Learning Objectives

- Explain states of matter.
- Define and explain what a phase is.
- Interpret these phase transitions: sublimation, deposition, vaporization, condensation, and melting and freezing.

States: Gas, Liquid and Solid

Gas, liquid, and solid are known as the three states of matter or material, but each of solid and liquid states may exist in one or more forms. Thus, another term is required to describe the various forms, and the term phase is used. Each distinct form is called a phase; however, the concept of phase defined as a homogeneous portion of a system extends beyond a single material, because a phase may also involve several materials. For example, a homogeneous solution of any number of substances is a one-phase system. Phase is a concept used to explain many physical and chemical changes (reactions).

- A solid has a definite shape and volume. A liquid has a definite volume but it takes the shape of a container whereas a gas fills the entire volume of a container. You already know that diamond and graphite are solids made up of the element carbon; they are two phases of carbon, but both are solids. Solids are divided into subclasses of amorphous (or glassy) solids and crystalline solids. Arrangements of atoms or molecules in crystalline solids are repeated regularly over a very long range of millions of atoms, but their arrangements in amorphous solids are somewhat random or short range of say some tens or hundreds of atoms.
- In general, there is only one liquid phase of a material. However, there are two forms of liquid helium; each have some unique properties. Thus, the two forms are different (liquid) phases of helium. At a definite temperature and pressure, the two phases co-exist.
- So far, all gases behave alike as do mixtures of gases. Thus, a gas is usually considered as a phase.

The Concept of Phase

A phase is a distinct and homogeneous state of a system with no visible boundary separating it into parts.

Water, \( \text{H}_2\text{O} \), is such a common substance that its gas (steam), liquid (water), and solid (ice) phases are widely known. An ice water mixture has two phases, as do systems containing ice-and-vapor, and water-and-vapor. To recognize the vapor system in these systems may require a keen observation, because the vapor usually blends with air, and is not detected directly.

You probably also know that several solids may exist for a substance, and each of the solid forms is also called a phase. Diamond and graphite are the most quoted examples; both are solid carbon, but they have different crystal shapes, colors, and structures. They represent two different phases of carbon. Ice is another example, under 1 atm, ice has hexagonal symmetry, while cubic ice is formed under high pressure. In fact, there are at least eight different types of ice, each being a solid phase.
When you mix water and alcohol, regardless of the relative amounts that you use, they are fully miscible. The resulting mixture has only one phase (a solution). However, water and oil are normally immiscible, and their boundary of separation is visible; they form a two-phase system. Sometimes you cannot "see" the boundary, and you will need scientific reasoning to realize the number of phases present in system.

Well, there is so much concept packed into one term that we can not make the definition any simpler for you. However, the term is useful because it can be used to explain many phenomena. There is no substitute for it. Learn it and use it to explain physical changes.

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**Phase Transitions**

The conversion between these phases is called a **phase transition**. A state change of any material due to temperature or pressure change is a phase transition. A phase transition is a physical change (or reaction). The following diagram illustrates the key phase transitions: You should know the names of the process for these phase transitions.

\[
\text{SOLID} \xrightarrow{\text{sublimation}} \text{GAS} \xrightarrow{\text{deposition}} \text{SOLID}
\]

\[
\text{SOLID} \xrightarrow{\text{melting}} \text{LIQUID} \xrightarrow{\text{solidification}} \text{SOLID}
\]

\[
\text{GAS} \xrightarrow{\text{condensation}} \text{LIQUID} \xrightarrow{\text{vaporization}} \text{GAS}
\]

The concepts of phase and phase transition introduce you into fields of materials studies. For example, if you search the internet with the phrase "phase transition", you get thousands of websites; some are related to the concept we have discussed here, but some may be using "phase transition" as a catchy phrase. The concept of phase transition is also applied to the study of nuclear matter such as protons and neutrons.

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**Confidence Building Questions**

1. How many phases are there in milk?
   
   Hint: more than one

   **Skill**
   Define phase and enumerate the number of phases in a system.
   Milk is a **colloid**.

2. Which one of the following systems has three phases that are at equilibrium with one another?
   a. a sealed container full of unsaturated \(\text{\text{\text{NaCl}}}\) solution.
   b. a sealed container full of oversaturated sugar solution.
   c. a sealed container full of colloid made by suspending solid in liquid.
   d. a sealed container half full of water and oil.
   e. an open container half full of oil and water and ice.

   Hint: d
Skill -
Identify the number of phases in a system.

3. How many phases are present in a closed flask if it contains ice, water and air?

Hint: Three phases: solid, liquid, and vapor (gas solution).

Discussion -
What will be the temperature for a system describe here?

4. How many phases are present in a closed flask if it contains dry ice and air?

Hint: Two phases: solid and vapor (gas solution).

Skill -
Define phase and enumerate the number of phases in a system.

5. A sealed 5-L flask contains 1.0 L of solution, some \(\ce{NaCl}\) crystals, and some ice crystals. The rest of the space is filled with air. How many phases are present in such a system?
   a. 1
   b. 2
   c. 3
   d. 4
   e. 5

Hint: d. Four phases: liquid, \(\ce{NaCl}\), ice, gas

Skill -
Enumerate the number of phases in a system.
Do you know what the temperature is for such a system to be at equilibrium? It's 0 degree F (the temperature of equal weight mixture of snow and salt).

6. A 750-mL bottle contains 300 mL clear colorless alcoholic beverage. What are the phases present in the bottle?

Hint: A liquid and a gas solution, 2 phases.

Skill -
Identify the phases in a system.

7. What is the name for the process of phase transition by which a gas is converted to a solid?

Hint: Deposition

Skill -
Know the names of all phase transition processes.

8. The vapor pressure of a solid
   a. increases as the volume of the solid increases.
   b. decreases as the temperature of the solid increases.
   c. increases as the temperature of the solid increases.
d. decreases as the volume of the solid increases.

Hint: c. increases as the temperature of the solid increases.

Skill -
This is a test of common sense.
A scientific way of looking at the vapor pressure of a solid as a function of temperature is given by the Clausius-Clapeyron Equation:

$$P_{\text{vap}} = A e^{-H_{\text{vap}}/RT}$$

where $H_{\text{vap}}$ is the heat of vaporization, and $R T$ are the gas constant and temperature respectively.

9. Water ALWAYS boils at 100 degree C: true or false?

Hint: false

Skill -
This is a test of common sense.
Only when the atmospheric pressure is 1.00 atm will the boiling temperature be 100 deg. C, which is the normal boiling point of water.

10. The volume of 18 grams of water increases as its temperature increases from 0 to 4 deg. C: true or false?

Hint: false!

Skill -
This is a test of common sense. You know that the density of water is the highest at 4 deg. C, and its volume for a mole is the lowest at 4 deg C.
One mole of water is 18 g, and its volume is called the molar volume. Water is a strange substance!

11. The volume of 18 grams of water increases as its temperature increases from 10 to 84 deg. C: true or false?

Hint: true!

Skill -
Analyze the problem carefully. Most substances expand when heated.

12. One mole water of which phase occupies the largest volume: solid, liquid or gas?

Hint: gas

Discussion -
Temperature is not specified here, but you may assume a temperature at which all three phases are stable. Under the circumstance, the pressure of vapor phase is much lower than 1 atm. For the same quantity of water, ice has a larger volume than water.
Contributors and Attributions

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