

Phase Equilibria

Dr. L.T.M. Muungo

A proper understanding of certain systems and processes in pharmaceutical practice necessitates knowledge of the principles that govern the equilibria between solid, liquid and gaseous phases.

The Phase Rule

Gibbs created the phase rule, which relates: the effect of the least number of independent variables (temperature, pressure and concentration) *upon* the various phases (solid, liquid and gaseous) that exist in an equilibrium system containing a given number of components.

Phase

A phase is defined as any **homogeneous** and **physically distinct** part of a system that is separated from other parts of the system by **definite boundaries**.

- For example, **ice, water, and water vapour** are three separate phases; each is physically distinct and there are definite boundaries between them.
- **Pure liquids or solutions** constitute homogeneous phases, but two immiscible liquids (or solutions) constitute two phases since there is a definite boundary between them.
- A **mixture of gases** always constitutes one phase because the mixture is homogeneous and there are no bounding surfaces between the different gases in the mixture.

Number of components

The number of components of a system is the number of constituents expressed in the form of a chemical formula.

For example in the 3-phase system ice, water, water vapour, the no of components is 1, since each phase is expressed as H_2O .

A mixture of **salt and water is a 2 component system** since both chemical species are independent.

Degrees of freedom

The number of degrees of freedom is the number of variable conditions (e.g. temperature, pressure, and concentration) that may affect the phase equilibrium.

The relationship between:

- the number of phases P ,
- components C ,
- degrees of freedom F

for equilibria that are influenced only by temperature, pressure, and concentration is given by equation

Gibbs phase rule:

$$F = C - P + 2$$

Systems Containing One Component

The phase diagram for the ice-water-water vapour system

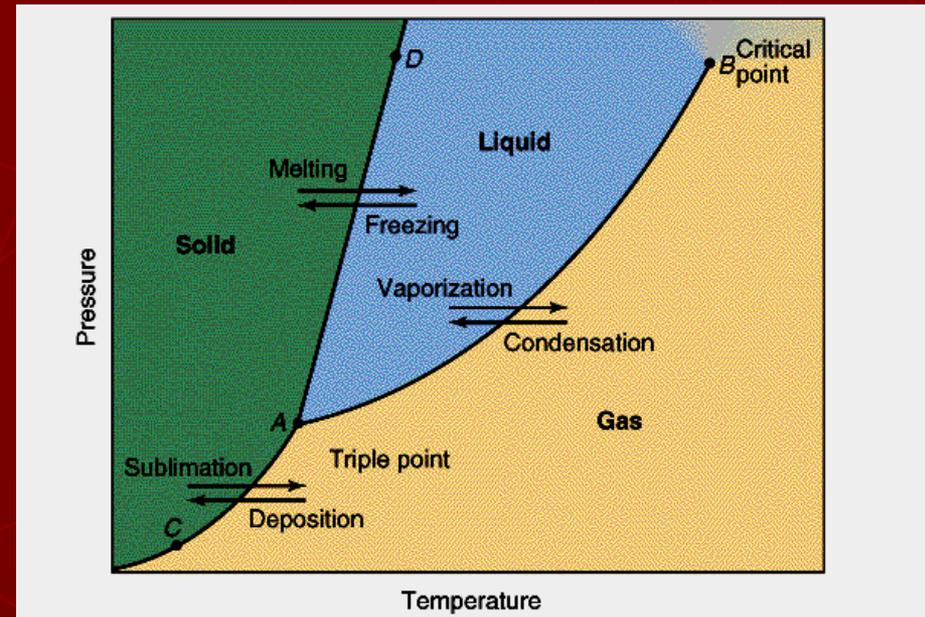
(phase diagram = graphical representation which indicates the phase equilibrium)

Each area correspond to a single phase.

The number of degrees of freedom in each area is :

$$F = C - P + 2$$

$$F = 1 - 1 + 2 = 2$$



This means that temperature and pressure can be varied independently within these areas without change in number of phases

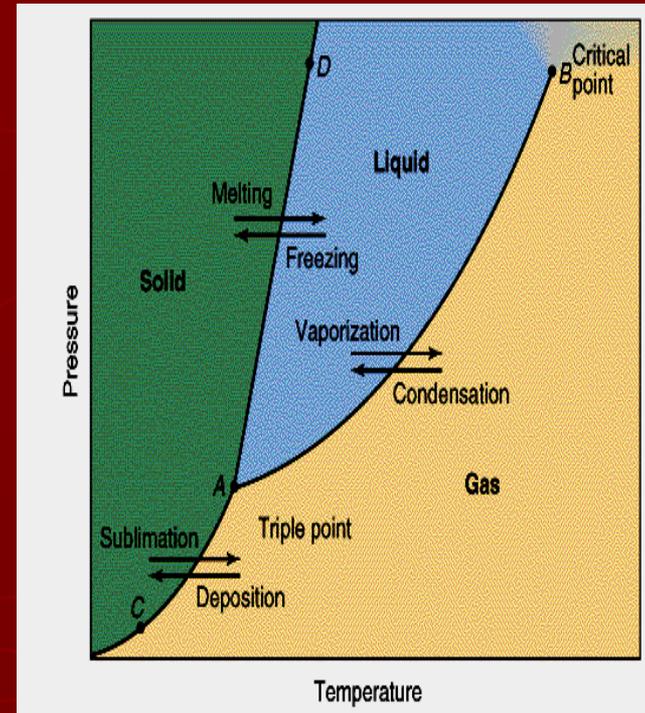
For points that lie on one of the lines AB, AC, or AD, these lines form the boundaries between different phases

2 phases exist in equilibrium with each other.

$$F = 1 - 2 + 2 = 1$$

1 variable exists when equilibrium is established between 2 phases.

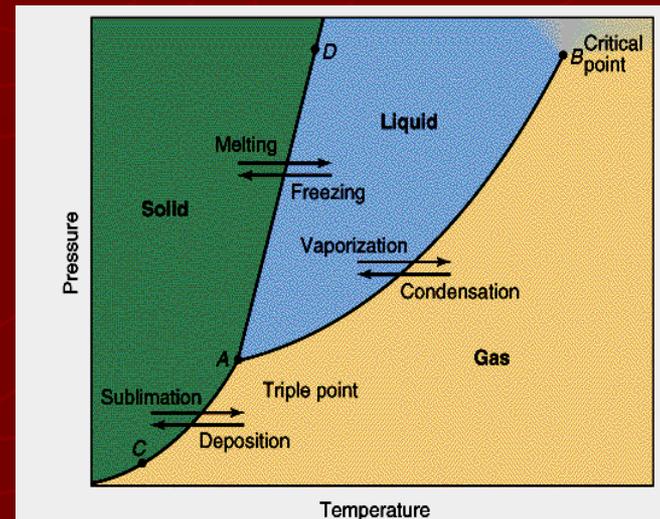
→ if the pressure is altered the temperature will assume a particular value and vice versa



- Independent variation will alter no. of phases
- To keep the no. of phases P and T must be changed at the same time

Melting Point

- ★ The boundary AD represents the coexistence of **liquid water** in **solid ice** at various temperature and pressures.
- ★ AD therefore indicates the effect of pressure on the melting point of ice.
- ★ If at any point on this line the temperature is increased while the pressure is maintained constant, then all the ice will be converted to liquid water.
- ★ i.e., only one phase will remain instead of two original phases that were in equilibrium at the point AD.
- ★ Thus, in order to maintain equilibrium conditions between the two phases, the temperature and pressure must not be varied independently of each other.

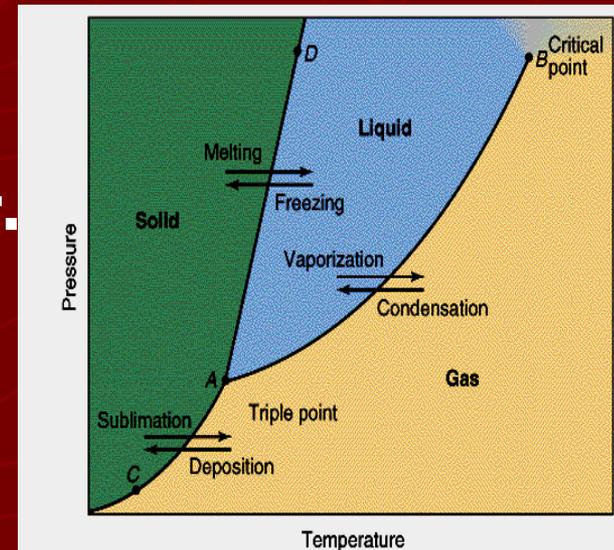


Boiling Point

- ★ The boundary AB, which is known as the vapour pressure curve, represents the coexistence of **liquid water** and **water vapour** under various conditions.
- ★ The temperature and pressure again cannot be varied independently otherwise a change from a two-phase system to a single-phase system will occur,
- ★ For example, if the pressure is kept constant at any point along AB while the temperature is increased, then all the water will be converted to vapour and only one phase will remain.

★ AB therefore represents the effect of pressure on the boiling point of water.

★ **Critical temperature** (374°C). This is the temperature above which it is impossible to liquefy water vapor no matter you increase the pressure.



Triple Point

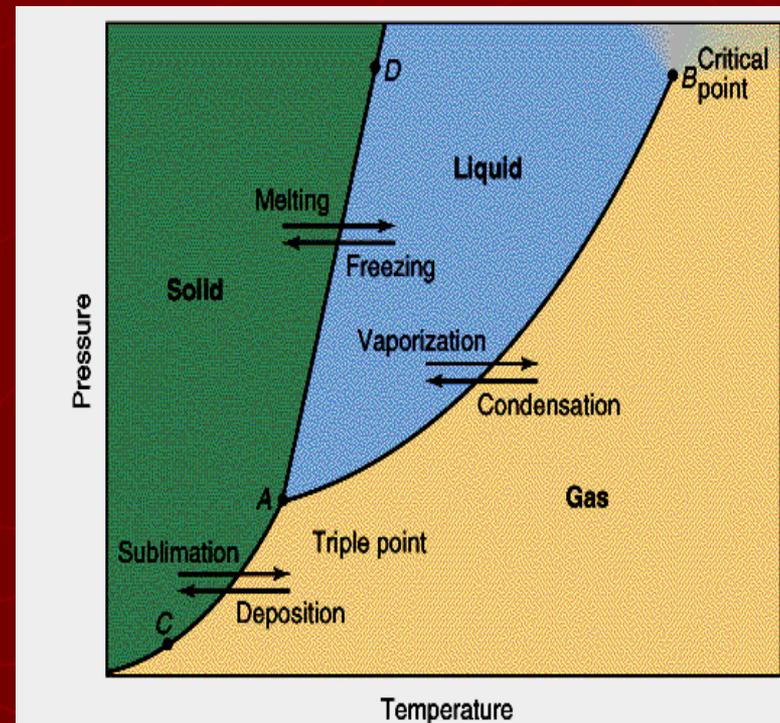
★ The boundary lines meet at A, which is the only point in the diagram where 3 phases may coexist in equilibrium and it is therefore termed **a triple point**.

★ $F = 1 - 3 + 2 = 0$

The system is **invariant**; i.e., any change in P or T will result in an alteration of the number of phases that are present.

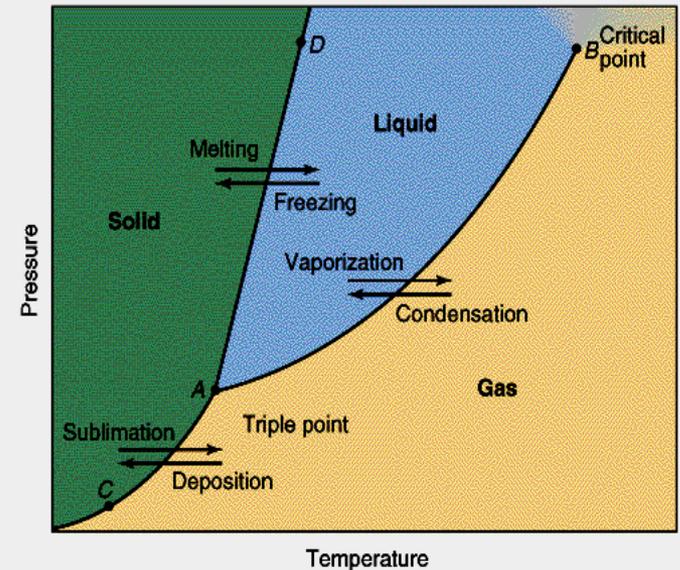
$$T = 0.0098^{\circ}\text{C}$$

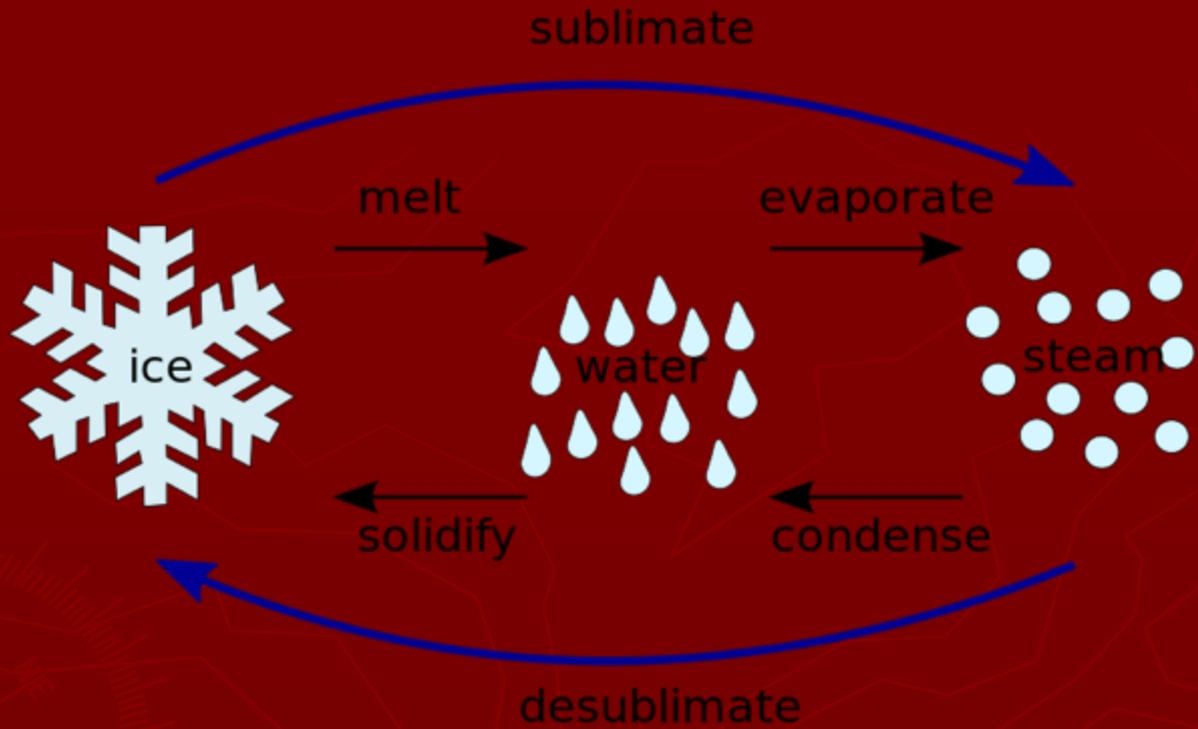
$$P = 4.58 \text{ mmHg}$$



Sublimation (Freeze Drying)

- ★ The boundary AC, which is known as the sublimation pressure curve for ice, indicates the conditions for the coexistence of **vapour** and **solid phases** in equilibrium.
- ★ A mass of ice may be converted directly into water vapour by heating, provided that the pressure is kept below triple point pressure. This is termed *Sublimation, Lyophilization or Freeze drying*.
- ★ This transition is particularly valuable in drying compounds that are sensitive to the higher temperature e.g. drying of blood plasma, blood serum and penicillin.





Any Question

Study Questions

❑ Define the following terms:

[homogeneous, heterogeneous, phase diagram, sublimation, Lyophilization, melting point, boiling point, triple point, etc]

❑ Respond to the following questions:

- Illustrate the process of sublimation in a pharmaceutical system

❑ Group work discussional questions:

- Discuss the variations in a solution that may constitute the pharmaceutical material phase changes equilibrium
- What are the main key points to consider when a pharmaceutical system is undergoing phase changes within a system.