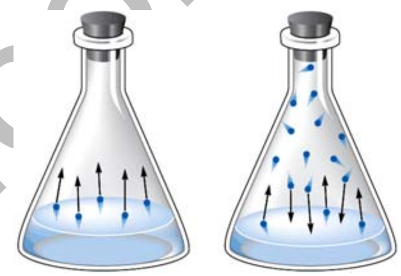
Name ______________________ **Chemistry** **___/___/___**

Kinetic Molecular Theory, Vapor Pressure and Phase Diagrams

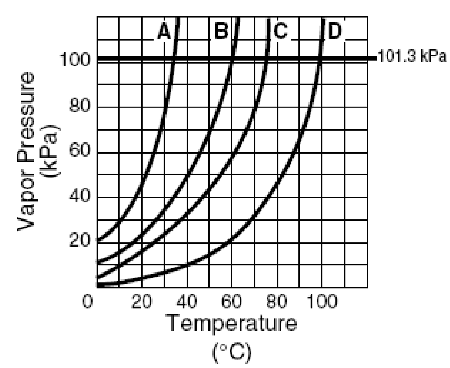
The Kinetic Molecular Theory of Gases

- The Kinetic Molecular Theory (KMT) is a model that attempts to explain the properties of an ideal gas.
- The KMT states:
    - The particles of an ideal gas are so small compared with the distances between them that the volume of individual particles can be assumed to be negligible (zero).
    - The particles of an ideal gas are in constant motion. The collisions of the particles with the walls of the container are the cause of the pressure exerted by the gas.
    - The particles of an ideal gas are assumed to exert no forces on each other; no attraction or repulsion between particles.
    - The average kinetic energy of gas particles of an ideal gas is assumed to be directly proportional to the Kelvin temperature of the gas.
- An ideal gas is a hypothetical concept. No gas exactly follows the ideal gas law, although many gases come very close at low pressures and/or high temperatures. The ideal gas behavior can best be thought of as the behavior approached by real gases under certain conditions

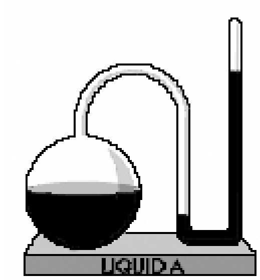
Vapor Pressure

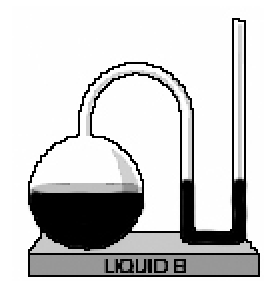


- The water level in a glass of water left out will gradually decrease until all of the water has evaporated. This vaporization of water molecules occurs as water molecules gain enough kinetic energy to overcome the attractive forces keeping them in the liquid. Remember that as one molecule evaporates, the particles left behind cool. In order to evaporate a particle must absorb energy. Once this happens, it changes state and the particles left behind have a lower average kinetic energy.
- When a liquid is placed in a sealed container, the amount of liquid at first decreases but eventually becomes constant. The decrease occurs because there is an initial net transfer of molecules from liquid to the vapor state. This evaporation process occurs at a constant rate at a given temperature.
- The process by which vapor molecules re-form a liquid is called condensation. Eventually, enough vapor molecules are present above the liquid so that the rate of condensation equals the rate of evaporation. At this point no further net change occurs in the amount of liquid or vapor because the two processes exactly balance each other; the system is at equilibrium. This process is highly dynamic.



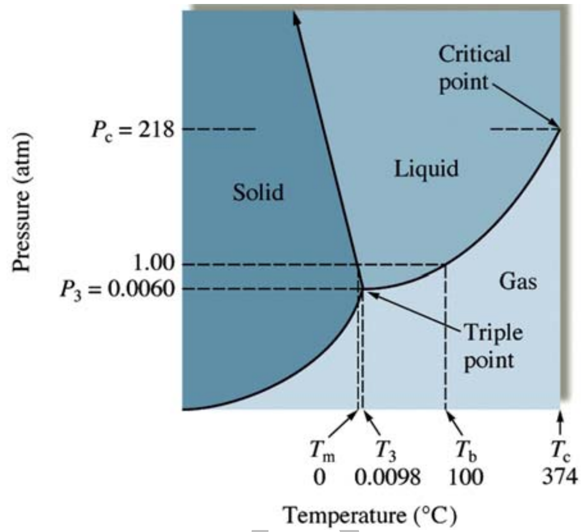
- Liquids with high vapor pressure are said to be **volatile**. The vapor pressure of a liquid is principally determined by the size of the intermolecular forces in the liquid.
- In general, substances with large molar masses have relatively low vapor pressures, mainly because of the large dispersion forces. The more electrons a substance has, the more polarizable it is, and the greater are the dispersion forces.
- Vapor pressure increases significantly with temperature. The diagram to the right shows how vapor pressure increases with temperature for 4 different substances
- Like liquids, solids have vapor pressures. Under normal conditions iodine and dry ice(solid CO_2) sublime; they go directly from the solid to the gaseous state without passing through the liquid state.
- Scientists use an instrument called a manometer (pictured below) in order to measure the pressure exerted by a gas. By comparing the heights of the mercury in the U-tube, scientists can calculate a substance's vapor pressure. In the diagrams below, the first graphic shows a higher vapor pressure than the second. As temperature increases, the vapor pressure of a liquid also increases, so you can assume that the first liquid is at a higher temperature than the second.





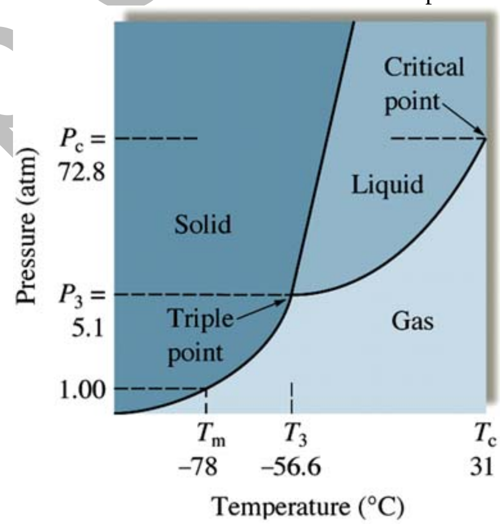
The images to the left show two manometers in which liquid A has a higher vapor pressure than liquid B.

Phase Diagrams



A phase diagram is a graphic representation of the relationship between the physical state of a substance and its pressure and temperature. A phase diagram describes conditions and events in a closed system. The phase diagram for water is shown to the right. A line that separates any two regions gives the conditions at which those two phases exist at equilibrium. The point at which the three segments meet is called the **triple point**. The triple point is the point on a phase diagram where all three states of a substance are present. For water, the triple point occurs when the pressure is 0.60 kPa and the temperature is 0.0098 °C. **Critical temperature** is defined as the temperature above which vapor cannot be liquefied no matter what pressure is applied. The **critical pressure** is the pressure required to produce liquefaction at the critical temperature. Together the critical pressure and the critical temperature define the **critical point**.

A phase diagram can be used to determine the melting point and boiling point for a substance at various temperatures and pressures. The **normal melting point** of a substance is the temperature at which the solid and liquid states have the same vapor pressure under conditions at standard pressure (1 atm or 101.3 kPa). For water, the normal melting point is 0°C. The **normal boiling point** is the temperature at which the vapor pressure of the liquid is equal to standard pressure (1 atm or 101.3 kPa). For water, the normal boiling point is 100°C. **Boiling point** is the temperature at which the vapor pressure of a liquid is just equal to the external pressure. As you can see from the diagram above, water can be made to melt or boil at temperature other than its normal melting and normal boiling points. Note that the solid/liquid boundary on the phase diagram for water has a negative slope. This means that the melting point of ice decreases as the external pressure increases. This behavior, which is opposite of most substances, occurs because the density of ice is less than that of the liquid water at its melting point. When water freezes it expands. The low density of ice means that ice formed on rivers and lakes will float, providing a layer of insulation that helps prevent bodies of water from freezing solid in the winter. Aquatic life can therefore continue to live through periods of freezing temperatures. The phase diagram for carbon dioxide is shown to the right. The solid/liquid line has a positive slope, since solid CO_2 is denser than liquid CO_2. Carbon dioxide is often used in fire extinguishers, where it exists as a liquid at 25°C under high pressures. Liquid CO_2 released from the extinguisher into the environment at 1 atm immediately changes to a vapor. Being heavier than air, this vapor smothers the fire by keeping oxygen away from the flame. The liquid/vapor transition is highly endothermic, so cooling also results, which helps to put out the fire.



Homework:

1. List the four properties assumed by the kinetic molecular theory.

2. What is vapor pressure?

3. What is meant when a liquid is said to be volatile?

4. Which of the following substances would have the lowest vapor pressure, CH_4, C_2H_6, C_3H_8 or C_4H_{10}? Explain!

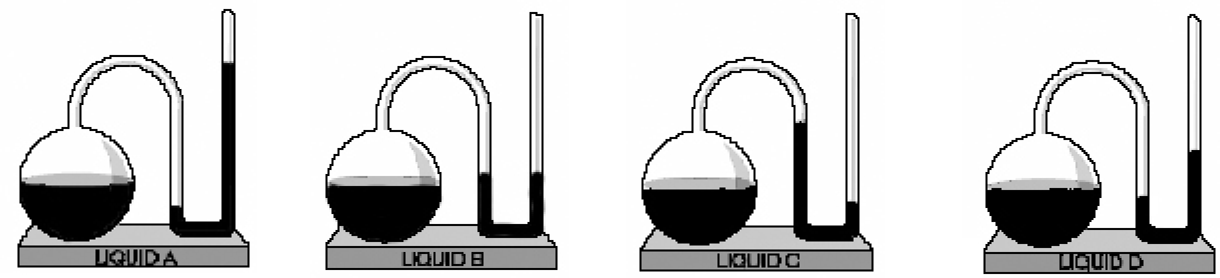
5. What happens to vapor pressure as temperature increases?

6. Do solids exert a vapor pressure?

7. Draw a graph that shows the relationship between vapor pressure and temperature.

8. What is a manometer?

9. Equal quantities of different liquids are placed in closed manometers at 20°C. Which liquid has the lowest vapor pressure?



10. Define triple point.

11. What are the triple point values of pressure and temperature for water?

12. Define critical temperature.

13. Define critical pressure.

14. Define critical point.

15. Define normal melting point.

16. Define normal boiling point.

17. Define boiling point.

18. What is the difference between boiling point and **normal** boiling point? (Don't just tell me the definitions!)

19. What can be done to get water to boil below its normal boiling point?

20. What characteristic of water's triple point graph indicates that solid water is less dense than liquid water?

21. On the diagram to the right, label all of the following: normal melting point, normal boiling point, solid, liquid, gas, triple point, the solid-vapor border, the liquid-vapor border and the solid-liquid border.