 grams of water? **The heat of vaporization of water is 40.67 kJ / mole.**

5) How many joules are required to heat 200 grams of water from 25 ^{0}C to 125 ^{0}C? **The heat capacity of steam is 1.84 J / g · ^{0}C**

6) How many joules are given off when 120 grams of water are cooled from 25 °C to -25°C? **The heat capacity of ice is 2.09 J / g · °C.** (AKA Sp. heat)
heat of solidification - 334 J/g·C

7) How many joules are required to heat 75 grams of water from -85 °C to 185°C? **The heat capacity of steam is 1.84 J / g · °C.** (AKA Sp. heat)
~~heat of~~

8) How many joules are required to heat a frozen can of juice (360 grams) from -5 ° C (the temperature of an overcooled refrigerator) to 110 °C (the highest practical temperature within a microwave oven)?

9) How many joules are released when 450 grams of water are cooled from 4×10^{7} °C (~~the hottest temperature ever achieved by man~~) to 1×10^{-9} °C (~~the coldest temperature achieved by man~~). Heat of solidification -334 J/g·C

10) How many joules are required to raise the temperature of 100 grams of water from -269 °C (the current temperature of space) to 1.6×10^{15} °C (the estimated temperature of space immediately after the big bang)?

IMF WKS

Intermolecular Forces Worksheet II

1) Using your knowledge of molecular structure, identify the main intermolecular force in the following compounds. You may find it useful to draw Lewis structures to find your answer.

   a) PF_3 _____

   b) H_2CO _____

   c) HF _____

2) Explain how dipole-dipole forces cause molecules to be attracted to one another.

3) Rank the following compounds from lowest to highest boiling point: calcium carbonate, methane, methanol (CH_4O), dimethyl ether (CH_3OCH_3).

4) Explain why nonpolar molecules usually have much lower surface tension than polar ones.

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Name_____

Period _____ Date ___/___/___

• IMF's, Liquids, and Solids

PRACTICE TEST

1. Surface tension in a liquid is due to the fact that
   a) surface molecules are pulled toward the interior
   b) liquids tend toward lowest energy
   c) PE is increased for molecules at the surface
   d) interior molecules are attracted in all directions
   e) all of the above

2. In which one of the following will dipole-dipole attractions play the most significant role as the intermolecular attraction?
   a) HCl
   b) NaCl
   c) Kr
   d) H_2O
   e) NH_3

3. With which type of substances do London dispersion forces play the most significant role?
   a) polar molecules
   b) metals
   c) ionic compounds
   d) non-polar molecules
   e) network compounds

4. The heat of vaporization of H_2S, at its boiling point (–61°C) is 18.8 kJ/mol. What mass of H_2S can be vaporized (at its boiling point) with 100 kJ of energy?
   a) $100 \times \frac{61}{18.8}$
   b) $34.1 \times \frac{18.8}{100}$
   c) $61 \times 18.8 \times 100 \times 34.1$
   d) $18.8 \times \frac{61}{34.1}$
   e) $100 \times \frac{34.1}{18.8}$

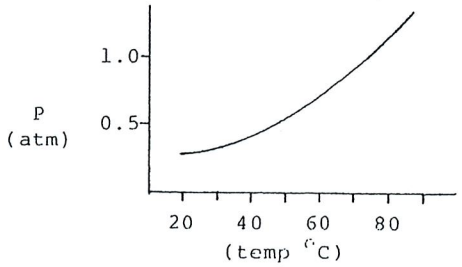
5. Which one of the following substances exhibits the strongest intermolecular forces of attraction?
   a) CH_4
   b) C_2H_6
   c) C_3H_8
   d) CH_3OH
   e) CH_3Cl

6. For which substance would you predict the highest heat of vaporization?
   a) F_2 b) H_2O c) HF d) NaCl e) Br_2

7. Which of the following will change the equilibrium vapor pressure of a liquid?
   I. Heat up or cool down the liquid
   II. Increase the Volume of the container
   III. Change the pressure above the liquid
   a) I only
   b) I and II only
   c) I, II, and III
   d) I and III only
   e) II and III only

8. Which of the following statements describes a substance above its critical point?
   a) the substance can be liquefied
   b) the vapor and liquid phase become indistinguishable
   c) the substance experiences no intermolecular interactions
   d) there is a distinct phase boundary between the liquid and vapor
   e) all of the above

9. At what temperature will the liquid (whose vapor pressure is shown below) boil if the air pressure is reduced to 380 mmHg?

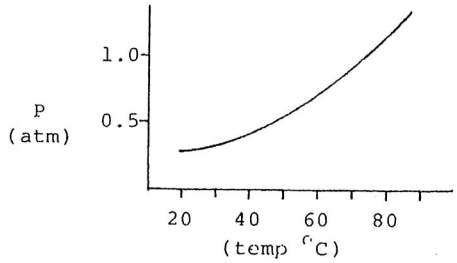


   a) 30°C b) 50°C c) 70°C d) 100°C
   e) the liquid will not boil at this pressure

10. Which one of the following is linked with the correct intermolecular force of attraction?
    a) NH_3 ..... dipole-dipole
    b) AlH_3 ..... London dispersion forces
    c) H_2 ..... hydrogen bonding
    d) C_2H_4 ..... covalent bonding
    e) HCl ..... ionic

10

11. The vapor pressure graph of an unknown liquid is shown below. Which of the following statements about this liquid is/are true?



I. This liquid has weaker IMF's than water.
II. The liquid's normal boiling point is around 75°C.
III. The liquid boils at room temperature when the pressure is dropped to about 0.25 atm.

a) II and III only
b) II only
c) I and III
d) I only
e) I, II, and III

12. How much energy does it require to melt 25.0 g benzene, C_6H_6? The heat of fusion of benzene is 2.37 kJ/mol. [molar mass = 78.0 g/mol)

a) 8.25 kJ
b) 59.3 kJ
c) 4625 kJ
d) 0.759 kJ
e) none of these

13. What type of solid(s) can contain covalent bonds?

a) molecular
b) metallic
c) ionic
d) network
e) all but "b"

14. Which type of solid generally has the highest melting point?

a) metallic
b) ionic
c) molecular
d) network

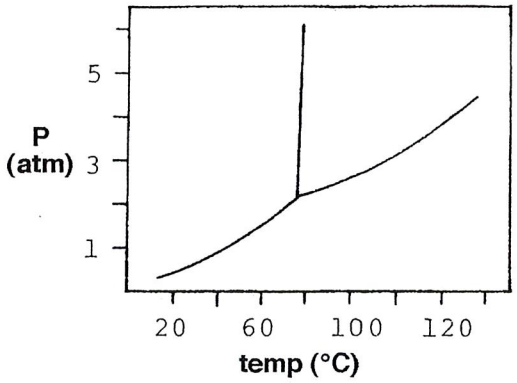
15. Which substance below exhibits the weakest IMFs?

a) IF_3 b) SO_2 c) CO_2 d) SiO_2 e) PH_3

16. During the condensing of a liquid, the kinetic energy _____ and the potential energy _____.

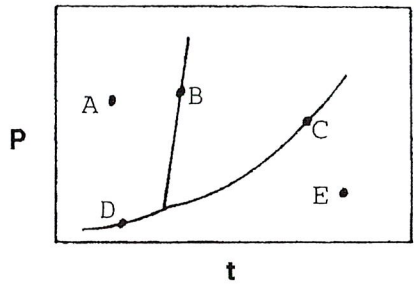
a) stays the same, increases
b) increases, decreases
c) increases, increases
d) decreases, stays the same
e) stays the same, decreases

17. The phase diagram of a substance is given below. What occurs when the substance is heated from 100° C to 120 °C at 3 atm pressure?



a) it melts
b) it sublimes
c) it boils
d) it freezes
e) no phase change occurs

18. A typical phase diagram for a substance is given below. At what point on the diagram do solid and liquid exist at equilibrium?



a) A b) B c) C d) D e) E

19. ~~Which one of the following as solids has a crystal structure containing discrete (separate) molecules?~~

~~a) potassium d) carborundum, SiC~~
~~b) glass e) hydrogen~~
~~c) quartz~~

20. The heat of sublimation of a compound equals

a) heat of fusion plus heat of vaporization
b) heat of ionization plus heat of crystallization
c) heat of vaporization minus heat of fusion
d) heat of vaporization plus heat of crystallization
e) heat of crystallization plus heat of vaporization

21. The normal boiling point of a liquid
    a) is 100 °C at 1 atm pressure.
    b) is the temperature at which the vapor pressure is 1 atm.
    c) is the temperature at which liquid and vapor are in equilibrium.
    d) is the temperature at which the vapor pressure equals the external pressure.
    e) is the temperature at which there is a continuous formation of gaseous bubbles in the liquid.

22. The vapor pressure of a liquid increases with an increase of temperature. Which of the following best explains this increase?
    a) The average kinetic energy of molecules is greater, thus more molecules can enter the gaseous state.
    b) The number of gaseous molecules above the liquid remains constant but these molecules have greater average kinetic energy.
    c) the faster moving molecules in the liquid exert a greater pressure.
    d) All the molecules have greater kinetic energies.
    e) The intermolecular forces between the molecules becomes less at higher temperatures.

23. Which of the following indicates very strong intermolecular forces of attraction in a liquid?
    a) A very low boiling point.
    b) A very low critical temperature.
    c) A very low heat of vaporization.
    d) A very low vapor pressure.
    e) A very low surface tension.

24. The compounds Br_2 and ICl have almost identical molecular weights, yet ICl boils at 97°C and Br_2 boils at 59 °C. The best explanation for the difference is
    a) ICl is an ionic compound and Br_2 is covalent.
    b) ICl is a nonpolar molecule and Br_2 is polar.
    c) ICl has a longer bond than that in Br_2 .
    d) ICl has a measurable dipole moment (is polar) and Br_2 does not (is nonpolar).
    e) ICl has a stronger bond than that in Br_2 .

25. In some compounds the hydrogen atom is covalently bonded to one atom and simultaneously attracted to another atom in another molecule by an electrostatic interaction. This interaction can occur when hydrogen is bonded to
    a) Cl b) Si c) N d) C e) Br

26. Which of the following compounds shows an abnormal boiling point due to hydrogen bonding?
    a) CH_3NH_2 d) CH_3Cl
    b) CH_3OCH_3 e) HCl
    c) CH_3SH

27. Which of the following has the **lowest** boiling point?
    a) H_2O d) H_2Te
    b) H_2S e) NH_3
    c) H_2Se

28. Which of the following would be expected to have the highest heat of vaporization?
    a) H_2O c) HF
    b) NH_3 d) all three are the same

29. Which element is considered a covalent/network solid?
    a) Cr b) O c) Xe d) B e) Na

30. Which one of the following compounds has intermolecular forces different than the others?
    a) quartz, SiO_2 d) $C_{(graphite)}$
    b) $C_{(diamond)}$ e) silicon carbide, SiC
    c) carbon dioxide, CO_2

Answers

1.	9.	17.	25.
2.	10.	18.	26.
3.	11.	19.	27.
4.	12.	20.	28.
5.	13.	21.	29.
6.	14.	22.	30.
7.	15.	23.	
8.	16.	24.	

12

Intermolecular Forces Sample AP Questions

2004 Question 7

Use appropriate chemical principles to account for each of the following observations. In each part, your response *must* include specific information about *both* substances.

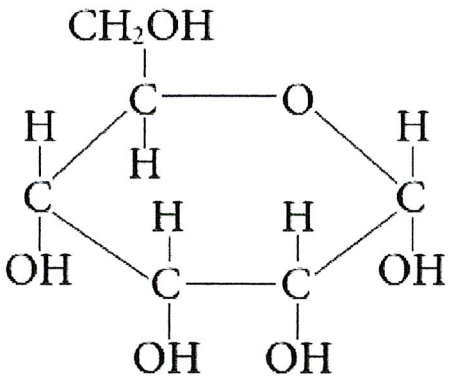
(a) At 25°C and 1 atm, F_2 is a gas, whereas I_2 is a solid.

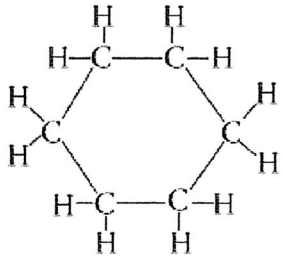
(d) Ammonia, NH_3, is very soluble in water, whereas phosphine, PH_3, is only moderately soluble.

2006 Question 6

Answer each of the following in terms of principles of molecular behavior and chemical concepts.

(a) The structures for glucose, $C_6H_{12}O_6$, and cyclohexane, C_6H_{12}, are shown below.





Identify the type(s) of intermolecular attractive forces in:

(*i*) pure glucose

(*ii*) pure cyclohexane

(b) Glucose is soluble in water but cyclohexane is not soluble in water. Explain.

2005 Question 7

Use principles of atomic structure, bonding and/or intermolecular forces to respond to each of the following. Your response *must* include specific information about *all* substances referred to in each question.

(a) At a pressure of 1 atm, the boiling point of $NH_3(l)$ is 240 K, whereas the boiling point of $NF_3(l)$ is 144 K.

(*i*) Identify the intermolecular force(s) in each substance.

(*ii*) Account for the differences in the boiling points of the substances.

2001 Question 8

Account for each of the following observations about pairs of substances. In your answers, use appropriate principles of chemical bonding and/or intermolecular forces. In each part, your answer must include references to *both* substances.

(a) Even though NH_3 and CH_4 have similar molecular masses, NH_3 has a much higher normal boiling point (-35°C) than CH_4 (-164°C).

2002 Multiple-Choice Questions

67. Which of the following describes the changes in forces of attraction that occur as H_2O changes phase from a liquid to a vapor?
    (a) H-O bonds break as H-H and O-O bonds form.
    (b) Hydrogen bonds between H_2O molecules are broken.
    (c) Covalent bonds between H_2O molecules are broken.
    (d) Ionic bonds between H^+ ions and OH^- ions are broken.
    (e) Covalent bonds between H^+ ions and H_2O molecules become more effective.

70. Of the following pure substances, which has the highest melting point?
    (a) S_8
    (b) I_2
    (c) SiO_2
    (d) SO_2
    (e) C_6H_6