AP Chemistry

**Unit 10 IMFs – Liquids, Solids, and Phase Changes**

This unit focuses on liquids, solids and phase changes. It addresses Topic II (States of Matter) in the College Board's Advanced Placement Chemistry Topic Outline. In particular it focuses on Liquids and solids. We’ll introduce properties of the condensed states: liquids and solids, beginning with a discussion of the forces that hold molecules together in the condensed states. We'll then explore the properties of liquids and solids that come from these intermolecular forces. We'll look at the four types of crystalline solids: metallic, ionic, molecular, and network. Finally, we'll explore unit cells, the building blocks of solids. In exploring the transitions between states of matter, we'll first look at vapor pressure of liquids and solids. Then, we'll introduce a graphical tool called a phase diagram that depicts the physical state of a substance as a function of temperature and pressure.

**Learning Targets**

8.1 Distinguish between INTRAmolecular forces and INTERmolecular forces.

8.2 Classify intermolecular forces.

8.3 Justify differences in properties of substances in terms of intermolecular forces.

8.4 Apply the Clausius-Clapeyron Equation to relate the vapor pressure of any substance to temperature

8.5 Interpret phase diagrams and phase changes according to the intermolecular forces.

8.6 Describe forms and properties of solids.

**READ AND OUTLINE CHAPTERS 11 AND 12.**

**CHAPTER 11 PROBLEM SET: 2, 5, 7, 16, 29, 37, 39, 50, 81, 89, 97**

**Podcast 8.1 Types of Forces Between Molecules**

INTRAMolecular Forces = \_\_\_\_\_\_\_\_\_\_\_\_

* Covalent (100)
* Ionic (85)
* Metallic (65)

Intermolecular Forces

* Interaction of molecules with other molecules
* \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ forces than bonds
* Less energy is required to overcome the force of an intermolecular attraction than a chemical bond.
* Examples of “breaking” intermolecular forces:

  + The stronger the IMF, the \_\_\_\_\_\_\_\_\_\_\_\_\_\_ the melting point/boiling point.

Types of Intermolecular Forces

1.

2.

3.

4.

* All are considered \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ in nature (attractions between + and – species)

Ion-Dipole Forces

* Exist between an ion and the \_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_ on the end of a polar molecule
* Remember that polar molecules are dipoles and have a dipole moment

Sketch an ion and a dipole below

Dipole-Dipole Forces

* The \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ end of one polar molecule is attracted to the \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ end on another polar molecule.
* Effective only when polar molecules are close together and in correct \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_than ion-dipole forces
* Dipole-dipole interactions involve both attractive and \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ forces

Sketch dipole-dipole interaction below

* Molecules of equal mass and size exhibit stronger intermolecular attractions with increasing \_\_\_\_\_\_

Hydrogen Bonding – NOT a true bond!

* Attraction between a hydrogen atom in a polar bond and an unshared electron pair on a nearby small \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ ion or atom (generally \_\_\_\_\_, \_\_\_\_\_, or \_\_\_\_\_)
* A strong intermolecular attraction that accounts for high m.p. and b.p., specific heat, and heat of vaporization
* Special kind of dipole-dipole attraction
* Strong because protons are more massive in size than electrons
* Reason ice is \_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_ than water

Boiling Points

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |

Hydrogen Bonds in Water



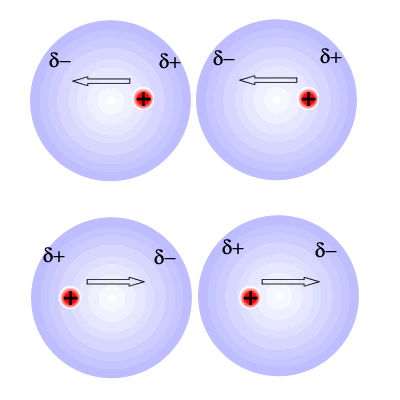
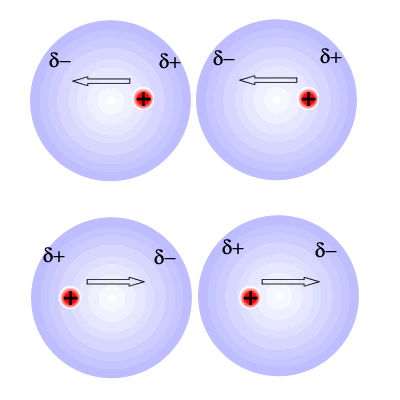
London Dispersion Forces

* Attraction based on \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ location of one molecule to electron location on a \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ molecule
* Non - polar molecules also exert forces on each other – otherwise, there would be no nonpolar solids or liquids.
* \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ can be induced by attraction of opposite dipoles

Sketch Interaction of Oxygen Molecules

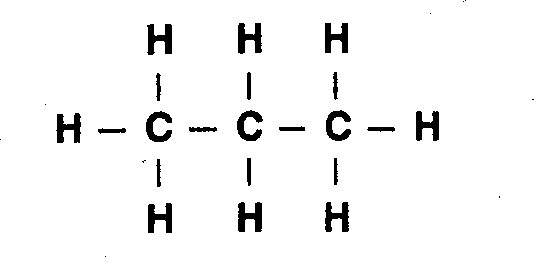
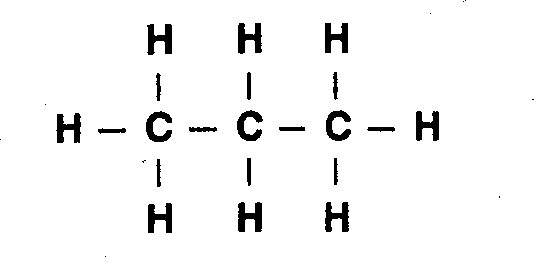
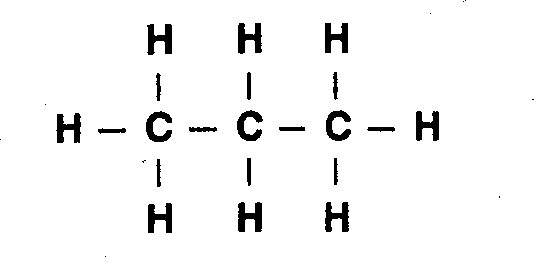
* More \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ molecules (“squishy electron clouds”) have \_\_\_\_\_\_\_\_\_\_\_\_\_ L-D forces, dependent on shape
* This force increases with \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ molecule size (larger molar mass)
* Weak, short-lived.
* Lasts longer at low \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.
* Explains the trend for bigger molecules, higher melting and boiling points.
* Much, much weaker than other forces.
* Also called \_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_ forces.

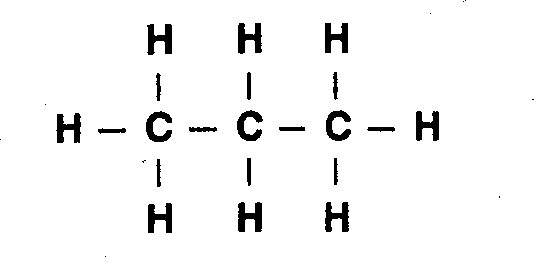
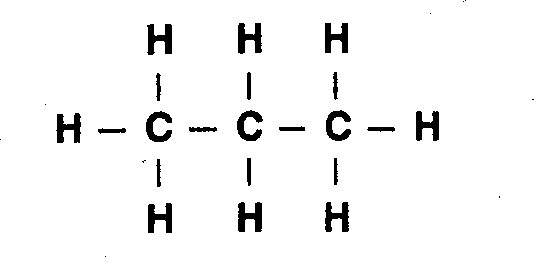
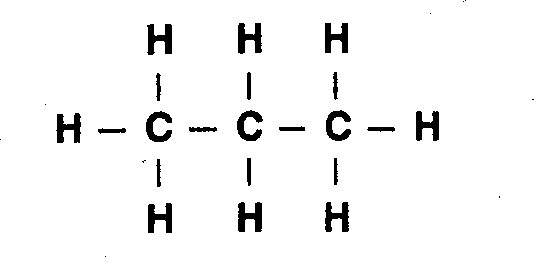
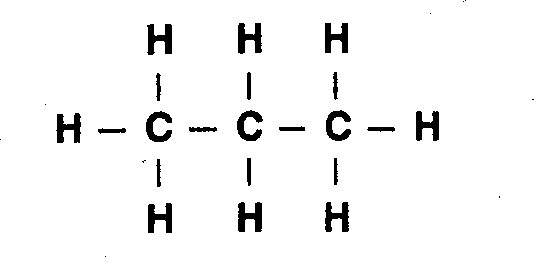
Example



* Vibrations of the nucleus within the electron charge cloud creates a \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ dipole, shown here as δ+ and δ- charges.
* This causes sympathetic vibrations of the nucleus in \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ atoms, so that the δ+ and δ- charges become arranged opposite one another (plus near minus, minus near plus)
* There is now attraction between the induced dipole of opposite δ charges on neighboring atoms, creating Van der Waal's forces.
* Eventually all of the atoms or molecules vibrate in unison, making the partial charges \_\_\_\_\_\_\_\_ \_\_\_ enough to hold the structure together.
* When enough energy is given to a substance held together by only Van der Waal's forces, they are overcome and the compound \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.

Compare Boiling Points of Alkanes





Paraffins C20 and up are low-melting solids (candles)

Asphalt C36 and up only produce gummy residues on heating

*Comparing Intermolecular Forces – Complete the Flow-Chart Below*

|  |  |  |  |
| --- | --- | --- | --- |
| **NETWORK COVALENT** | **METALLIC** | **IONIC** | **MOLECULAR COVALENT** |
|  |  |  |  |
| **Tm:** Glass ~1450oC, Diamond ~3500oC | **Tm:** 60oC to over 3000oC | **Tm:** Can be over 3000oC | **Tm:** -272 (He) to >100oC (I2 is 113oC) |

Assignment 1: Identifying Intermolecular Forces

1. Identify the most important types of inter-particle (between “molecules”) forces present in the solids of each of the following substances

a) BaSO4

b) H2S

c) Xe

d) CHCl3

e) NH3

2. Predict which substance from the following pairs would have the greater intermolecular forces. (you WILL need to draw the Lewis structures to answer correctly)

a) CO2or OCS

b) PF3or PF5

c) SO3or SO2

d) HF or HBr

e) CH3OH or H2CO

f) CH3CH2CH2NH2 or H2NCH2CH2NH2



**Podcast 8.2 Influence of IMFs on Properties**

Properties of Liquids – Many of the properties are due to internal \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ of atoms.

Viscosity – the resistance of a liquid to \_\_\_\_\_\_\_\_\_\_\_\_\_.

* + The greater the viscosity, the slower it flows
  + Can be measured as a rate of flow through a metal tube or the rate at which an object falls through the liquid.
  + Viscosity increases with an increase in \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* Large IMFs = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ viscous liquid
* Large molecules can get tangled up.
* Cyclohexane has a \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ viscosity than hexane because it is a circle- more compact.

Sketch molecular structures of cyclohexane and n-hexane below

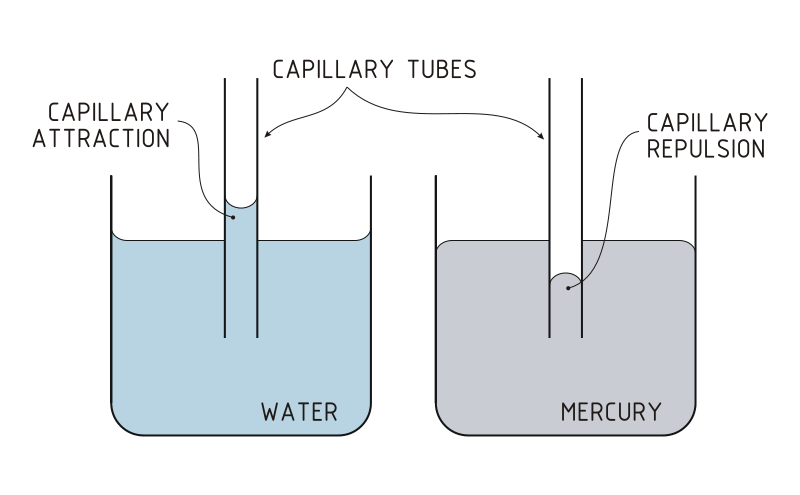
Surface Tension: Energy required to increase the surface area of a liquid by a unit amount

* Inward forces that must be overcome
* Atoms at surface are closer together
* Sketch Surface Tension Below: Molecules in the middle are attracted in all directions.

Cohesion vs Adhesion

* Forces that bind similar molecules (such as H-bonding) are called \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_forces
* Forces that bind a substance to a surface are called \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ forces

Example:

* Water in a glass adheres to the glass because the adhesive force is larger than the cohesive forces of the H2O molecules
* Mercury is the opposite

Capillary Action

* Liquids spontaneously rise in a narrow tube
* Occurs when a small tube is placed in H2O and the water rises into the tube
* Glass is \_\_\_\_\_\_\_\_\_\_\_. It attracts water molecules

Beading: If a polar substance is placed on a non-polar surface.

* + There are \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_, but no adhesive forces.
  + And Visa Versa

Sketch

**Assignment 2: Intermolecular Forces**

The following answer choices can be used in questions 1-3. Each answer may be used once, more than once, or not at all.

(A) London dispersion forces

(B) Hydrogen bonding

(C) Dipole-dipole intermolecular forces

(D) Ionic bonding

(E) Covalent bonding

1. The interaction that occurs between molecules of water but NOT between molecules of chlorine.
2. The interaction that occurs between molecules of hydrogen chloride but NOT between molecules of chlorine
3. The interaction that accounts for the increasing melting and boiling points of the halogens on descending group 17.
4. When sodium chloride dissolves in water, which of the following statements is true?

I. As part of the process, the lattice energy of the sodium chloride must be overcome.

II. The attraction between the sodium and chloride ions and the water molecules can be

described as an ion-dipole interaction.

III. The polarity of the water molecules is essential to the process.

(A) I only

(B) II only

(C) III only

(D) I and II only

(E) I, II, and III

5. Which of the following molecules will have London dispersion forces that form *some* part of the intermolecular attractions present?

I. Fluorine, F2

II. Ammonia, NH3

III. Hydrogen fluoride, HF

(A) I only

(B) III only

(C) I and II only

(D) II and III only

(E) I, II, and III

6. Which of the following has the substances listed in order of increasing boiling point?

I. Water < nitrogen < ammonia

II. Nitrogen < water < chlorine

III. Chlorine < bromine < iodine

(A) I only

(B) II only

(C) III only

(D) II and III only

(E) I, II, and III

7. Which of the following statements is true on descending group 17?

I. The boiling points of the halogen molecules decrease.

II. The molecules become more polarizable.

III. The dipole-dipole intermolecular interactions increase.

(A) I only

(B) II only

(C) III only

(D) II and III only

(E) I, II, and III

8. 2008 FRQ #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 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) SO2 melts at 201 K, whereas SiO2 melts at 1883 K. Account for the difference in melting points. You must discuss both of the substances in your answer.

d) The normal boiling point of Cl2(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.

**Podcast 8.3: Phase Changes**

Phase Changes

* Every phase change is accompanied by a change in the \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ of the system
* ∆Hfus (\_\_\_\_\_\_\_ \_\_\_ \_\_\_\_\_\_\_\_\_\_\_) – molecules of a solid free up, having more ability to move.
* ∆Hvap (\_\_\_\_\_\_\_ \_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_) – molecules of a liquid break free
* ∆Hvap is almost always larger in comparison to ∆Hfus WHY?

Explain

* ∆Hsub (\_\_\_\_\_\_\_ \_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_) – molecules transition from a solid to a gas
* ∆Hsub = ∆Hfus + ∆Hvap

Example: A 5.00 g sample of H2O is removed from a freezer and heated from an initial temperature of -5.00oC to a final temperature of 102.0oC.

1. Given the following data, calculate the amount of energy that has to be absorbed by the H2O during the whole process.

Freezing point of H2O=0.00oC; Boiling point of H2O = 100.oC

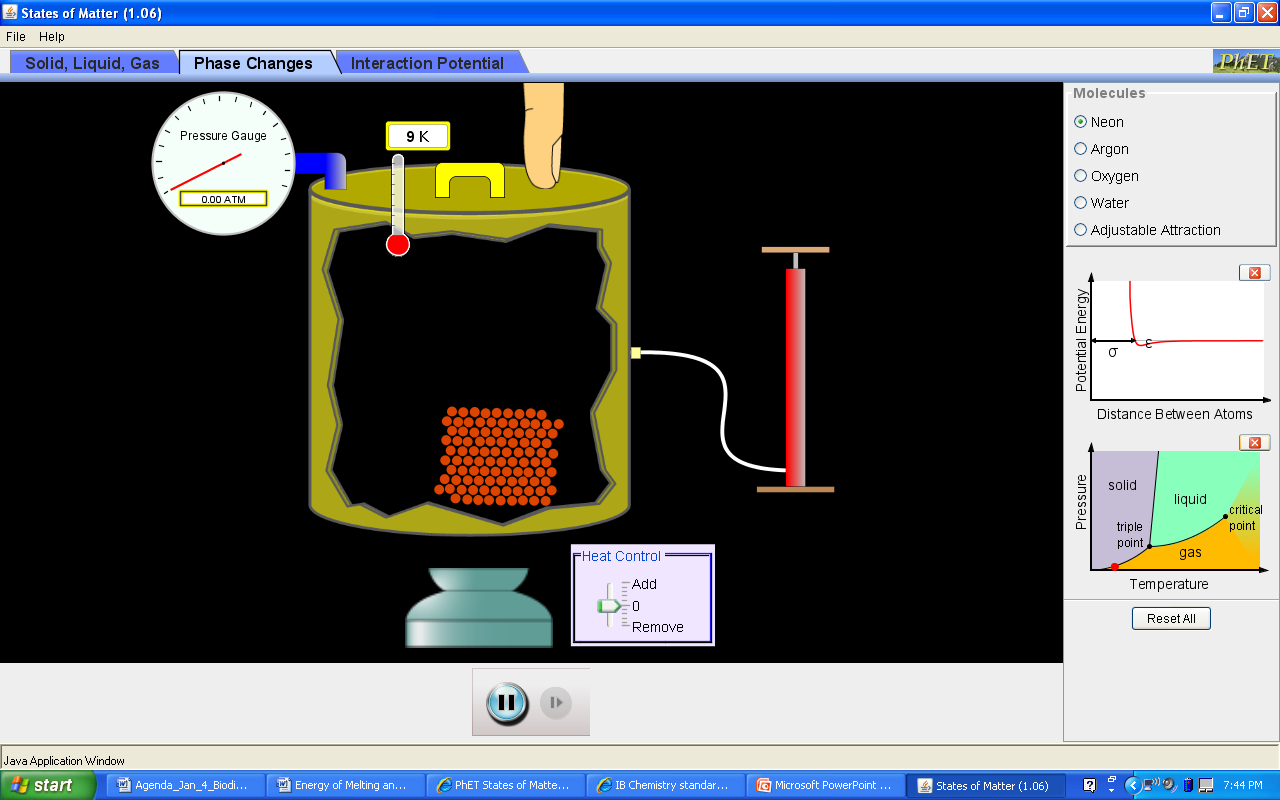
ΔHfus of H2O = 6.01 kJmol-1

ΔHvap of H2O = 40.7 kJmol-1

specific heat capacity of water = 4.18 Jg-1K-1

specific heat capacity of steam = 2.08 Jg-1K-1

1. Calculate the percentage of the total energy required for the overall process in a) that is used just in heating the liquid water.
2. Calculate the mass of ice at 0.00oC that can be melted in 30 minutes by a heater that produces 8000 kJ of energy per hour but in such a way that only 70% of the heat produced is absorbed by the ice.



Phase Diagrams

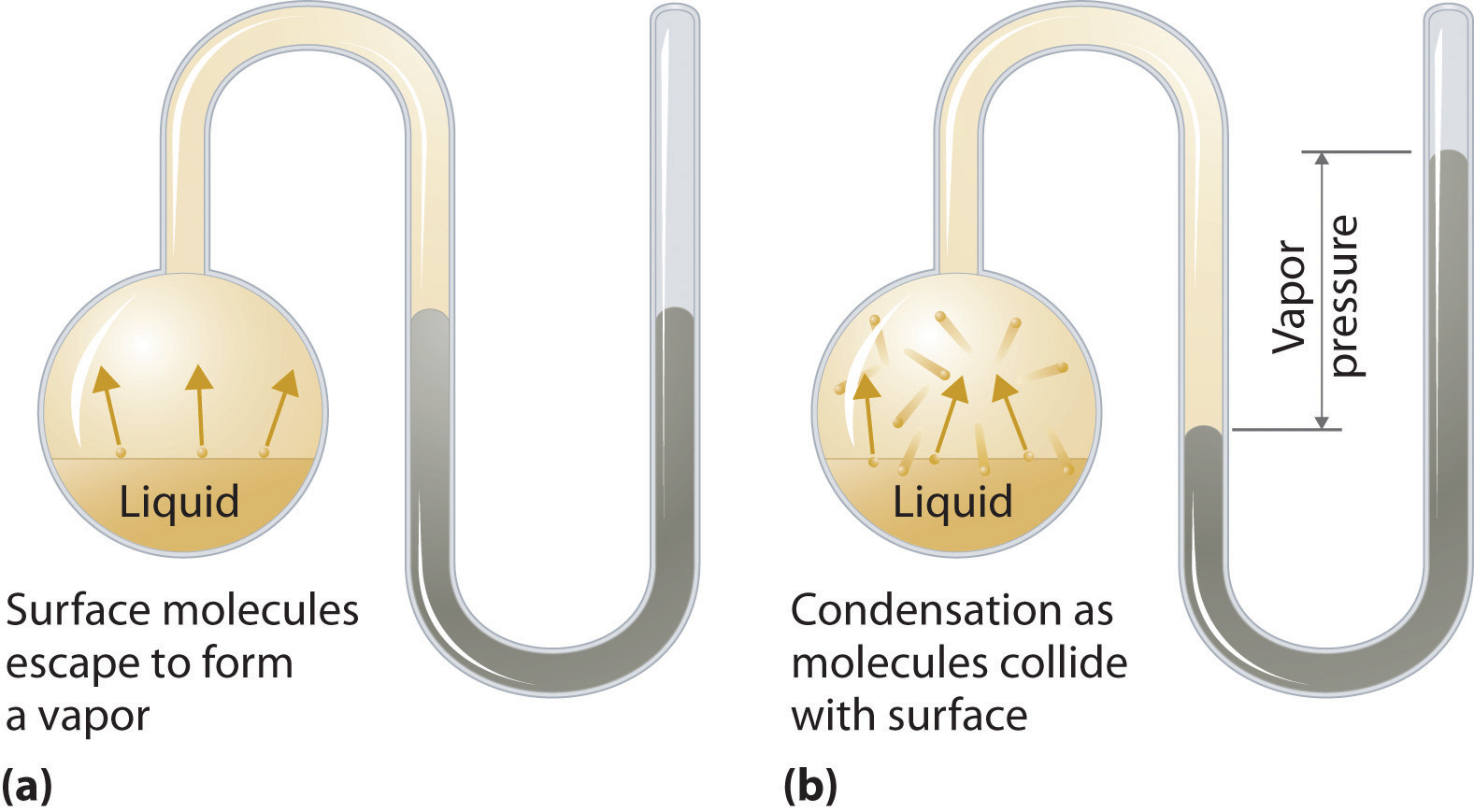
* A graphical way to summarize the conditions under which \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ exist between different states of matter
* Predicts the phase of a substance at a given temperature and pressure

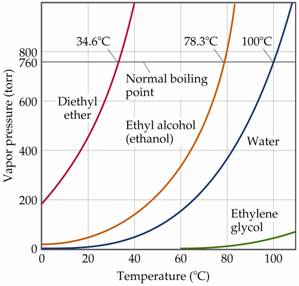
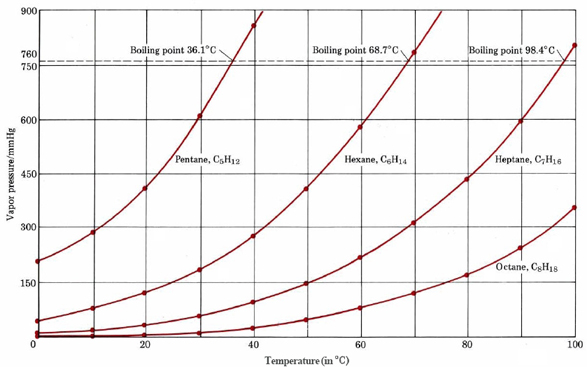
Interpreting a Phase Diagram

* Critical Temperature: The highest temperature at which a distinct liquid phase can form
* Critical Pressure: pressure required to bring about liquefaction at this critical temperature
* \_\_\_\_\_\_\_\_\_\_\_\_\_\_ and/or low \_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_ substances have lower values for critical temperature and pressure

Vapor Pressure: The pressure exerted by a vapor in the \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

* \_\_\_\_\_\_\_\_\_\_\_\_\_\_ intermolecular forces = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ vapor pressure
* \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Equilibrium: rates of changing from gas to liquid and liquid to gas is the same
* Volatile Liquids: substances with higher vapor pressure that allow liquids to evaporate to dryness (no dynamic equilibrium exists)

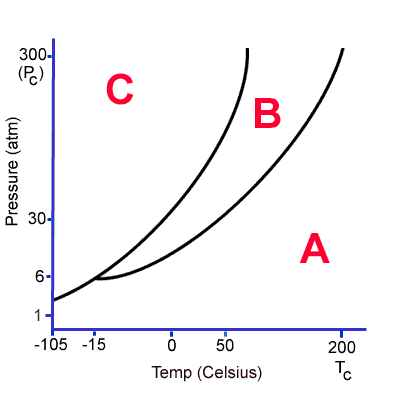




Boiling

* Liquids boil when the vapor pressure equals the \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ pressure acting on the surface of the liquid.
* Bubbles of vapor form within the interior of the liquid
* Lower pressure = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ boiling point
* Vapor pressure and temperature are related through The Clausius-Clapeyron Equation

**Assignment 3: Interpreting Phase Diagrams**

**1.** The area of the graph that represents the liquid phase is:

* + 1. C
    2. B
    3. A

2. Condensation occurs by:

A. release of energy

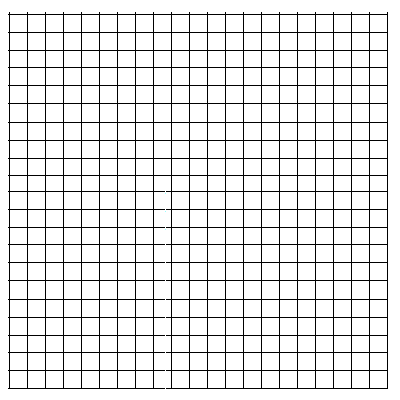
B. absorption of energy

1. At 30 atmospheres pressure, the melting point of this substance is:
   1. 200 ºC
   2. 0 ºC
   3. 50 ºC
   4. -15 ºC
   5. -105 ºC
2. At 30 atmospheres pressure, the boiling point of this substance is:
   1. 0 ºC
   2. -15 ºC
   3. -105 ºC
   4. 50 ºC
   5. 200 ºC
3. A phase change from Phase C to Phase A is known as:
   1. Melting
   2. Condensation
   3. Vaporization
   4. Sublimation
   5. Deposition
   6. Freezing
4. Vaporization occurs by:
   1. Release of energy
   2. Absorption of energy
5. A phase change from Phase A to Phase B is known as:
   1. Melting
   2. Condensation
   3. Vaporization
   4. Sublimation
   5. Deposition
6. Above 300 atm (Pc), this substance cannot exist as:
   1. A solid
   2. A liquid
   3. A gas
7. If the temperature of the substance is held constant at -15 ºC, the phase change that would occur with a pressure increase from 1 atmosphere to 30 atmospheres is:
   1. Melting
   2. Condensation
   3. Vaporization
   4. Sublimation
   5. Deposition
   6. Freezing
8. Sublimation occurs by:
   1. Release of energy
   2. Absorption of energy
9. A phase change from Phase A to Phase C is known as:
   1. Melting
   2. Condensation
   3. Vaporization
   4. Sublimation
   5. Deposition
   6. Freezing
10. At STP, this substance can exist as:
    1. A solid only
    2. A liquid only
    3. A solid or a gas
    4. A gas only
11. A phase change from Phase B to Phase A is known as:
    1. Melting
    2. Condensation
    3. Vaporization
    4. Sublimation
    5. Deposition
    6. Freezing
12. Freezing (solidification) occurs by:
    1. Release of energy
    2. Absorption of energy
13. Melting occurs by:
    1. Release of energy
    2. Absorption of energy
14. Deposition occurs by:
    1. Release of energy
    2. Absorption of energy
15. The triple point of this substance occurs at:
    1. 200 oC and 300 atm
    2. -15 oC and 6 atm
    3. 0 oC and 6 atm
    4. -15 oC and 1 atm
16. Above 200 ºC (Tc), this substance can only exist as:
    1. A solid
    2. A liquid
    3. A gas
17. The area of the graph that represents the gas phase is:
    1. A
    2. B
    3. C
18. A phase change from Phase C to Phase B is known as:
    1. Melting
    2. Condensation
    3. Vaporization
    4. Sublimation
    5. Deposition
    6. Freezing
19. A phase change from Phase B to Phase C is known as:
    1. Melting
    2. Condensation
    3. Vaporization
    4. Sublimation
    5. Deposition
    6. Freezing
20. The area of the graph that represents the solid phase is:
    1. A
    2. B
    3. C

**Assignment 4: Clausius-Clapeyron Equation**

|  |  |
| --- | --- |
| Temperature (°C) | Water Vapor Pressure (mm Hg) |
| 0 | 4.58 |
| 20 | 17.54 |
| 40 | 55.32 |
| 60 | 149.38 |
| 80 | 355.1 |

(a) From the data in the above table, use a graph to find the standard enthalpy of vaporization of water.

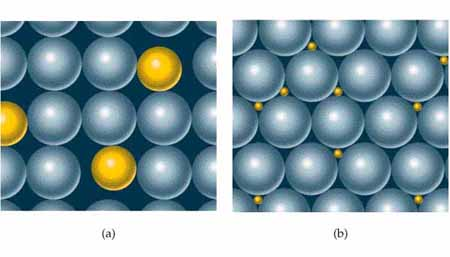


(b) Find the boiling point temperature of water when the ambient pressure is 1 atm.

**Podcast 8.4: Forms and Properties of Solids**

Structures of Solids

* Crystalline Solid – atoms, ions, or molecules are ordered in \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ arrangements
  + Have flat surfaces, or faces
  + Definite angles
  + Regular shapes – “structured”
* Amorphous Solid – solid whose particles have no orderly structure
  + Lack of well-defined faces and shapes
  + Mixtures of molecules that do not \_\_\_\_\_\_\_\_\_\_\_together well
  + Generally composed of large, complicated molecules
* Crystalline solids – melts at a \_\_\_\_\_\_\_\_\_\_\_\_\_\_ temperature
* Amorphous solids – soften over a \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ of temperatures.
* Metals and Alloys
  + Substitutionary (brass)
  + Interstitial (steel)

Bonding Models for Metals

* \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_: A regular array of metals in a “sea” of electrons. Metals conduct heat and electricity very efficiently because of the availability of highly mobile e-
* Metallic Bonds: Band (\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_ Model: Electrons assumed to travel around metal crystal in MOs formed from valence atomic orbitals of metal atoms.
* Network Solids: Composed of strong directional \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ bonds that are best viewed as a “giant molecule”. (Examples: graphite, diamond, ceramics, glass )

**Assignment 5:**

1. Which one of the following statements does **not** describe the general properties of solids accurately?

a. Solids have characteristic volumes that do not change greatly with changes in temperature.

b. Solids have characteristic volumes that do not change greatly with changes in pressure.

c. Solids diffuse only very slowly when compared to liquids and gases.

d. Solids are not fluid.

e. Most solids have high vapor pressures at room temperature.

2, Which one of the following statements is **not** applicable to **molecular** solids?

a. The units that occupy the lattice points are molecules.

b. The binding forces in molecular solids are dispersion forces or dispersion forces and dipole-dipole interactions.

c. Molecular solids have relatively low melting points.

d. Molecular solids are usually excellent conductors of electric current.

e. Molecular solids are soft compared to covalent solids.

3. Which one of the following is a covalent solid?

a. sulfur trioxide

b. nickel

c. ammonium chloride

d. silicon carbide, SiC

e. sucrose, C12H22O11

4. Which one of the following is an ionic solid?

a. graphite

b. nickel

c. ammonium chloride

d. silicon carbide, SiC

e. sucrose, C12H22O11

5. Which one of the following crystallizes in a metallic lattice?

a. C10H8

b. graphite

c. In

d. LiF

e. KMnO4

6. Which one of the following pairs is **incorrectly** matched?

Substance

a. H2O

b. paraffin

c. KF

d. CsI

e. Ni

Classification

molecular solid

molecular solid

ionic solid

covalent solid

metallic solid

7. Which of the following compounds would be expected to have the highest melting point?

a. BaF2 b. BaCl2 c. BaBr2

d. BaI2 e. NaF

8. Arrange the following in order of increasing melting points.

KCl, He, H2O, HF

a. He < H2O < HF < KCl b. H2O < HF < He < KCl c.KCl < H2O < HF < He d. He < HF < H2O < KCl e. H2O < He < KCl < HF

**Assignment 6: Unit 8 Review**

1. Describe the interparticle forces at work in the following:

a. within a water molecule H2O

b. in a crystal of the salt NaCl

c. in a solution of potassium nitrate

d. in diamond

e. in a fiber of nylon

f. in liquid butane

g. between water molecules in ice

h. between the two strands in the double helix of DNA

i. in paraffin wax

j. between the molecules of carbon dioxide CO2 in dry ice

k. between the molecules of HCl in liquid HCl

l. in tungsten metal

m. in a solution of perchloric acid

2. Which one of the following pairs of molecules would you expect to have the higher melting point?

a. Cl2 or Br2

b. C4H10 or C5H12

c. NH3 or PH3

d. Na or Mg

e. BeO or KCl

f. ICl or Br2

3. Which states or types of matter would be characterized by each of the following statements?

a. High individual molecular speeds.

b. A melting point spread over a wide temperature range.

c. A regular repeating array of structural units.

d. Molecules move with respect to one another but are held together in a condensed state.

e. Molecules close together but having sufficiently high kinetic energies to overcome the intermolecular forces.

f. Valence electrons delocalized over huge arrays of atoms.

g. Totally random molecular order with comparatively great distances between individual molecules.

h. A three-dimensional network of covalent bonds.

4. Acetone and chloroform form an unusually strong intermolecular bond. Why is this? Draw a picture of how the molecules attract each other.

5. a. How much heat is required to melt 15 grams of ice at 0°C?

b. How much heat is released when 100 grams of steam condenses at 100°C?

c. If a system of ice and water has a mass of 12 grams, and it is converted completely to water at 0.0°C by supplying 1.33 kJ of heat, how much water was initially present?

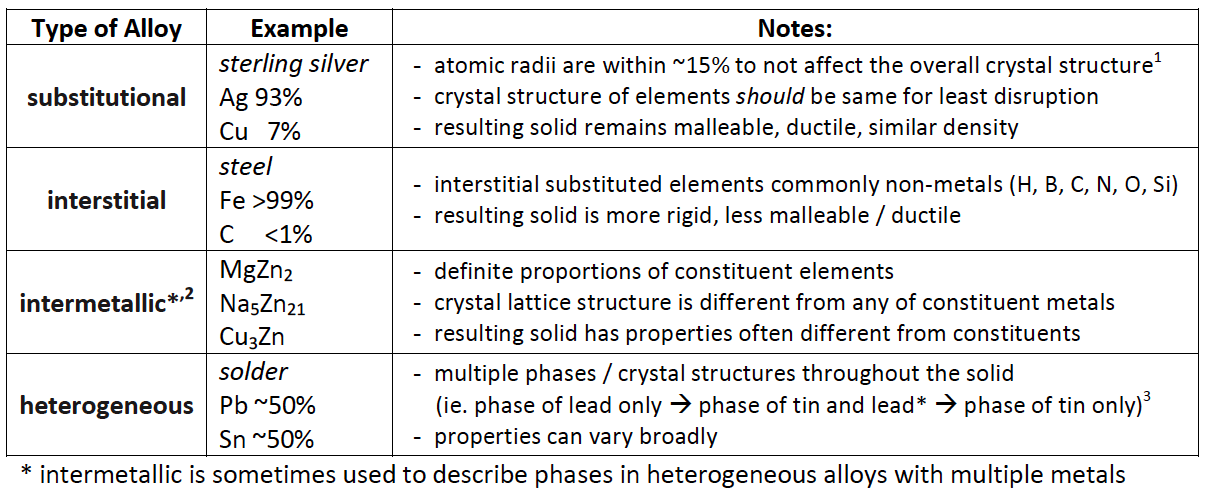
Heat of fusion of ice = 333 J/g Heat of vaporization of water = 2250 J/g

6. Solve Problem 11.89 in your textbook using the Clausius-Clapyeron Equation.

7. List five alloys that contain copper, underlining those that are greater than 50% copper.

8. What is pewter? Give its composition and a use. Which metal dominates the composition?

9. What is an amalgam? Which metal dominates the alloy? Give a use for an amalgam.



10. A student is assigned the task of determining the mass percent of silver in an alloy of copper and silver by dissolving a sample of the alloy in excess nitric acid and then precipitating the silver as AgCl. First the student prepares 50. mL of 6 M HNO3 .

The student is provided with a stock solution of 16 M HNO3 , two 100 mL graduated cylinders that can

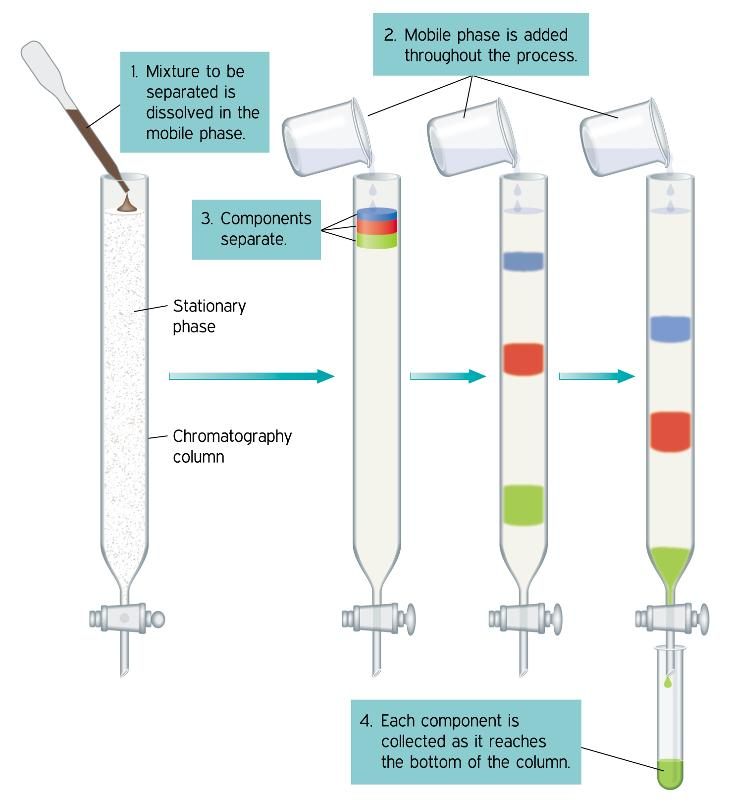
be read to **±**1 mL, a 100 mL beaker that can be read to **±**10 mL, safety goggles, rubber gloves, a glass stirring rod, a dropper, and distilled H2O.

1. Calculate the volume, in mL, of 16 M HNO3 that the student should use for preparing 50. mL of 6 M HNO3 .
2. Briefly list the steps of an appropriate and safe procedure for preparing the 50. mL of 6 M HNO3. Only materials selected from those provided to the student (listed above) may be used.
3. Explain why it is not necessary to use a volumetric flask (calibrated to 50.00 mL ±0.05 mL) to perform the dilution.
4. During the preparation of the solution, the student accidentally spills about 1 mL of 16 M HNO3 on the bench top. The student finds three bottles containing liquids sitting near the spill: a bottle of distilled water, a bottle of 5 percent NaHCO3(aq), and a bottle of saturated NaCl(aq). Which of the liquids is best to use in cleaning up the spill? Justify your choice.

**PAPER CHROMATOGRAPHY LAB**

INTRODUCTION/THEORY

The process of chromatography involves a means of separating mixtures of materials based on differences in migration rates among sample components. All chromatographic methods have in common the use of a **stationary phase** and a **mobile phase**. Components of a mixture are carried through the stationary phase by the flow of a gaseous or liquid mobile phase. The time in which components flow differs with the interaction of each component with the stationary phase, leading to differences in time of travel. Thus, parts of the mixture emerge at the other end of the stationary phase at different times (see figure 1).

 Paper chromatography makes use of a flat, relatively thin layer of material (such as filter paper) that is either self-supportive or is coated. The mobile phase moves through the stationary phase by capillary action. The theory behind how paper chromatography works is identical to column chromatography, but instead of packed columns the columns are flat media.

All important data from paper chromatography comes from movement of substances, particularly the distance moved by the component in question along the paper related to the overall movement of the solvent. This can be represented mathematically by the retardation factor, Rf:

Rf = Ds/Df

where Ds and Df are the distances moved by the unknown component and solvent, respectively. The lab that will be done following this discussion deals with paper chromatography techniques. The goal will be to obtain Rf values for all unknown dyes in question (See figure 2 below).



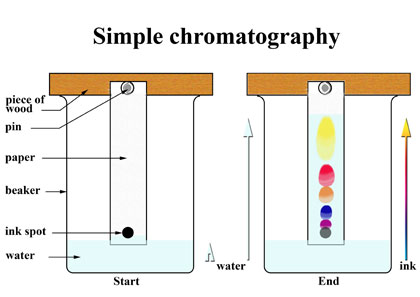
OBJECTIVE

The goal of this experiment is to show how ink can be separated into its component dyes by chromatography. This is an illustration of an important technique used in all chemical sciences.

PROCEDURE

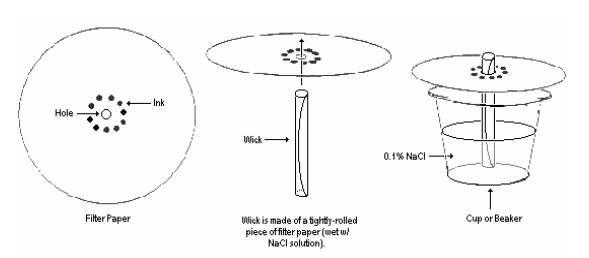
I. *Separation of Ink*

1. Put a 50 mL of 0.1 M NaCl in a beaker or flask, so as to barely cover the bottom. Cover the flask with parafilm to allow the solvent vapors to saturate the air inside the flask.
2. Cut a strip of filter paper about 15 cm long. Mark the paper with a horizontal PENCIL line 2 cm from the bottom.
3. Place a 2 mm spot of ink from a black marker in the middle of the bottom line. With a PENCIL, label the strip with the BRAND of marker you used and the solvent, NaCl.
4. Place the paper with the spot down into the solvent. **The spot should not touch the solution in the bottom of your beaker/bottle**!!! The strip should also not touch the sides of the glassware.



1. Remove the paper from the solvent when the solvent has advanced to within about 2 cm from the top of the paper. MARK the top point that the solvent actually advances.
2. On a separate sheet of paper labeled DATA, both group members should trace their chromatograph, labeling all pertinent information. Included in this should be the colors produced in the separation and the following distances:
   1. Distance traveled by solvent in cm (a constant, Df)
   2. Distances traveled by the leading edge of the colored dyes (Ds) and
   3. Rf values (Rf = Ds/Df)
3. Repeat the above using distilled water then with isopropyl alcohol in the beaker/bottle instead of salt water. Compare the color patterns produced with each solvent.

II. *Radial Chromatography (Refer to figure 3 for assistance in setup)*



*This part of the lab gives you and your lab partner an opportunity to be artistic. Step 3 below is meant to follow figure 2, but you are permitted to make any distribution of dots around the center. You can try to spell things, make a design, or whatever. Be creative!*

*Each person can do a radial chromatograph if they want. Two can be done simultaneously.*

1. Cut a circular piece of filter paper into 8 pie shaped wedges. These wedged shaped sections will serve as wicks. Obtain a wedge and roll it into a cone.
2. Punch a pencil sized hole in the center of a second piece of filter paper.
3. Place a series of 6-8 one cm spots of water soluble ink (**you may use any colors!)** around the hole in the second filter paper. The ink spots should be dark and concentrated. *On your data sheet draw a picture of your setup with the colors of markers that make up each dot*. We want to know the mixtures of colors that go into each color tested.
4. Roll up the paper wedge from part one and insert it into the hole in the filter paper.
5. Fill your Petri dish to within a few mm of the top.
6. Set the circle on top of the dish with the wick down in the water. Watch what happens as the water spreads out over the filter paper. Record all observations on your data sheet.
7. When the water has advanced to within 1-2 cm of the outside edge of the paper, carefully lift off the paper, remove the wick and place it on a new beaker to dry.
8. Display your chromatograph proudly.

CALCULATIONS

Calculate the Rf values for both the ink/water and ink/alcohol systems in part I. These calculations should be on your data sheet you made above.

QUESTIONS

1. (a) Why do the colored bands appear at different positions on the chromatography paper? Discuss in terms of interactions between the dyes in the ink and the water.

(b) Which colored dye from the ink from part I was most strongly attracted to the solvent? Explain

your choice.

1. How did the behavior of the dyes differ in the two solvents (water vs. alcohol)? Explain.
2. Provide an example on how paper chromatography could be used in real life.
3. Name two other separation techniques used by scientists, describe how they work, and give a practical application.
4. Describe the mixtures of colors that go into some of the colors you tested (use part II for help). Are there any colors that seem to consist of only one color? What are they?
5. Different brands of pen create different separation patterns. List some factors you would think would affect the separation patterns of different pens.