CHAPTER

2

Thermodynamics

Petroleum Engineering
Second year

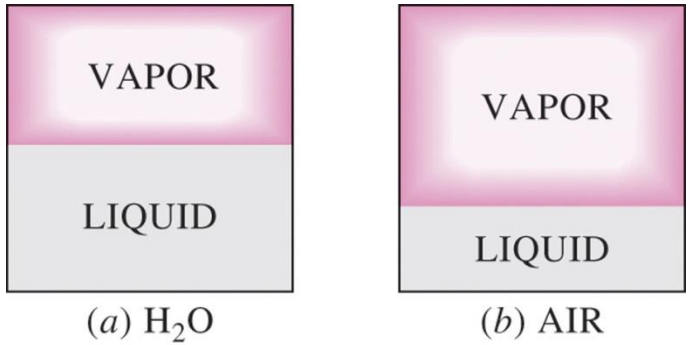
Properties of Pure Substances

What is Pure Substances?

- **A pure substance** is one that has a homogeneous and invariable chemical composition.
- It may exist in more than one phase, but the chemical composition is the same in all phases.
- Pure substances can be divided into two groups, elements and compounds.

- *liquid water, a mixture of liquid water and water vapor (steam), and a mixture of ice and liquid water are all pure substances; every phase has the same chemical composition.*

- *a mixture of liquid air and gaseous air is not a pure substance because the composition of the liquid phase is different from that of the vapor phase*



(*a*) H_2O (*b*) AIR

Examples:

- Water (solid, liquid, and vapor phases)
- Mixture of liquid water and water vapor
- Carbon dioxide, CO_2
- Nitrogen, N_2
- Mixtures of gases, such as air, as long as there is no change of phase.

Phases of A Pure Substance

- The substances exist in different phases, e.g. at room temperature and pressure, copper is solid and mercury is a liquid.

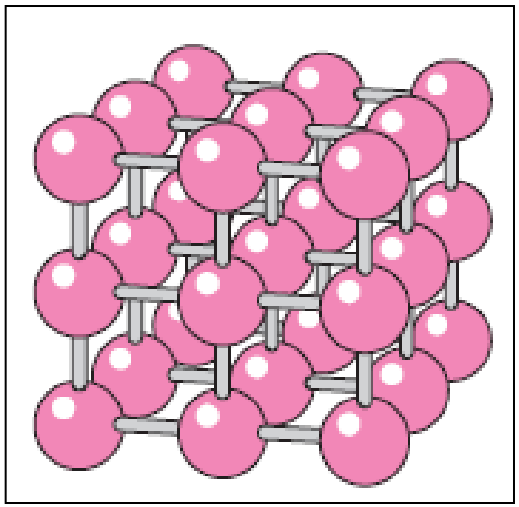
- It can exist in different phases under variations of condition.

- There are 3 Principal phases
  - *solid*
  - *Liquid*
  - *gas*

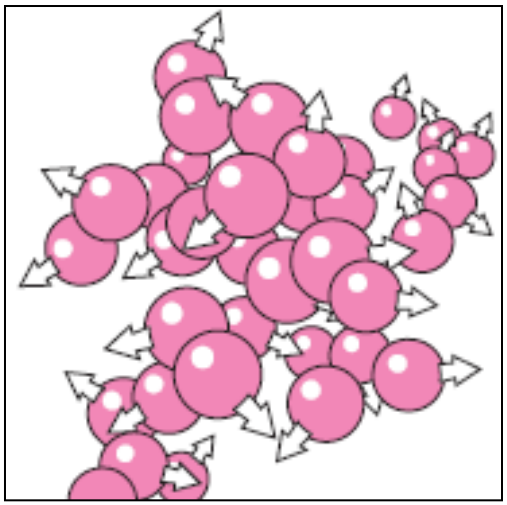
  Each with different molecular structures.

Phase-change Processes of Pure Substances

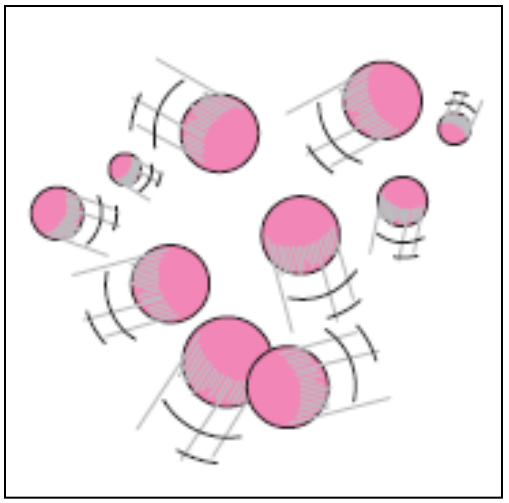
- There are many practical situations where two phases of a pure substances coexist in equilibrium.
- E.g. water exists as a mixture of liquid and vapor in the boiler and etc.
  - Solid: strong intermolecular bond
  - Liquid: intermediate intermolecular bonds
  - Gas: weak intermolecular bond



Solid

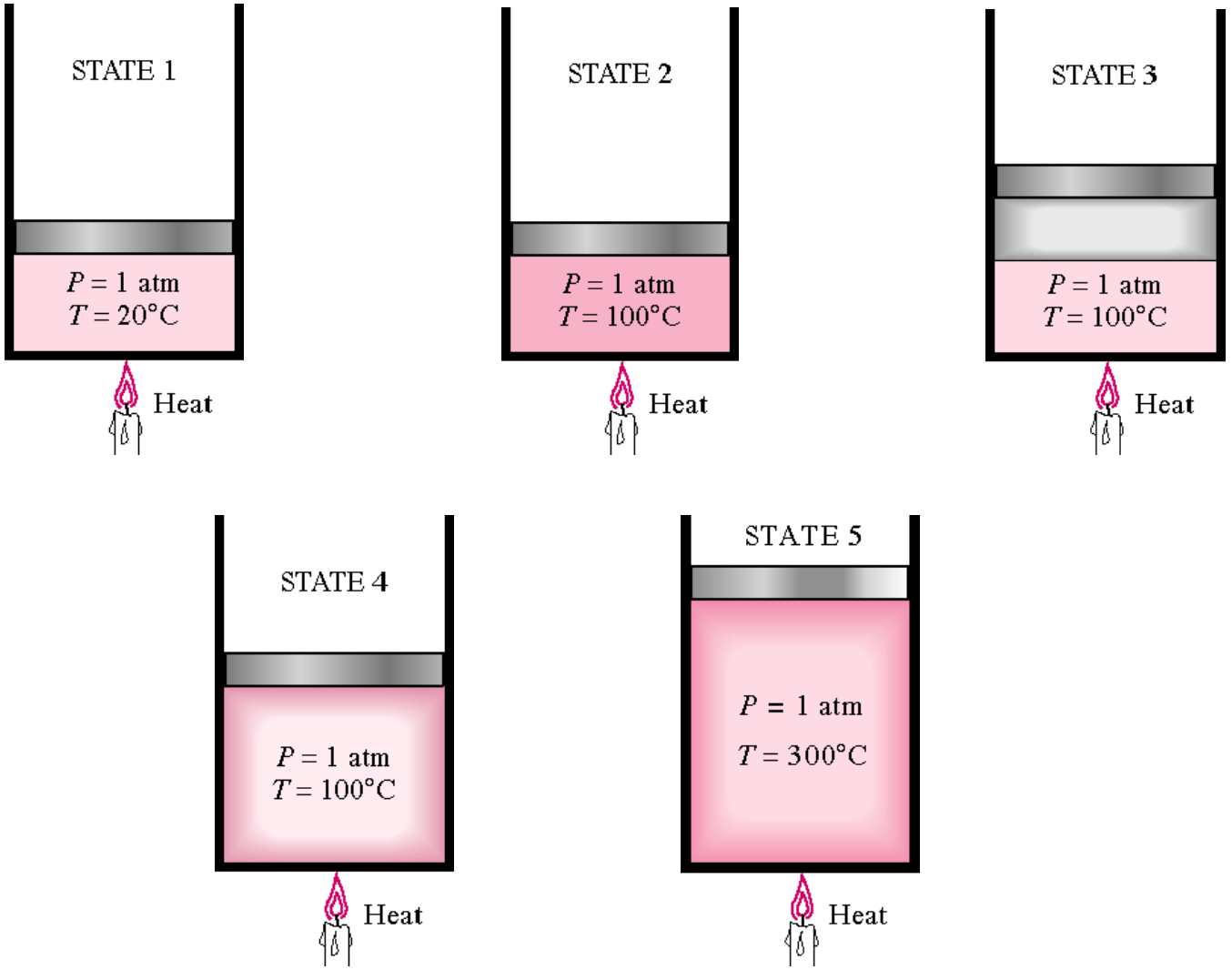


Liquid

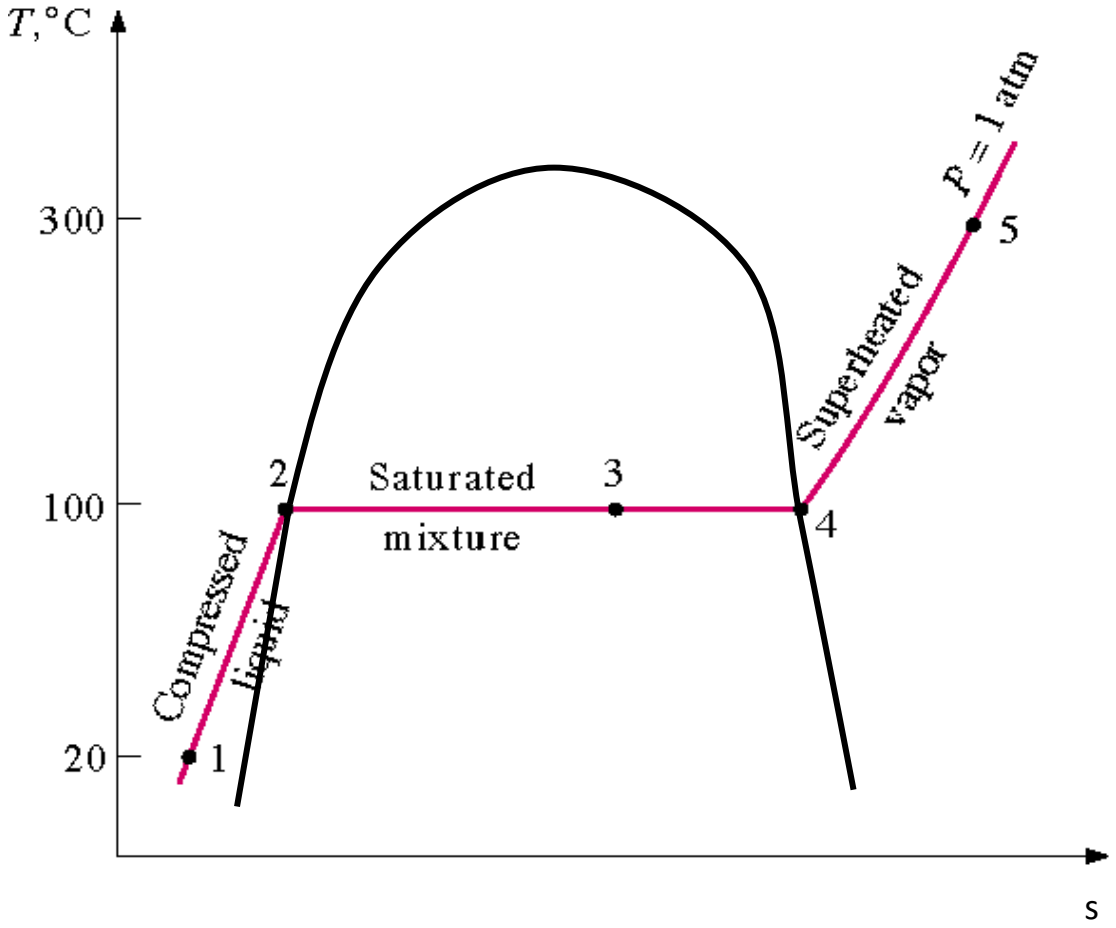


Gas

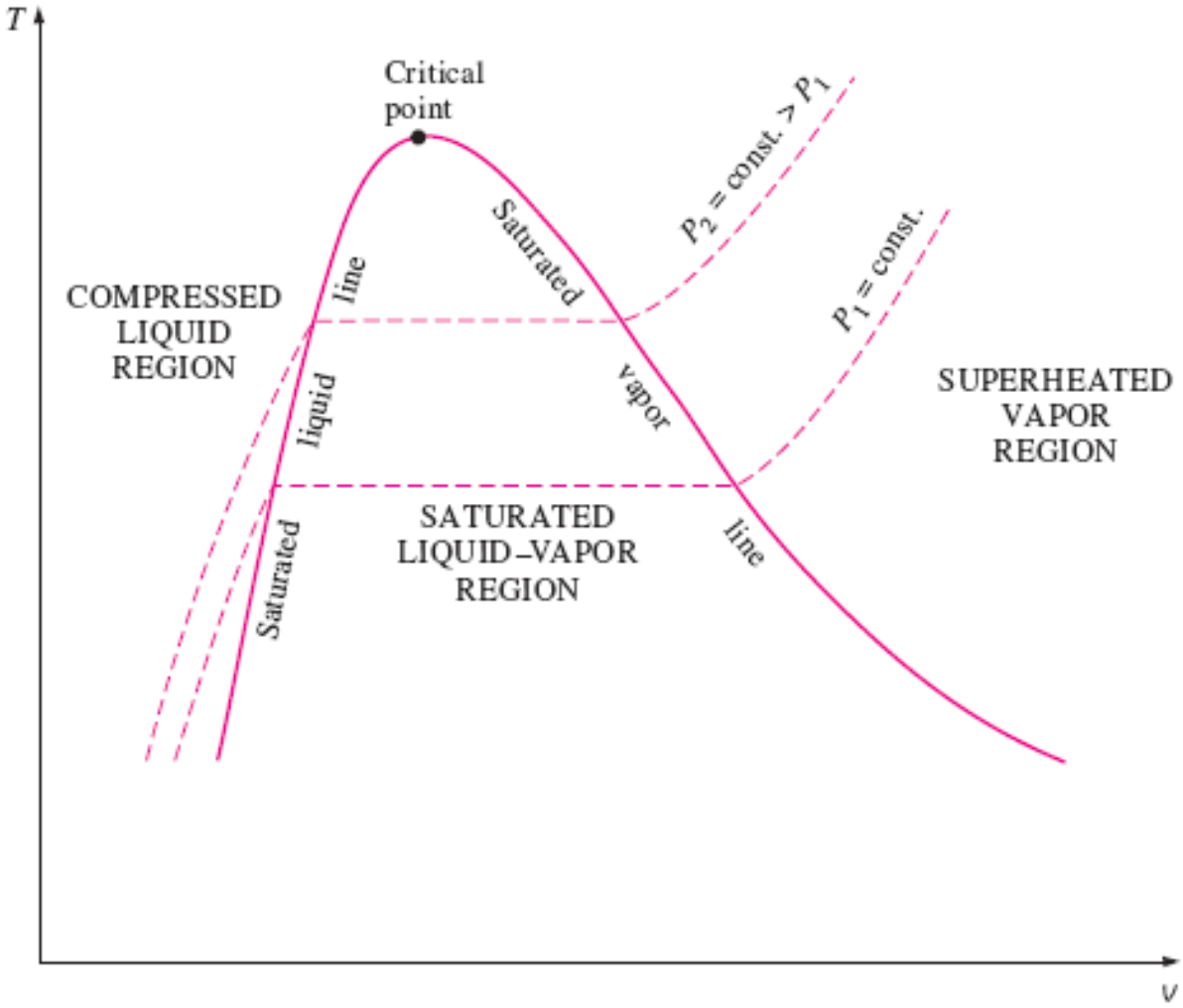
Phase-change Processes



This constant pressure heating process can be illustrated as:



Property Diagram



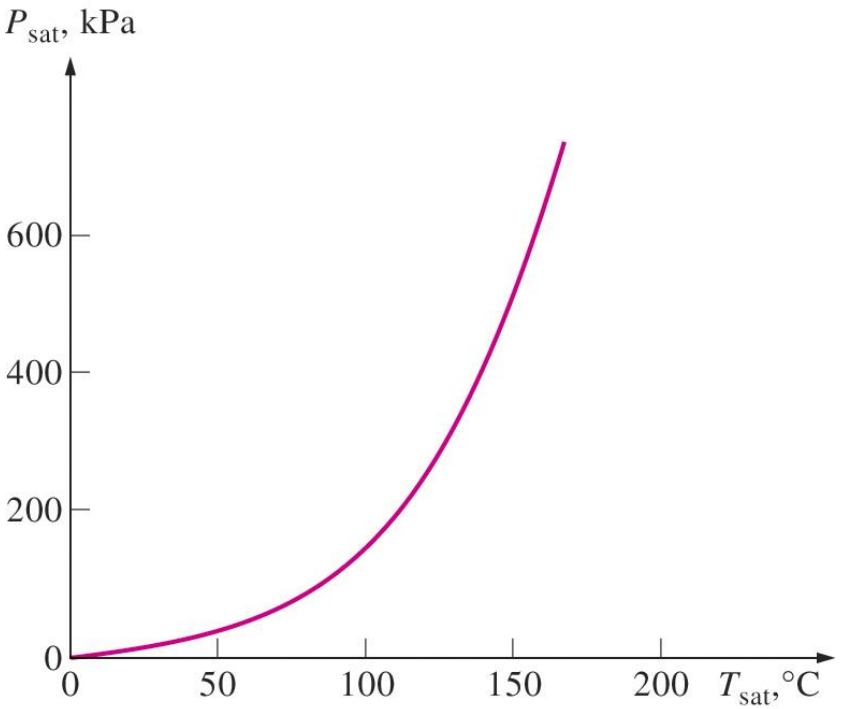
Saturation

- *Saturation* is defined as a condition in which a mixture of vapor and liquid can exist together at a given temperature and pressure.

- *Saturation temperature* The term saturation temperature designates the temperature at which vaporization takes place at a given pressure. This pressure is called the "Saturation pressure" for the given temperature.

- For a pure substance there is a definite relationship between saturation pressure and saturation temperature. Where higher pressure mean the higher saturation temperature

The graphical representation of this relationship between temperature and pressure at saturated conditions is called the *vapor pressure curve*



Vapor-pressure curve of a pure substance (her for water)

TABLE 3–1

Saturation (boiling) pressure of water at various temperatures

Temperature, T, °C	Saturation pressure, P_{sat}, kPa
−10	0.26
−5	0.40
0	0.61
5	0.87
10	1.23
15	1.71
20	2.34
25	3.17
30	4.25
40	7.39
50	12.35
100	101.4
150	476.2
200	1555
250	3976
300	8588

Saturated and Sub-cooled Liquids

- If a substance exists as liquid at the saturation **temperature** and **pressure**, it is called a **saturated liquid**.

- If the temperature of the liquid is lower than the saturation temperature for the existing pressure, it is called:
  - Either a subcooled liquid (implying that the temperature is lower than the saturation temperature for the given pressure)

or

  - A compressed liquid (implying that the pressure is greater than the saturation pressure for the given temperature).

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Saturated and Superheated Vapors

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- If a substance exists entirely as vapor at saturation temperature, it is called *saturated vapor*.
- When the vapor is at a temperature greater than the saturation temperature, it is said to exist as *superheated vapor*.
- The pressure and temperature of superheated vapor are **independent properties**, since the temperature may increase while the pressure remains constant

Latent Heat

- **Latent heat**: The amount of energy absorbed or released during a phase-change process.
- **Latent heat of fusion**: The amount of energy absorbed during melting. It is equivalent to the amount of energy released during freezing.
- **Latent heat of vaporization:** The amount of energy absorbed during vaporization and it is equivalent to the energy released during condensation.
  - *At 1 atm pressure, the latent heat of fusion of water is 333.7 kJ/kg and the latent heat of vaporization is 2256.5 kJ/kg.*

Quality

- When a substance exists as part liquid and part vapor at saturation conditions, its *quality* (x) is **defined** as the ratio of the mass of the vapor to the total mass of both vapor and liquid.
- The quality is zero for the saturated liquid and one for the saturated vapor ($0 \leq x \leq 1$)
- For example, if the mass of vapor is 0.2 g and the mass of the liquid is 0.8 g, then the quality is 0.2 or 20%.

$$x = \frac{mass_{saturated\ vapor}}{mass_{total}} = \frac{m_g}{m_f + m_g}$$