ChemQuest 9

Phase Diagrams

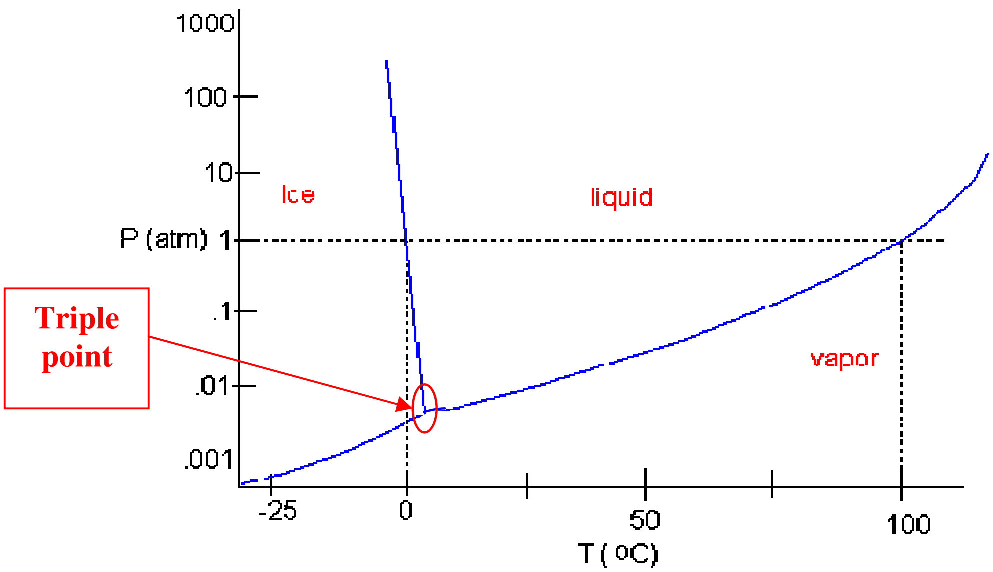
Name: ______________________

Date: ______________

Hour: _____

Information: Phase diagrams

Figure 1: Phase diagram for water. Note that the unit for pressure on the diagram is atmospheres (atm). Another unit is the kilopascal (kPa). Standard pressure is the pressure at sea level and it is equal to 1 atm, which is equivalent to 101.325 kPa. Standard temperature is 273 Kelvin (K), which equals 0°C. The abbreviation STP is used for "standard temperature and pressure" and it denotes a temperature of 0°C and 1 atm (or 273K and 101.325 kPa).



A phase diagram is a graph that illustrates under what conditions the states of matter exist. For example, in the phase diagram of water above, it should be noted that at 1 atm (which equals 101.325 kPa) of pressure and 50 °C, H_2O exists as a liquid. The dark solid lines represent the boundaries between different states. The term "vapor" is used instead of "gas" because vapor describes a substance that is normally a liquid at STP. The line that divides the liquid area from the vapor area has a special name: the vapor pressure curve. (The vapor pressure of water at any given temperature can be found looking at the vapor pressure curve.) To the left of the line, liquid exists. To the right of the line, vapor (gaseous H_2O) exists. Right on the line, for example when the pressure is 1 atm and the temperature is 100°C, both liquid and vapor exist at the same time. When two or more things coexist at the same time it is called "equilibrium". During equilibrium, liquid changes to vapor and vapor changes to liquid all at the same time and rate.

Critical Thinking Questions

1. When a substance melts, what happens to the motion of the molecules of the substance?
The molecules begin to move faster and get farther apart.

2. What is the freezing point and boiling point of water when the pressure on the water is 1 atm? (I.e. at what temperature will the water freeze and boil when the pressure is 1 atm?)

Freezing point = 0^oC; Boiling point = 100^oC

3. How does lowering the pressure affect the boiling point?

The boiling point also gets lower.

4. Estimate the boiling point of water when the pressure on the water is 0.1 atm.

Approximately 73^oC.

5. The triple point of a substance is the conditions under which a solid, liquid and gas all exist in equilibrium. On the phase diagram of water, label the location of the triple point.

See diagram.

6. Dry ice sublimes; that is, it changes directly from a solid to a gas. Is it ever possible for ice to sublime? If so, describe the conditions necessary for sublimation to occur.

Yes, ice will sublime at pressures below approximately 0.007 atm.

7. What is meant by the "vapor pressure" of water?

The pressure that gaseous water exerts, or, the force that water molecules exert after the molecules have evaporated.

8. From the phase diagram, estimate the vapor pressure of water at 25 ^oC.

Approximately 0.01 atm.

9. What is the vapor pressure of water when the temperature is 100 ^oC?

Approximately 1 atm.

10. When the atmospheric pressure equals 1 atm, what is the boiling point of water?

100^oC

11. From your answers to questions 9 and 10, formulate a definition for boiling point in terms of atmospheric pressure and vapor pressure of the liquid.

The boiling point is the temperature at which the vapor pressure of a liquid equals the atmospheric pressure. As the atmospheric pressure decreases, so does the liquids vapor pressure and, thus, the boiling point will also decrease.

12. Is it ever possible for solid H_2O to exist at a temperature above 0 ^oC?

Yes, at lower pressures (pressures below 1 atm).

13. Is it ever possible for solid H_2O to exist at a temperature above 25 ^oC?

No, there is no solid region on the phase diagram at any temperature above roughly 5^oC.

14. Describe the region where a solid-liquid equilibrium exists.

A solid liquid equilibrium exists along the line that divides the liquid region from the vapor region.

15. Why might an equilibrium situation be described as a "reversible change"?

Equilibrium describes a situation where two equal and opposite processes occur at the same rate. In this case, water evaporates and some vapor condenses, thereby "reversing" the change.

ChemQuest 10

Specific Heat

Name: ______________________

Date: ________________

Hour: _____

Information: Heat and Temperature

When a substance absorbs heat energy, the temperature of the substance increases. There are a number of factors (such as mass of the substance) that affect *how much* the temperature of a substance changes.

Critical Thinking Questions

1. Consider two pots of water. Each pot has the same diameter, but pot A is deeper than pot B and so there is more water in pot A. If both of the pots are exposed to exactly the same amount of heat for five minutes on a stove, which pot will contain the hottest water after heating?
   The water in Pot B will be hotter.

2. Propose an explanation for the fact that even though both pots were exposed to the same amount of heat, one got hotter.
   Since Pot A has more water in it, it will take more heat to increase the temperature.

3. Fill in the blank: *The greater the mass of a substance (like water in questions 1 and 2), the*

   _______lower_________ *the temperature change when heat is applied.*
   greater or lower

4. Consider the metal hood of a car on a warm sunny day. Next to the car is a large puddle of water. The puddle of water is so large that it has the same mass as the hood of the car. Assume that the hood of the car and the puddle are exposed to the same amount of sunlight. Which will be hotter after two hours—the hood of the car or the puddle?
   The hood of the car will be hotter.

5. Propose an explanation for the fact that even though both the hood and the puddle were exposed to the same amount of heat energy and their masses were the same, one still got much warmer than the other.
   The metal must heat up faster than water does. There must be something about metal that allows it to heat up faster than water.

6. In general is it harder to change the temperature of metal (like on a car hood) or of water? In other words, would it require more heat energy to change the temperature of metal or of water?
   It would require more heat energy to change the temperature of water.

7. In one of the following blanks you will need to write "400" and in the other blank you will need to write "200".
If we wanted to change the temperature of water by 4 °C, then _400___ *Joules of heat energy are required, but to change the temperature of metal by 4°C, then* __200___ *Joules of heat energy are required.*

Information: Specific Heat

In questions 1 and 2 above you probably recognized that the temperature change of a substance depends on the mass of the substance. You also have probably experienced the fact that different substances heat at different rates as was discussed in questions 3 and 4 above. Each substance has its own specific heat capacity. The specific heat capacity is a measure of the amount of energy needed to change the temperature of the substance. The higher the specific heat, the more energy is required to change the temperature of the substance.

Critical Thinking Questions

8. Which substance has a higher specific heat—water or a metal like the aluminum in a car hood?
Since it requires more heat energy change the temperature of water and since specific heat is a measure of how much energy is needed to change the temperature of a substance, water must have a higher specific heat.

9. Consider 200 Joules (J) of heat energy applied to several objects and fill in the blank: *The higher the specific heat of the object, the* __lower____________ *the temperature change of the object.*
lower or higher

10. Given the following symbols and your answers to the above questions, which of the following equations is correct. Make sure you have the correct answer before proceeding to the next questions!

ΔT = temperature change of a substance
C_p = specific heat capacity
m = mass of the substance
q = amount of heat energy applied to the substance

A) $\Delta T = qmC_p$ B) $\Delta T = \dfrac{q}{(m)(C_p)}$ C) $\Delta T = \dfrac{(q)(m)}{C_p}$ D) $\Delta T = \dfrac{(C_p)(m)}{q}$

HINT: equation D is not correct because according to that equation, a large mass (m) will lead to a large temperature change (ΔT), but this is not consistent with question 3.

11. If ΔT is measured in °C, m is measured in grams (g) and q is measured in Joules (J), what are the units for specific heat capacity?

$$\Delta T = \frac{q}{(m)(C_p)} \longrightarrow C_p = \frac{q}{(m)(\Delta T)} \longrightarrow C_p = \frac{J}{(g)(^{o}C)}$$

12. What is the temperature change of a 120 g piece of aluminum whose specific heat is 1.89 J/g°C after 1800 J of heat energy is applied?

$$\Delta T = \frac{q}{(m)(C_p)} \longrightarrow \Delta T = \frac{1800\,J}{(120\,g)(1.89\,\frac{J}{g^oC})} = 7.936508^oC = 7.9^oC$$

13. A beaker containing 250.0 g of water is heated with 1500.0 J of heat energy. If the temperature of the water changed from 22.0000°C to 23.4354°C, what is the specific heat of water?

$\Delta T = 23.4354\,^oC - 22.0000\,^oC = 1.4354\,^oC$

$$\Delta T = \frac{q}{(m)(C_p)} \longrightarrow C_p = \frac{q}{(m)(\Delta T)} \longrightarrow C_p = \frac{1500\,J}{(250\,g)(1.4354^o\,C)} = 4.180\frac{J}{g^oC}$$

14. Heat energy equal to 25,000 J is applied to a 1200 g brick whose specific heat is 2.45 J/g°C.

a) What is the change in temperature of the brick?

$$\Delta T = \frac{q}{(m)(C_p)} = \frac{25{,}000}{(1200)(2.45)} = 8.503401 = 8.5^oC$$

b) If the brick was initially at a temperature of 25.0°C, what is the final temperature of the brick?

$25.0 + 8.5 = 33.5\,^oC$

ChemQuest 11

Energy and Changes in Matter

Name: ______________________

Date: ______________

Hour: _____

Information: Specific Heat Constants Depend on the State of Matter

Recall that specific heat is the energy necessary to raise the temperature of one gram of a substance by one degree Celsius. The specific heat of liquid water is a constant equal to 4.18 J/(g-^{o}C). This means that it takes 4.18 Joules (J) of heat energy to raise the temperature of each gram of water by one degree Celsius. For ice, the specific heat is 2.06 J/g^{o}C. Steam's specific heat is 2.02 J/g^{o}C. You will want to remember the three different specific heat values for H_2O.

Critical Thinking Questions

1. How much energy is required to heat 32.5g of water from 34^{o}C to 75^{o}C?
   $\Delta T = 75-34 = 41$
   $q = (m)(C_p)(\Delta T) = (32.5)(4.18)(41) = 5569.9$ J

2. How many J of energy are needed to heat 45.0g of steam from 130^{o}C to 245^{o}C? Why don't you use 4.18 J/g^{o}C in this calculation?
   $\Delta T = 245-130 = 115$
   $q = (m)(C_p)(\Delta T) = (45.0)(2.02)(115) = 10{,}453.5$ J
   You don't use 4.18 because 4.18 is the specific heat for liquid water; 2.02 is for steam.

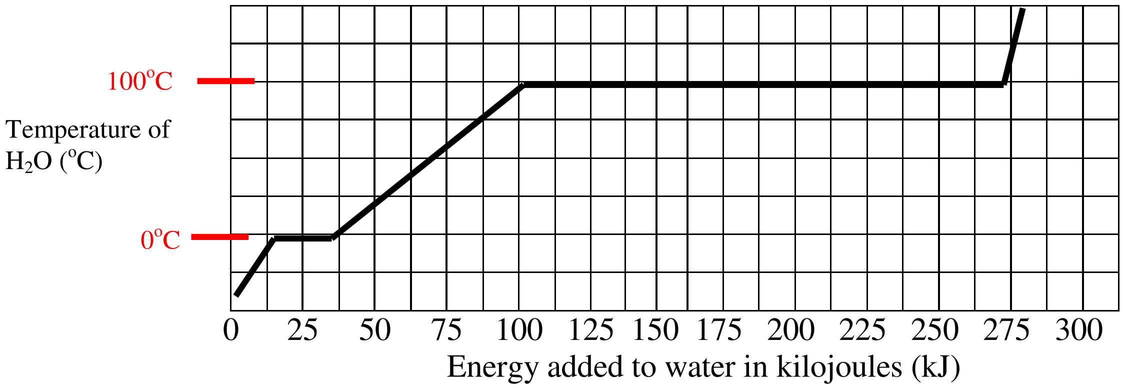
3. Why is it impossible for you to answer the following question right now: How much energy is required to heat 35g of H_2O from 25^{o}C to 150^{o}C?
   The problem involves both liquid water and steam and we don't know how to combine them in the same calculation….YET

Information: Energy Involved in Changing State

Obviously, it takes energy to heat a substance such as water. There is also an energy change when a substance changes state. For example, when water freezes, energy is taken away from the water and when water boils, energy is being added to the water.

When water is heated up to 100^{o}C, it will NOT automatically boil unless more energy is added. Once water is at the correct temperature (100^{o}C), it will boil IF you add energy to change it from a liquid to a gas. The extra energy is needed to separate the molecules from one another. Note: **at the boiling point of a liquid energy is added to the liquid, but the temperature of the liquid does NOT change.** The temperature of H_2O will increase above 100^{o}C only after all of the water has been changed to steam. After the phase change, if more energy is applied, the temperature will go up.

Figure 1: Graph of the temperature of H_2O vs. energy added to the water.



Critical Thinking Questions

4. What is the significance of the horizontal portions of the graph? What is going on during those times?
   The horizontal portions indicate a phase change such as melting or boiling.

5. Label the temperature scale on the graph.
   See graph.

6. Does it require more energy to "vaporize" water at the boiling point or to melt water at the melting point? Explain.
   It takes more energy to vaporize than to melt because the horizontal section of the graph is much longer during the vaporizing, or boiling.

Information: Mathematics of Changes of State

Recall the equation: $q = (m)(C_p)(\Delta T)$ where q is the heat energy, C_p is the specific heat of the substance, m is the mass of the substance, and ΔT is the change in the temperature. This equation works ONLY when there is **no phase change**. You use it to find how much energy is required to change the temperature of a certain substance as long as you know the specific heat of the substance and as long as no change in state occurs.

Now for when there is a change in state: The energy required for a change of state is given a special name called enthalpy. So the "enthalpy of vaporization" (symbolized by ΔH_{vap}) of water is the energy needed to vaporize (or boil) one gram of water when the water is already at its boiling point. The ΔH_{vap} of water is 2260 J/g. So for each gram of hot (100°C) water, 2260 J are required to vaporize it. Similarly, the enthalpy of fusion (ΔH_{fus}) of H_2O is 334 J/g. So each gram of ice at 0°C there are 334 J of energy required to melt it. (Fusion is melting.)

Critical Thinking Questions

7. Verify that it takes 4140.7 J of energy to heat 12.7 g of water from room temperature (22^oC) to the boiling point (100^oC). Recall that the specific heat (C_p) of water is 4.18 J/(g-^oC).
   $\Delta T = 100-22 = 78$
   $q = (m)(C_p)(\Delta T) = (12.7)(4.18)(78) = 4140.7$ J

8. Given the fact that the ΔH_{vap} of water is 2260 J/g we know that 2260 J of energy is required to vaporize 1 gram of water. To vaporize 2 grams of water it requires 4520 J. For 3 grams, 6780 J are needed. Verify that it takes 28,702 J of energy to vaporize 12.7 g of water, when the water is already at its boiling point.
   (2260 J/g)(12.7g) = 28,702 J; note: a helpful equation for phase changes is $q=(m)(\Delta H)$

9. Verify that it takes 1513.6 J of energy to heat 12.7 g of steam from 100^oC to 159^oC. Note: the specific heat of steam (C_p) is 2.02 J/(g-^oC).
   $\Delta T = 159-100 = 59$
   $q = (m)(C_p)(\Delta T) = (12.7)(2.02)(59) = 1513.6$ J

10. Using only your answers to questions 7-9, calculate how many Joules of energy it takes to change 12.7 g of water at 22^oC to steam at 159^oC.
    Questions 7-9 are each different "steps" for taking 12.7g of water from 22^oC to 159^oC so you can simply add the answers: 4140.7 + 28,702 + 1513.6 = 34,356.3 J

11. Calculate how many Joules of energy would be required to change 32.9 g of water at 35^oC to steam at 120^oC. You will need to break this problem into four steps.
    a) Find the Joules needed to heat the water to the boiling point.
       $q = (m)(C_p)(\Delta T) = (32.9)(4.18)(65) = 8938.9$ J

    b) Find the Joules needed to vaporize the water.
       $q=(m)(\Delta H) = (32.9)(2260) = 74,354$ J

    c) Find the Joules needed to heat the vapor (steam) from the boiling point to 120^oC.
       $q = (m)(C_p)(\Delta T) = (32.9)(2.02)(20) = 1329.2$ J

    d) Add your answers to steps a, b, and c.
       8938.9 + 74,354, + 1329.2 = 84,622 J

12. How much heat energy would be required to change the temperature of 125g of ice from -32.9^oC to liquid water at 75^oC?
    $q = (m)(C_p)(\Delta T) = (125)(2.06)(32.9) = 8471.75$ J
    $q=(m)(\Delta H) = (125)(334) = 41,750$ J
    $q = (m)(C_p)(\Delta T) = (125)(4.18)(75) = 39,187.5$ J
    Total: 8471.75 + 41,750 + 39,187.5 = 89,406 J