Chemistry A
States of Matter
Packet

Worksheet #1: States of Matter

In this packet we will discuss three general states of matter: solid, liquid and gas. **In each state of matter, there are many molecules acting together. The motion and interactions of these molecules can largely be explained by considering the intermolecular forces acting between them.** Below is a summary of the shape, volume and strength of the intermolecular forces in each state of matter.

Draw the particles of the 3 states of matter in the boxes on the left below.

SOLIDS

- Fixed shape AND volume that does not change
- Intermolecular forces are very strong
- Motion of the molecules is very small (molecules vibrate around a fixed location).

MELTING FREEZING

DEPOSITION

LIQUIDS

- Fixed volume, but a shape that can change
- Intermolecular forces are not as strong as in a solid
- Molecules are closely packed, but do not have fixed positions (molecules "slip and slide" past one another allowing liquids to flow)

SUBLIMATION

EVAPORATION CONDENSATION

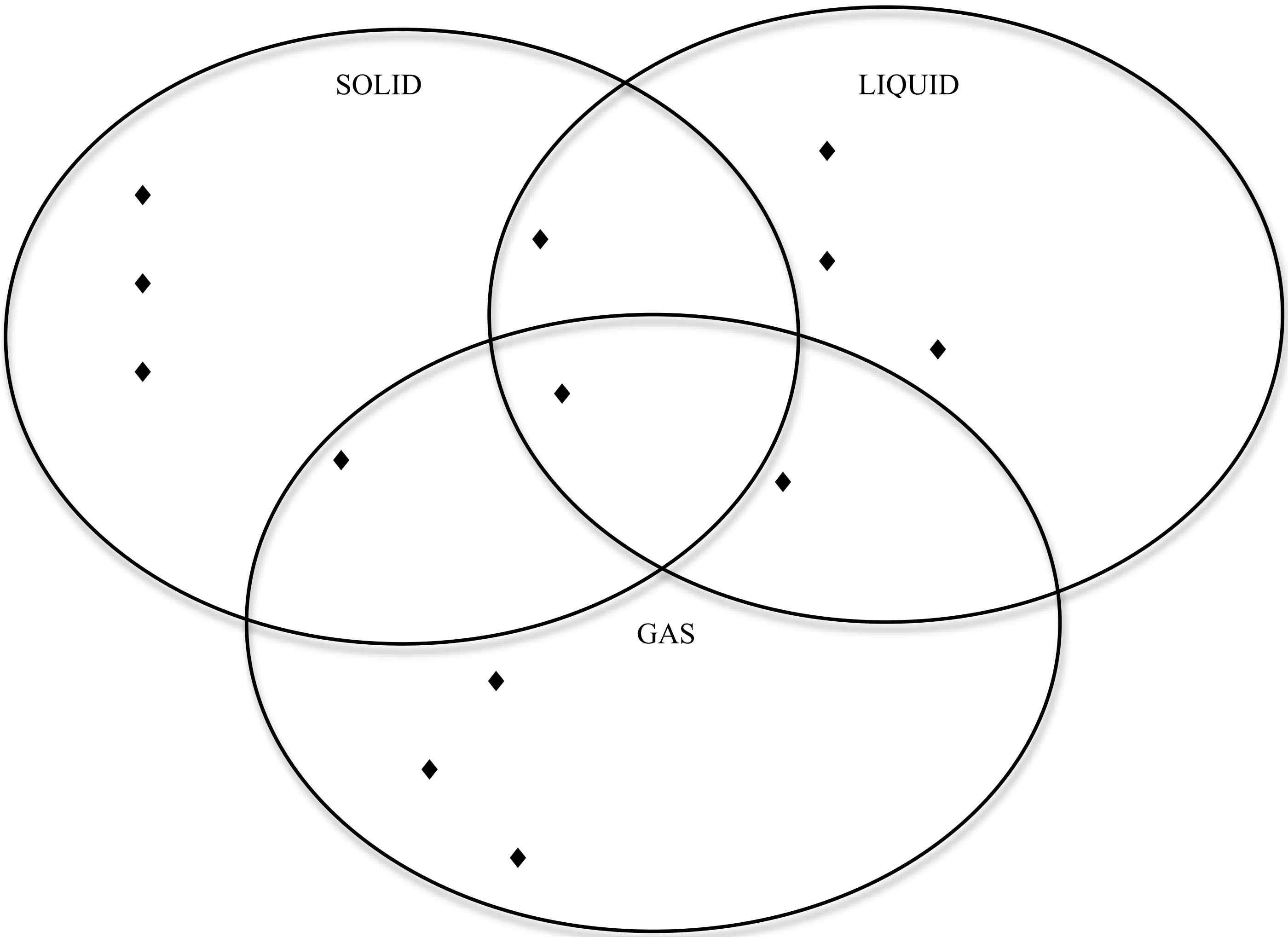
GASES

- No fixed shape OR volume
- Intermolecular forces are weaker in gases than in solids or liquids.
- Molecules move about freely without being held together (this allows gases to expand to fill any container they are in)

In the summary above, the phase changes between states of matter are also included**. A phase change is when a material changes from one state of matter to another. This does NOT rearrange the molecules of the substance, so we call this a physical change, rather than a chemical change. For example, water vapour, liquid water and ice are all made of H_2O molecules. The only difference is how tightly packed those molecules are.** Phase changes do require adding or removing energy from the system.

Worksheet #1 Continued- States of Matter

Create a Venn Diagram below to compare and contrast solids, liquids and gases. Try to fill in each bullet point with a new idea. Use the summary on the front of this page to help you.



Explain the following phase changes in your own words:

1. Melting = ____

2. Freezing = ____

3. Evaporation = ____

4. Condensation = ____

5. Sublimation = ____

6. Deposition = ____

Worksheet #2: Phase Changes

Look back to Worksheet #1 of this packet and answer the following questions:

1. What is a phase change?

2. Using water, give an example of a phase change:

3. Do phase changes rearrange the molecules of a substance?

4. A phase change requires ____________________ or ______________________ energy from a system.

Phase Changes that Require Adding Energy:

Because you are familiar with the phases of water- ice, liquid and water vapor- and have observes changes between those phases, we can use water as the main example in our lesson on phase changes.

1. **Melting** When ice cubes are placed in water, the water is at a higher temperature than the ice. Heat flows from the water to the ice. **Heat is the transfer of energy from an object at a higher temperature to an object at a lower temperature.** The energy absorbed by the ice is not used to raise the temperature of the ice. Instead it disrupts the bonds holding the water molecules together in the ice crystal. When molecules on the surface of the ice absorb enough energy to break the bonds, they move apart and enter the liquid phase. As molecules are removed, the ice cube shrinks. The process continues until all of the ice melts.

   The amount of energy required to melt a solid depends on the strength of the forces keeping the particles together in the solid. Because bonds between water molecules are strong, a relatively large amount of energy is required. However, the energy required to melt ice is much less than the energy required to melt table salt because the bonds in sodium chloride are much stronger than the bonds in ice.

   The temperature where the liquid phase and the solid phase of a substance exist at the same time is a characteristic of many solids. The **melting point of a solid is the temperature where the forces holding it together are broken and it becomes a liquid.**

Define the following terms:

- Heat-

- Melting Point-

2. **Vaporization** While ice melts, the temperature of the ice-water mixture is constant. Once all of the ice has melted, more energy added to the system increases the kinetic energy of the liquid molecules. The temperature of the system starts to rise.

   Particles that escape from the liquid enter the gas phase. For a substance that is normally liquid at room temperature, **the gas phase is called a vapor. Vaporization is the process of changing a liquid to a gas or vapor.** If the energy is added slowly, the molecules at the surface of the liquid are the first to escape, because they are bonded to fewer molecules than molecules on the inside **Evaporation is when vaporization happens on at the surface of a liquid.** As the temperature rises, more and more molecules get enough energy to escape from the liquid.

Worksheet #2 Continued

As water vapor collects above a liquid it creates pressure on the surface of the liquid. **The pressure of a vapor over a liquid is called vapor pressure**. **The temperature where the vapor pressure of a liquid is as strong as the normal pressure of the surrounding environment (atmospheric pressure) is called the boiling point**. At the boiling point, molecules throughout the liquid have enough energy to vaporize.

- Vapor-

- Vaporization-

- Evaporation-

- Vapor Pressure-

- Boiling Point-

3. **Sublimation** Many substance has the ability to change directly from the solid phase to the gas phase. **Sublimation is the process where a solid changes directly to a gas without first becoming a liquid**.

   - Sublimation-

Phase Changes that Require Removing (Releasing) Energy

1. **Condensation** When a water vapor molecule loses energy, it slows down. This means it is more likely to form a bond with another water molecules when they collide. The formation of bonds causes the change from the vapor phase to the liquid phase. **The process of a gas or vapor becoming a liquid is called condensation.**

   There are different causes for the condensation of water vapor. All involve a transfer of energy. The vapor molecules can come in contact with a cold surface such as the outside of a glass containing ice water. Heat from the vapor molecules is transferred to the glass as the water vapor condenses. The water vapor that condenses on blades of grass or a car forms liquid droplets called dew. When a layer of air near the ground cools, water vapor in the air condenses and creates fog. Dew and fog evaporate when exposed to sunlight. Clouds form when layers of air high above the surface of the Earth cool. Clouds are made entirely of water droplets. When the drops grow large enough, they fall to the ground as rain.

Worksheet #2 Continued- Phase Changes

2. **Deposition** Some substances can change directly into a solid without first forming a liquid. When water vapor comes in contact with a cold window in winter, it forms a solid deposit on the window called frost. **Deposition is the process of a substance changing from a gas or vapor to a solid without first becoming a liquid.** Deposition is the reverse of sublimation. Snowflakes form when water vapor high up in the atmosphere changes directly into solid ice crystals. Energy is released as the crystals form.
3. **Freezing** Suppose you put liquid water in an ice tray in a freezer. As heat is removed from the water, the molecules lose kinetic energy and slow down. The slow molecules are less likely to move past one another. When enough energy has been removed, the hydrogen bonds between water molecules keep the molecules fixed, or frozen, into set positions. Freezing is the reverse of melting. **The freezing point is the temperature where a liquid is converted into a solid.**

Define the following terms:

- Condensation-

- Deposition-

- Freezing Point-

**How do the melting point and freezing point of a substance compare? (Hint: What is the melting point of ice? What is the freezing point of water?)

Worksheet #3: Polarity and Electronegativity

When atoms share valence electrons they do not always share them equally. Frequently one atom has a stronger attraction for the electrons than the other atom does. This uneven attraction causes the electrons to be held closer to one end of the bond than the other; we say this makes one end of the bond slightly positive and the other end of the bond slightly negative. **A covalent bond with uneven sharing of the electrons is called a polar covalent bond. A bond in which the electrons are shared equally is called a nonpolar covalent bond.**

1. Define the following terms:

    a. polar covalent

    b. nonpolar covalent

Electro<u>negativity</u> is a measure of the ability of an atom of an element to attract electrons to itself. Put another way, electronegativity is a measure of the force of attraction that exists between an atom and a shared pair of electrons in a covalent bond. Linus Pauling developed a scale of electronegativities that run from a low of 0.7 for several metals in Group I to a high of 4.0 for fluorine.

The table below gives **Pauling Values for Electronegativity**:

H 2.1																	He ....
Li 1.0	Be 1.5											B 2.0	C 2.5	N 3.0	O 3.5	F 4.0	Ne ....
Na 0.9	Mg 1.2											Al 1.5	Si 1.8	P 2.1	S 2.5	Cl 3.0	Ar ....
K 0.8	Ca 1.0	Sc 1.3	Ti 1.5	V 1.6	Cr 1.6	Mn 1.5	Fe 1.8	Co 1.8	Ni 1.8	Cu 1.9	Zn 1.6	Ga 1.6	Ge 1.8	As 2.0	Se 2.4	Br 2.8	Kr ....
Rb 0.8	Sr 1.0	Y 1.2	Zr 1.4	Nb 1.6	Mo 1.8	Tc 1.9	Ru 2.2	Rh 2.2	Pd 2.2	Ag 1.9	Cd 1.7	In 1.7	Sn 1.8	Sb 1.9	Te 2.1	I 2.5	Xe ....
Cs 0.7	Ba 0.9	La-Lu 1.1-1.2	Hf 1.3	Ta 1.5	W 1.7	Re 1.9	Os 2.2	Ir 2.2	Pt 2.2	Au 2.4	Hg 1.9	Tl 1.8	Pb 1.8	Bi 1.9	Po 2.0	At 2.2	Rn ....
Fr 0.7	Ra 0.9	Ac-Lr 1.1-															

We use electronegativity values when we discuss bond polarity. **If two atoms sharing a pair of electrons have equal values for electronegativity the bond is clearly nonpolar. As the difference in electronegativity increases the polarity of the bond increases, and if the difference in electronegativity is very large the bond is ionic.**

1. What is electronegativity?

2. Sodium chloride (NaCl) is an example of an ionic bond. What is the difference in electronegativity between sodium and chlorine?

3. Nitrogen dioxide (NO_2) is an example of a covalent bond. What is the difference in electronegativity between nitrogen and oxygen?

Worksheet #4: Intermolecular Forces

Kinetic Molecular Theory describes the states of matter in terms of the movement of the molecules in each state. The word kinetic means "to move". **Objects in motion have energy called kinetic energy. Temperature is a measurement of the average kinetic energy of all the molecules in a sample of matter**. For example, molecules of H_20 in water vapor at 100 º C are moving much faster than molecules of H_20 in a block of ice that is 0 º C.

Considering Kinetic Molecular Theory, one might ask "If all the molecules at room temperature have the same average kinetic energy, why are some materials gases and others liquids or solids?". To understand why this is, we must consider *intra*molecular and *inter*molecular forces. We defined the following terms in the Covalent Compounds Packet:

♦ Intramolecular force = ____
____

♦ Intermolecular force = ____
____

♦ What are stronger- intramolecular forces or intermolecular forces?

In this packet, we will focus on the three intermolecular forces: Dispersion/London forces, dipole-dipole forces and hydrogen bonds.

Dispersion (London) Forces
At room temperature oxygen molecules (O_2) act as a gas. Under the right conditions; however, oxygen molecules can be compressed (squished) into a liquid. For oxygen to be compressed there must be some force of attraction between its molecules. Because oxygen molecules are non-polar, they do not have a positive or negative end. **The weak force between non-polar molecules is called a dispersion (London) force.** Draw a picture of this below:

Dipole-Dipole Forces
When carbon dioxide (CO_2) gas molecules get close to each other, the partially positive carbon atom in one molecule is attracted to the partially negative oxygen atoms in another molecule. **The strong force between positive and negative ends of polar molecules is called a dipole-dipole force.** Draw a picture of this below:

Hydrogen Bonds
In a water molecule (H_2O), the hydrogen atoms have a large partial positive charge and the oxygen atom has a large partial negative charge. When water molecules get close to each other, a hydrogen atom on one molecule is attracted to the oxygen atom on another molecule. **The very strong force between polar molecules containing hydrogen is called a hydrogen bond.** Draw a picture of this below:

Worksheet #5: Bonding Forces Chart

Now that we know about intermolecular forces, we can connect the ideas of electronegativity and bonding forces:

Difference in electronegativity (BIG – small)	**Intramolecular Forces (within ONE molecule)**	**Intermolecular Forces (between MULTIPLE molecules)**	**Examples**
0 - 0.49	Nonpolar Covalent (electrons are SHARED EQUALLY)	Dispersion (London) Forces	O_2
0.5 – 1.69	Polar Covalent (electrons are SHARED UNEQUALLY)	1. Hydrogen Bonding (any polar molecules WITH HYDROGEN) 2. Dipole-Dipole (any polar molecule WITHOUT HYDROGEN)	H_2O
1.7 or greater	Ionic (electrons are TRANSFERRED)	Ionic (positive ions are attracted to negative ions)	NaCl

Use your electronegativity table and the chart above to answer the following questions:

1. Determine the INTRAmolecular force for the following compounds: (nonpolar covalent, polar covalent, ionic)

CH_4 = _______________ CF_4= _______________ HI = _________________

CO_2 = _______________ NH_3= _______________ NaCl = ________________

2. Determine the INTERmolecular force for the compounds above: (dispersion forces, dipole-dipole, H bonding, ionic)

CH_4 = _______________ CF_4= _______________ HI = _________________

CO_2 = _______________ NH_3= _______________ NaCl = ________________

Worksheet #6 – Ranking Strength of Bonding Forces

Melting or boiling a substance breaks down (weakens) the forces between molecules in the substance.

Therefore, the stronger the intermolecular and intramolecular forces in a substance, is the more energy is required to melt the solid or boil the liquid. Below is a list of all the forces we have discussed, in order of strength.

High Melting/ Boiling Points	Metallic (Intra)	Ionic (Intra)	Covalent (Intra)	Hydrogen Bond (Inter)	Dipole-Dipole (Inter)	Dispersion Forces (Inter)	**Low Melting/ Boiling Points**

1. Why is water a liquid at room temperature when compounds of similar mass are gases? (Hint: think about the strength of the intermolecular forces)

2. For the following, state **AND EXPLAIN** which one of the two has a higher melting/boiling point:

   a. Sodium Chloride (NaCl) or Ammonia (NH_3)?

   b. Iron (Fe) or Methane (CH_4)?

   e. Carbon Dioxide (CO_2) or Sulfur Dioxide (SO_2)?

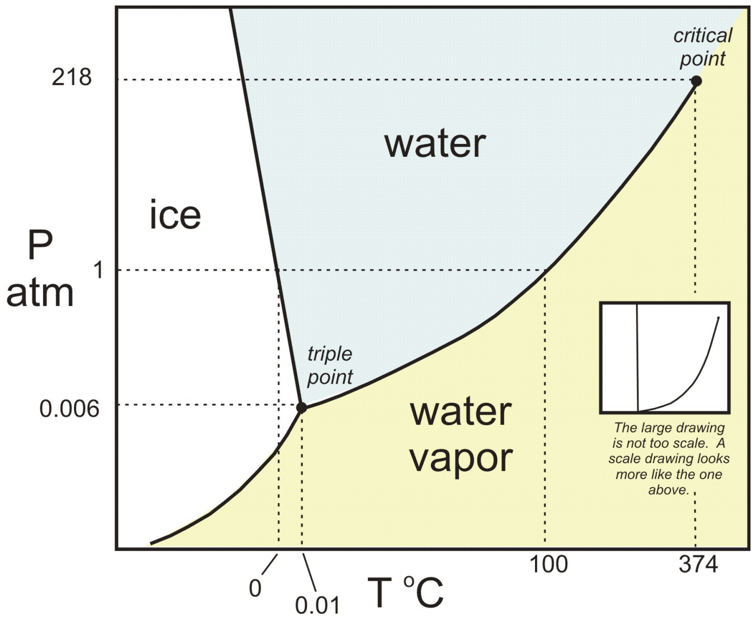
Complete the table below: Room temperature 22^0C

Example: Since the melting point of ethanol is - 114˚C, above that temperature it is a liquid. Since the boiling point of ethanol is 79˚C, above that temperature it is a gas. Since room temperature is 22^0C, ethanol is a gas at room temperature.

CHEMICAL NAME	MELTING POINT (°C)	BOILING POINT (°C)	STATE AT ROOM TEMPERATURE
Hydrogen	-259	-252	
Oxygen	-218	-183	
Nitrogen	-210	-195	
Ethanol (Alcohol)	-114	79	LIQUID (see explanation above)
Water	0	100	
Common Salt	804	808	
Iron	1535	2750	

Worksheet #7: Phase Change Diagrams

There are two variables that combine to control the phase of a substance: temperature and pressure. These variables can have opposite effects on a substance. For example, a temperature increase causes more liquid to vaporize, but an increase in pressure causes more vapor to condense. **A phase diagram is a graph of pressure versus temperature that shows the phases of a substance under different conditions of temperature and pressure.**



The diagram above shows the phase diagram for water. **You can use this graph to predict what phase water will be in for any combination of temperature and pressure.** Notice that there are three regions representing the solid, liquid and vapor phases of water and three curves that separate the regions from one another. At points that fall along the curves, two phases of water can coexist.

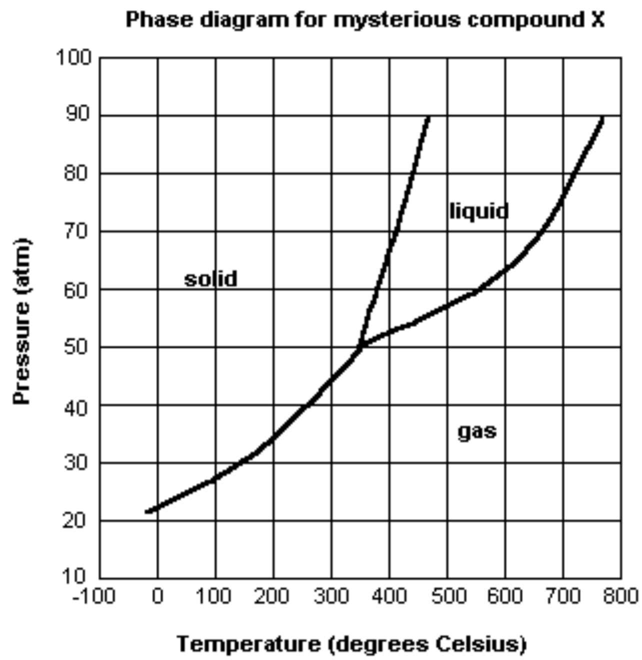
Label the boiling point and melting point of water on the graph above.

The triple point is already labeled on the graph above. **This is the point on a phase diagram that represents the temperature and pressure conditions under which solid water, liquid water and water vapor can all exist at the same time.** All six phase changes can occur at the triple point: freezing and melting, evaporation and condensation, sublimation and deposition.

The critical point is also already labeled on the graph. **This point indicates the temperature and pressure above which water cannot exist as a liquid.** If water vapor is at the critical temperature, an increase in pressure will not change the vapor into a liquid.

The phase diagram for each substance is different because the boiling and freezing points of substances are different. However, each diagram will supply the same type of information for the phases, including a triple point.

For each of the questions on this worksheet, refer to the phase diagram for mysterious compound X.



1) What is difference in the shape of this phase diagram compared to the phase diagram of water on the previous page? (Hint: Look at the liquid region AND the slope of the solid/liquid line)

2) If you were to have a bottle containing compound X in your closet, what phase would it most likely be in? (Hint: Assume room temperature is 22ºC and pressure is 1 atm)

3) At what temperature and pressure will all three phases coexist?

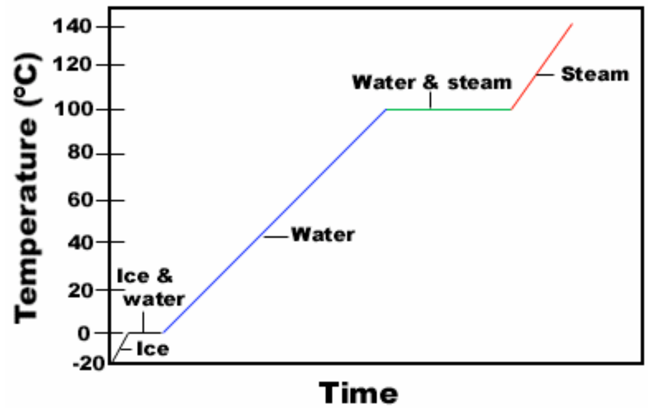
4) If I have a bottle of compound X at a pressure of 45 atm and temperature of 100^0 C, what will happen if I raise the temperature to 400^0 C?

5) Why can't compound X be boiled at a temperature of 200^0 C?

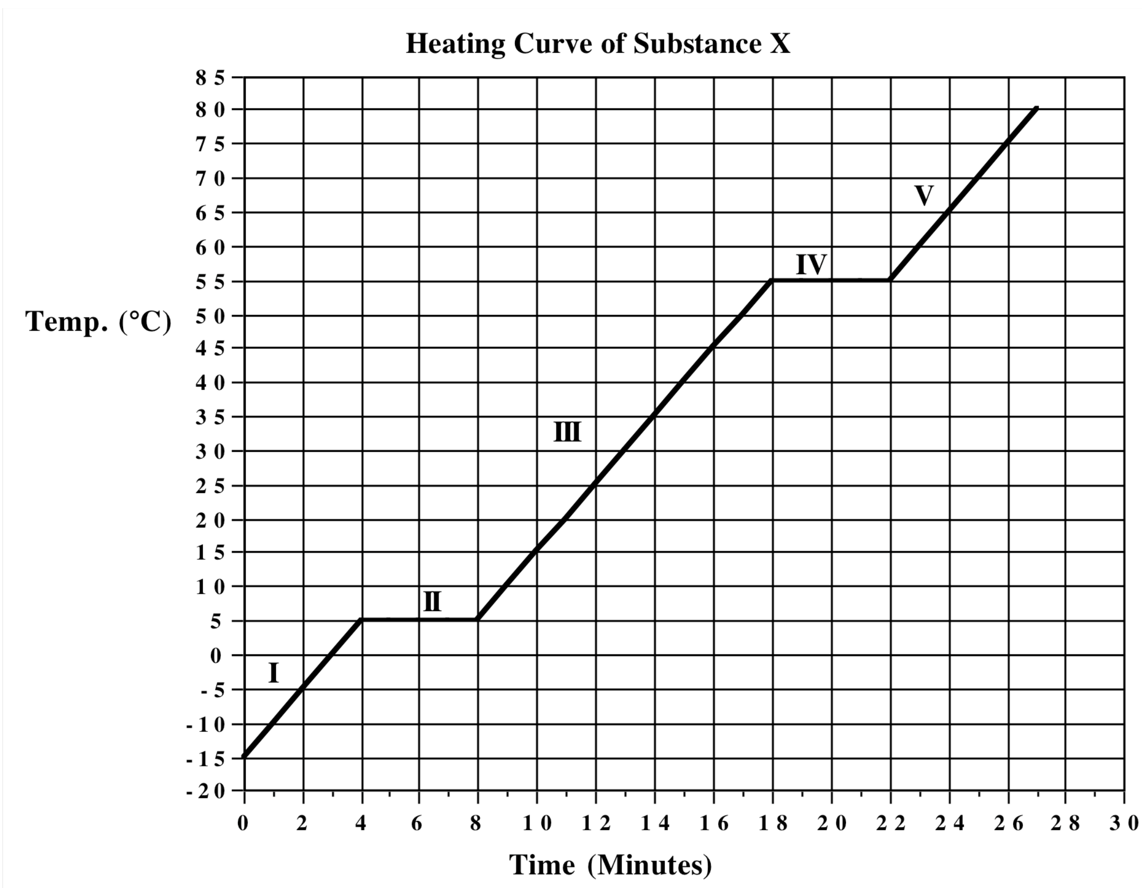
6) If I wanted to, could I drink compound X? Why or why not?

Worksheet #8: Heating Curves

Along with phase change diagrams, we can also learn about the phase changes of a substance by reading a heating curve. **Heating Curves are graphs that show the phase changes that occur as a specific substance is heated**. Below is the heating curve for water:



Label the heating curve below with the terms "gas", "liquid", "solid", "melting" and "evaporating":



Now use this heating curve to answers the questions on the following page.

______1. In what part of the curve would substance X have a definite shape and definite volume?

______2. In what part of the curve would substance X have a definite volume but no definite shape?

______3. In what part of the curve would substance X have no definite shape or volume?

______4. What part of the curve represents a mixed solid/liquid phase of substance X?

______5. What part of the curve represents a mixed liquid/vapor phase of substance X?

______6. What is the melting temperature of substance X?

______7. What is the boiling temperature of substance X?

______ 8. What part of the curve would have the largest kinetic energy? (Hint: Kinetic energy is define on WS#3)

______ 9. What part of the curve would have the lowest kinetic energy?

______ 10. In what part of the curve would the molecules of the substance be the farthest apart?

______ 11. In what part of the curve would the molecules of the substance be closest together?

Worksheet #9: Bonding Forces Vocabulary Review Sheet

Give the type of bond or force described by the following:

Your choices can be (and you will use some them more than once):
Covalent **Metallic Bond**
Ionic bond **Intermolecular Forces**

___________________________ 1. This bonding is found between cations and anions.

___________________________ 2. This is found between atoms of nonmetals.

___________________________ 3. This is found between atoms of metals.

___________________________ 4. This is a term to describe all forces between multiple molecules.

___________________________ 5. This is the force that conducts electricity in the solid state.

___________________________ 6. This is the force that does not conduct electricity as a solid but does when dissolved in liquid or melted

___________________________ 7. This is the force that holds crystals of table salt (NaCl) together.

Your choices can be (and you will use some them more than once):
Polar Covalent **Hydrogen Bond** **London Force**
Nonpolar Covalent **Dipole-Dipole Force** **Ionic Bond**

___________________________ 10. This is the term to describe the attraction between one polar molecule and another polar molecule.

___________________________ 11. This is the term to describe the attraction between one nonpolar molecule and another nonpolar molecule.

___________________________ 12. This is the force inside a molecule of bromine (holds **the** molecule together).

___________________________ 13. This is the force between two molecules of bromine (holds molecul**es** together).

___________________________ 14. This is the force **inside a molecule** of methane CH_4.

___________________________ 15. This is the force **between two molecules** of methane CH_4.

___________________________ 16. This is the force that holds cesium fluoride together.

___________________________ 17. This is the force that holds the carbon to the oxygen in carbon dioxide.

___________________________ 18. This is the force **inside a water molecule** (H_2O)

___________________________ 19. This is the force **between water molecules**.

___________________________ 20. This is the force **inside a molecule** of nitrogen (N_2).

___________________________ 21. This is the force **between two molecules** of nitrogen.

Worksheet #10 States of Matter Review

Modified True/False

Indicate whether the sentence or statement is true or false. If false, change the identified word or phrase to make the sentence or statement true.

____1.Temperature is the measure of the average kinetic energy of a substance. ____________________

____2.When a gas condenses to a liquid it absorbs heat from its surroundings. ____________________

____3.The rate of evaporation of a liquid decreases as the temperature decreases. __________________

____4. A(n) liquid does not have a definite shape, but it does have a definite volume. ________________

____5.Particles in a liquid move around just as freely as particles in a solid. ______________________

Completion

Complete each sentence or statement using the word bank provided

Evaporation	Condensation	Liquid	Freezing	Kinetic	Melting Point	Gas	Heat	Temperature

6. The change in state from a liquid to a solid is called ___________________.

7. The temperature at which ice changes into liquid water is called its ___________________.

8. Vaporization is when a ___________________ changes into a ___________________.

9. A shrinking puddle is an example of ___________________, or vaporization that takes place only on the surface of a liquid.

10. When a substance cools, it loses ___________________ energy to its surroundings.

11.___________________ occurs when particles in a gas lose enough thermal energy to form a liquid.

12.___________________ is a measure of the average energy of motion of the particles of a substance.

13. The temperature of a substance increases when the ___________________ energy of the substance increases.

Short Answer

1. Suppose you were the size of a water molecule and could stand on a water molecule in a glass of water. Someone takes that glass of water and puts it in the freezer. After awhile the water turns to ice. Describe how what you would see and feel would change.

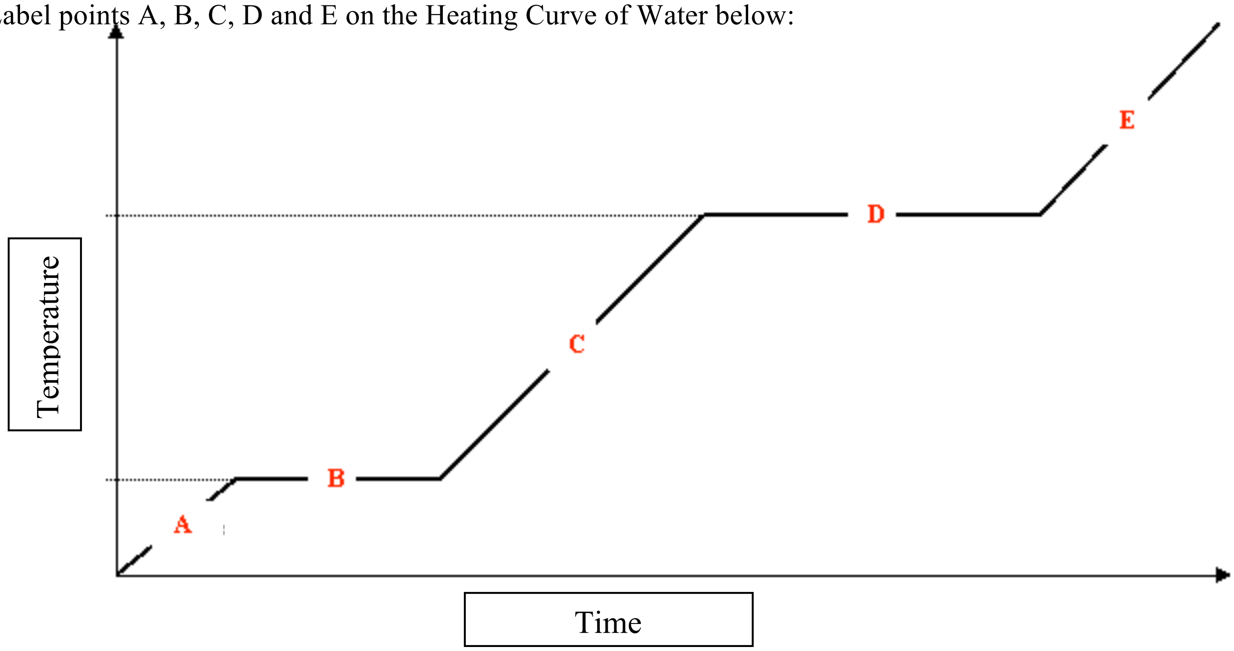
2. Substances that are solid at room temperature have STRONGER, WEAKER (circle one) intermolecular forces than substance that are liquid at room temperature. In addition, substances that are liquid at room temperature have STRONGER/WEAKER (circle one) intermolecular forces than substances that are gas at room temperature. Explain:

3. Explain how the different strengths of intramolecular forces determine the melting point and boiling points for ionic, metallic, and covalent compounds.

4. Sketch the phase diagram for water below. **Be sure to label all parts of the graph.**

Define Triple Point-

5. Label points A, B, C, D and E on the Heating Curve of Water below:



6. What is the boiling point of water? ____________ * Label this on the graph above

7. What is the melting point of water? ____________ * Label this on the graph above