Phase Diagrams – In Class Notes

1) A **phase diagram** is a graph of pressure vs. temperature that shows the conditions at which the phases of the substance exist. It also shows how the phases change with changing temperatures and pressures.

2) Key Parts of a Phase Diagram:

   a) States of Matter:

   - Solids exist at high pressures and low temperatures, while gases exist low pressures and high temperatures

   b) Atmospheric Pressure:

   - This is the pressure our atmosphere exerts on us (at sea level). There are several units for pressure, but all of the following are equal each another and reflect atmospheric pressure:

1 **atm** (atmosphere) = 760 **torr** = 760 **mm Hg** (millimeters of mercury) = 101.325 **kPa** (kilopascal)

   c) Melting & Boiling Points:

   - **Melting Point** – the temperature at which a substances changes from a solid to liquid; this phase change occurs when the solid and liquid states are in equilibrium with one another
   - **Boiling Point** – the temperature at which a substances changes from a liquid to gas; this phase change occurs when the liquid and gas states are in equilibrium with one another
     - All substances have only one **NORMAL melting point** and one **NORMAL boiling point** which occur at atmospheric pressure
     - If the pressure is changed to something other than atmospheric pressure, then the substance will have different melting and boiling points

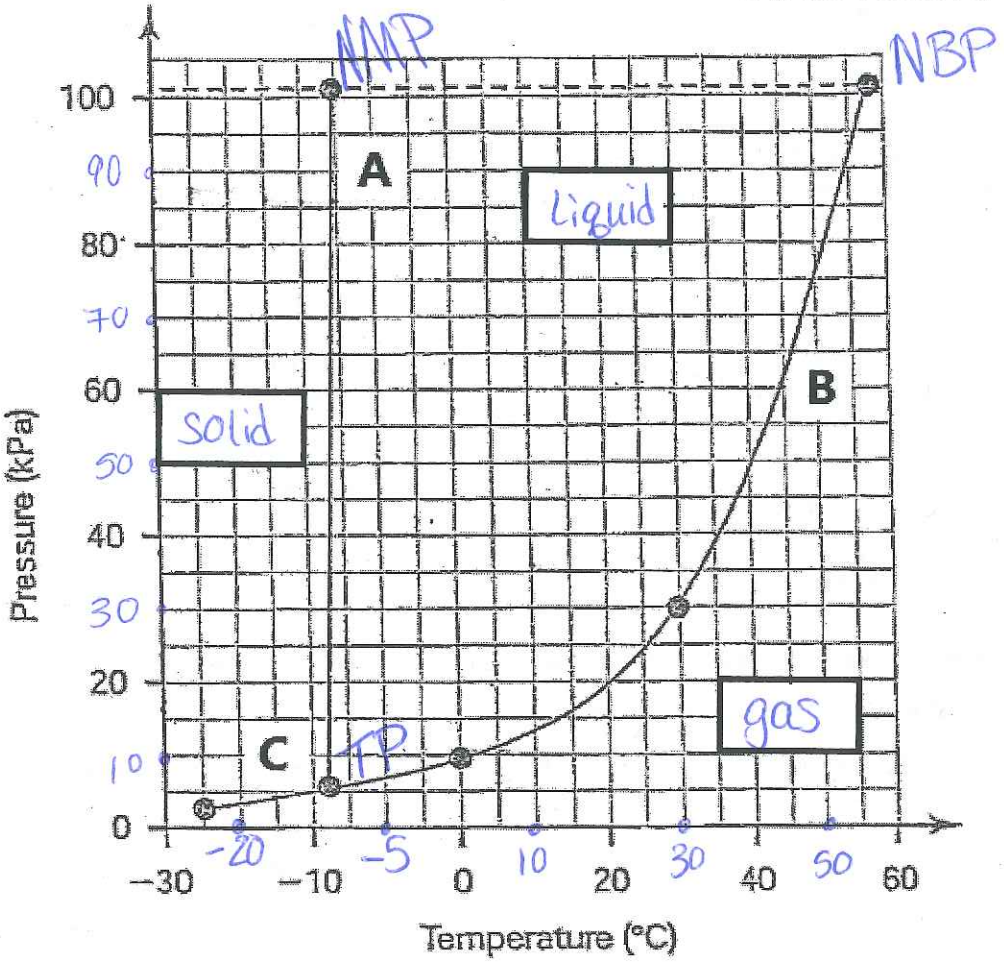
   d) **Triple Point** – indicates the temperature & pressure conditions at which the solid, liquid, and gas phases of a substance coexist at the same time in equilibrium with each other

   e) **Critical Point** - the temperature & pressure at which there is no longer distinct liquid and gas phases

   - Once a substance reaches the critical point or exceeds the **critical temperature** or **critical pressure**, it becomes a **supercritical fluid**
   - **Supercritical Fluid** – the substance exhibits behaviors of both liquids and gases (it can behave as a gas, both effusing & diffusing, but it can also dissolve other substances like a liquid).

Phase Diagram of Bromine (Br_2) – In Class Example

[Note that the scales are distorted to emphasize some of the graph's features]



Directions: Answer the questions below using the phase diagram of bromine.

1) Label the states of matter in the appropriate places on the phase diagram above.

2) Identify the phase changes that occur on the line next to points A, B, and C on the diagram.

A: melting and freezing

B: vaporization and condensation

C: sublimation and deposition

3) Label bromine's **normal melting point (MP)**, **normal boiling point (BP)**, **triple point (TP)**, & **critical point (CP)** on the diagram & estimate the temperature & pressure values at each point:

	Temperature (°C)	Pressure (kPa)		Temperature (°C)	Pressure (kPa)
Normal MP	−7.5	101.325	**Triple Point**	−9	6
Normal BP	58	101.325	**Critical Point**	off chart	off chart.

4) Looking at the diagram, describe what happens to the *melting point* of bromine as the external *pressure increases*.

As external pressure increases, melting point increases (directly proportional)

What can you conclude about the *forces of attraction* between the bromine molecules as the pressure increases?

higher boiling point = stronger forces

Increased pressure forces the molecules closer together, meaning forces of attraction become stronger. (directly proportional)

What is the *relationship* between the melting point (or boiling point) of a substance and the strength of attractive forces between its molecules?

The stronger the attractive forces, the higher the melting & boiling points. (directly proportional)

5) If you keep the temperature of a substance constant, but increase the pressure the *more dense state of matter* is always favored. If you look at the slope of the melting-point equilibrium line, a positive slope (as seen with bromine) means that with increasing pressure will favor the ___solid___ state as the more dense state of matter. Rarely, a substance may have a negative slope signifying that the ___liquid___ state of matter would be denser. An example of a substance like this would be ___water___ (ice floats)

6) What is the boiling point of bromine when the external pressure is 75 kPa? ___50°C___

7) Complete the following sentences by filling in to correct phase change that occurs:

a) Bromine at 15°C will ___condense___ when the pressure is raised from 10 kPa to 50 kPa.

gas → liquid

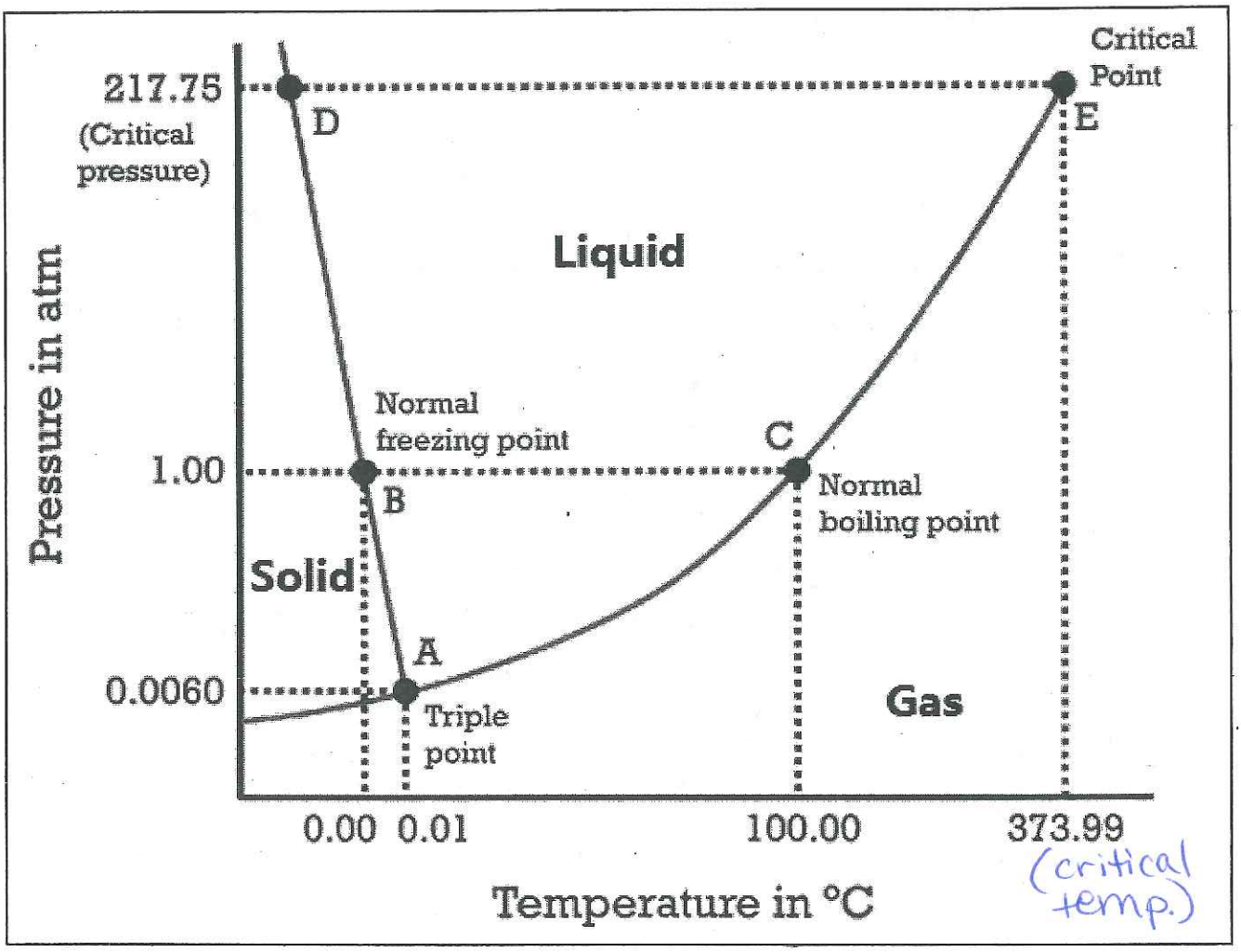
b) Br_2 at 70 kPa ___freezes___ when the temperature is decreased from 20°C to –15°C.

liquid → solid

c) Bromine at –20°C will undergo ___deposition___ is the pressure is increased from 0 kPa to 10 kPa.

gas → solid

Phase Diagram of Water – In Class Example



1) Describe all the phase changes a sample of solid water would undergo when heated from -10°C to its critical temperature at a constant pressure of 1.00 atm.

-10°C → 373.99°C (heated)

solid → liquid (melting)

liquid → gas (vaporization)

2) Describe all the phase changes a sample of water vapor would undergo when cooled from 110°C to 5°C at 1.00 atm of pressure.

110°C → 5°C (cooled)

gas → liquid (condensation)

3) At what pressures will water be a vapor at 0°C? below 0.0060 atm

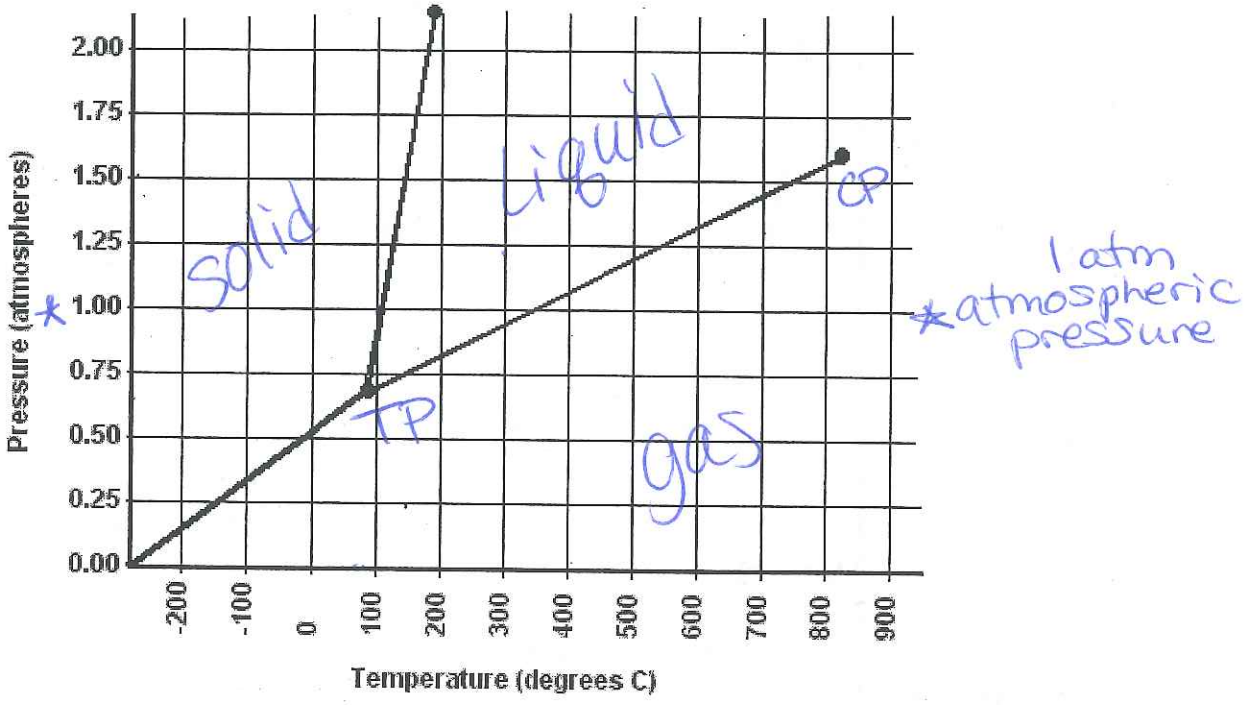
4) Within what range of pressures will water be a liquid at temperatures above its normal boiling point?

100°C

between 1 atm and 217.75 atm

Phase Diagrams – Homework WS #1

Directions: Refer to the phase diagram below when answering the questions on this worksheet:



1) At atmospheric pressure at room temperature (27°C), what state of matter is this substance?

Solid

2) What is the normal melting point of this substance? 100°C @ 1 atm

3) What is the normal boiling point of this substance? 350°C @ 1 atm

4) What is the normal freezing point of this substance? 100°C @ 1 atm = MP

5) If I had a quantity of this substance at a pressure of 1.25 atm and a temperature of 300°C and lowered the pressure to 0.25 atm, what phase transition(s) would occur?

Liquid → gas (vaporization)

6) At what temperature and pressure do the gas and liquid phases become indistinguishable from each other? What is this point called?

Critical Point @ 1.6 atm and 825°C

7) If I had a quantity of this substance at a pressure of 0.50 atm and a temperature of –100°C, what phase change(s) would occur if I increased the temperature to 600°C? At what temperature would this occur?

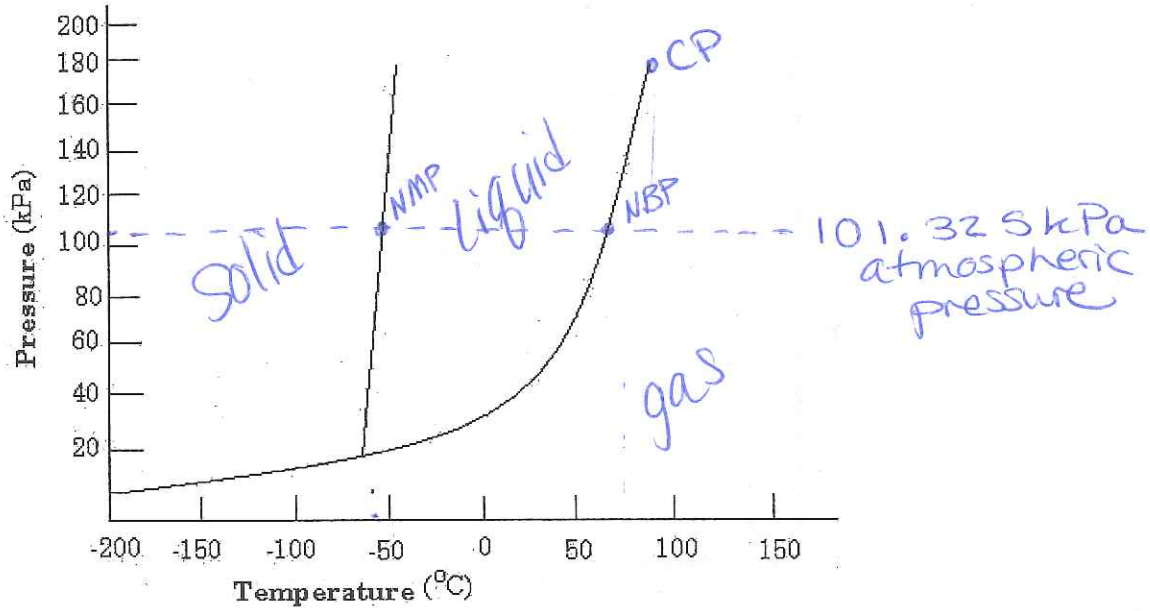
solid → gas (sublimation)

8) Under what conditions of temperature and pressure are all three states of matter in equilibrium? What is this point called?

Triple Point @ 0.65 atm and 85°C

Phase Diagrams – Homework WS #2

Use the phase diagram for water below to answer the following questions.



1) Label the three states of mater on the diagram above.

2) What is standard atmospheric pressure on this graph? 101.325 kPa [look at units]

3) What is the normal melting point of this substance? -60°C

4) What is the normal boiling point of this substance? 50°C

5) At atmospheric pressure and room temperature (27°C), what state of mater is this substance?

Liquid

6) If the external pressure was raised to 160 kPa, what would be the new melting and boiling points of this substance?

Melting Point = −50°C Boiling Point = 75°C

7) What phase change occurs when a substance at 60 kPa and 0°C has its pressure lowered to 10 kPa?

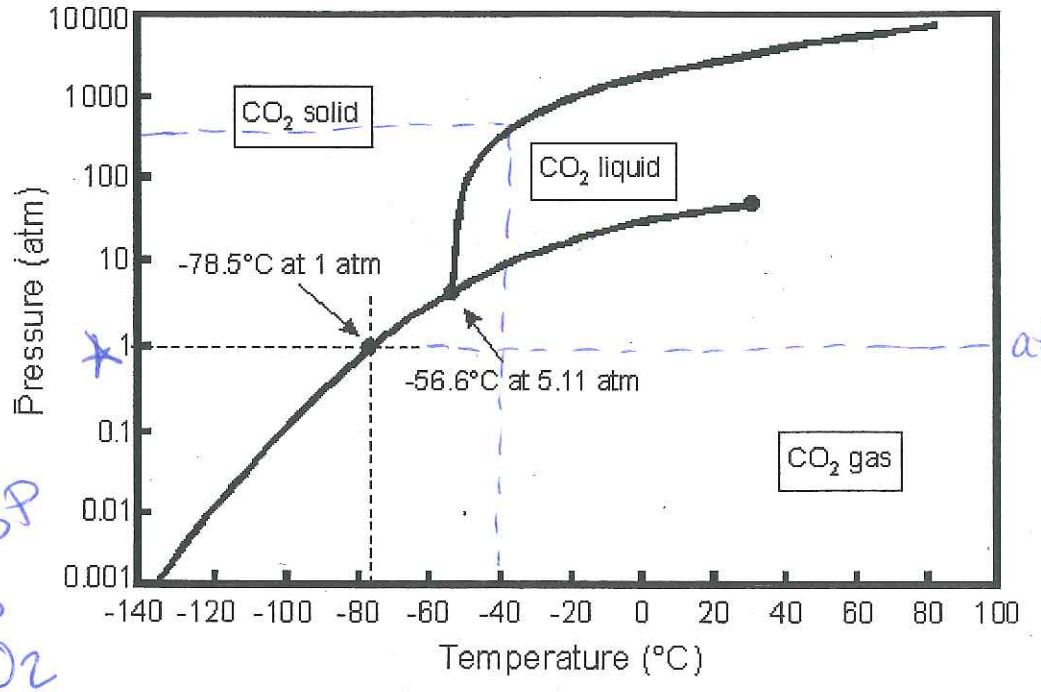
Liquid → gas (vaporization)

8) At what temperature and pressure is the critical point? What is the critical point?

The point at which the liquid & gas phases are indistinguishable @ 180 kPa and 90°C

Phase Diagrams – Homework WS #3

Use the phase diagram for water below to answer the following questions.



1 atm atmospheric pressure

★ No normal MP or BP exists for CO_2

Carbon dioxide is a unique substance, hence its very a-typical phase diagram. The states of matter have been labeled to help assist you in answering the questions below.

1) At atmospheric pressure and room temperature (27°C), what state of matter is the substance?

gas

2) At the point labeled -78.5°C at 1 atm, what phase change is occurring? What would we call this point?

Solid → gas (sublimation) ↓ Sublimation Point

3) What is happening at the conditions of -56.6°C at 5.11 atm?

This is the triple point where all three states of matter coexist in equilibrium.

4) It is very difficult to get CO_2 into the liquid phase. At a temperature of –40.0°C it is possible to melt solid CO_2 into a liquid; what pressure would be necessary to do this?

500 atm & -40°C = Melting Point.

5) Under what range of pressure conditions would CO_2 be a liquid at –20.0°C?

between 20 atm and 1000 atm