# University of Anbar

## Engineering Thermodynamics
## CHE 215

**Lecture # 06**
**Properties of Pure Substances**

## Objectives of Lecture Note

- Introduce the concept of a pure substance.
- Discuss the physics of phase-change processes.
- Illustrate the *P*-*v*, *T*-*v*, and *P*-*T* property diagrams and *P*-*v*-*T* surfaces of pure substances.

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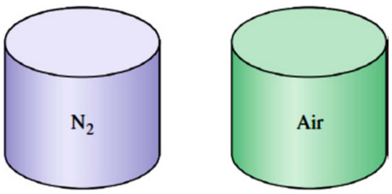
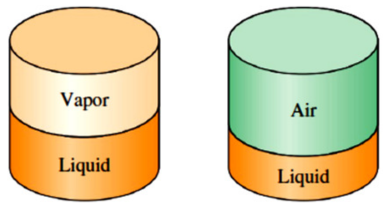
## Pure Substance

- **Pure substance: A substance that has a fixed chemical composition throughout. Water, nitrogen, helium, and carbon dioxide, for example, are all pure substances.**
- **Air is a mixture of several gases, but it is considered to be a pure substance because it has a uniform chemical composition.**




**Nitrogen and gaseous air are pure substances.**




(*a*) $H_2O$ (*b*) Air

**A mixture of liquid and gaseous water is a pure substance, but a mixture of liquid and gaseous air is not.**

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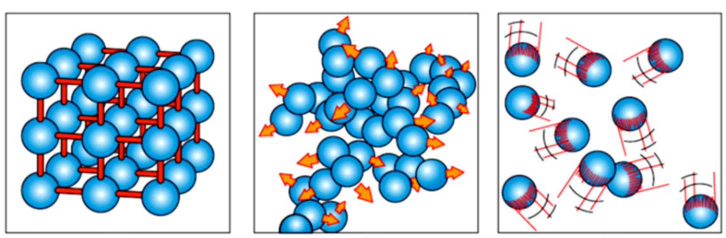
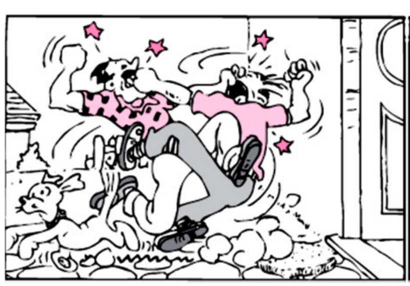
## Phases of a Pure Substance



(*a*) (*b*) (*c*)

**The arrangement of atoms in different phases: (*a*) molecules are at relatively fixed positions in a solid, (*b*) groups of molecules move about each other in the liquid phase, and (*c*) molecules move about at random in the gas phase.**



**In a solid, the attractive and repulsive forces between the molecules tend to maintain them at relatively constant distances from each other.**

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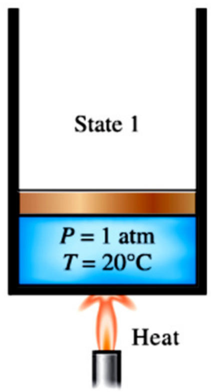
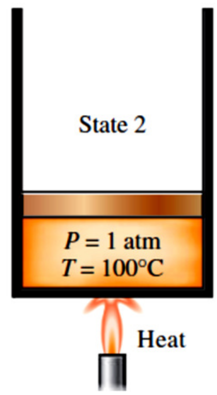
## Phase-Change Processes of Pure Substances

- **Compressed Liquid (subcooled liquid): A substance that it is *not about to vaporize*.**
- **Saturated Liquid: A liquid that is *about to vaporize*.**




**At 1 atm and 20°C, water exists in the liquid phase (*compressed liquid*).**




**At 1 atm pressure and 100°C, water exists as a liquid that is ready to vaporize (*saturated liquid*).**

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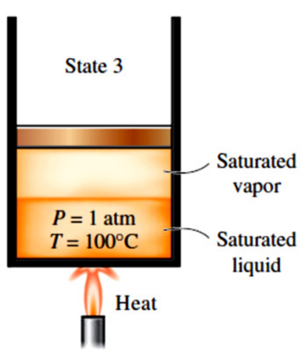
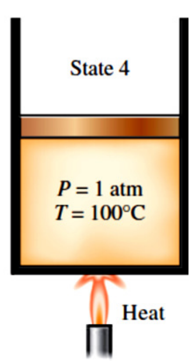
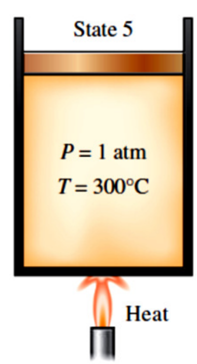
- **Saturated Vapor: A vapor that is *about to condense*.**
- **Saturated Liquid–Vapor Mixture: The state at which the *liquid and vapor phases coexist* in equilibrium.**
- **Superheated Vapor: A vapor that is *not about to condense* (i.e., not a saturated vapor).**




**As more heat is transferred, part of the saturated liquid vaporizes (*saturated liquid–vapor mixture*).**




**At 1 atm pressure, the temperature remains constant at 100°C until the last drop of liquid is vaporized (*saturated vapor*).**




**As more heat is transferred, the temperature of the vapor starts to rise (*superheated vapor*).**

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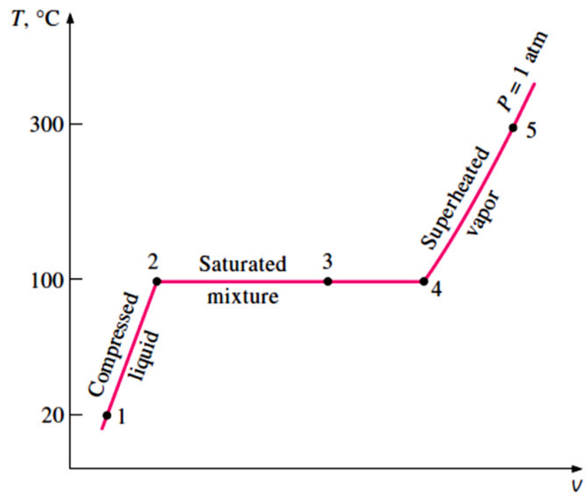
If the entire process between **STATE 1** and **STATE 5** described in the figure is reversed by cooling the water while maintaining the pressure at the same value, the water will go back to state 1, retracing the same path, and in so doing, the amount of heat released will exactly match the amount of heat added during the heating process.



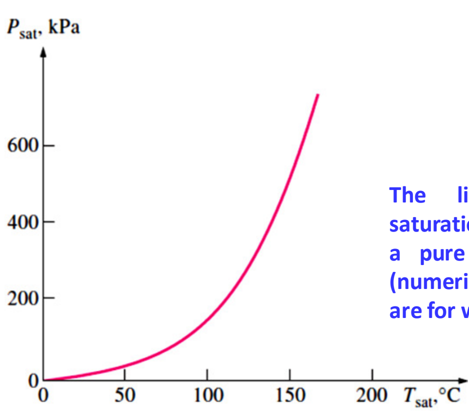

**$T - v$ diagram for the heating process of water at constant pressure**



## Saturation Temperature and Saturation Pressure

The temperature at which water starts boiling depends on the pressure; therefore, if the pressure is fixed, so is the boiling temperature.

- Water boils at 100°C at 1 atm pressure.
- Saturation temperature $T_{sat}$: The temperature at which a pure substance changes phase at a given pressure.
- Saturation pressure $P_{sat}$: The pressure at which a pure substance changes phase at a given temperature.

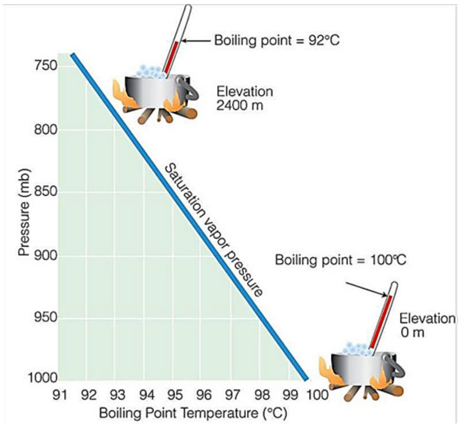



The liquid–vapor saturation curve of a pure substance (numerical values are for water).

**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 (1atm) |
| 150 | 476.2 |
| 200 | 1555 |
| 250 | 3976 |
| 300 | 8588 |



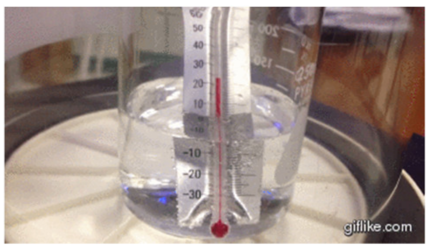




**TABLE 3–2**

Variation of the standard atmospheric pressure and the boiling (saturation) temperature of water with altitude

| Elevation, m | Atmospheric pressure, kPa | Boiling temperature, °C |
|---|---|---|
| 0 | 101.33 | 100.0 |
| 1,000 | 89.55 | 96.5 |
| 2,000 | 79.50 | 93.3 |
| 5,000 | 54.05 | 83.3 |
| 10,000 | 26.50 | 66.3 |
| 20,000 | 5.53 | 34.7 |

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- **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.**

- **The magnitudes of the latent heats depend on the temperature or pressure at which the phase change occurs.**

- **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.**

- **The atmospheric pressure, and thus the boiling temperature of water, decreases with elevation.**

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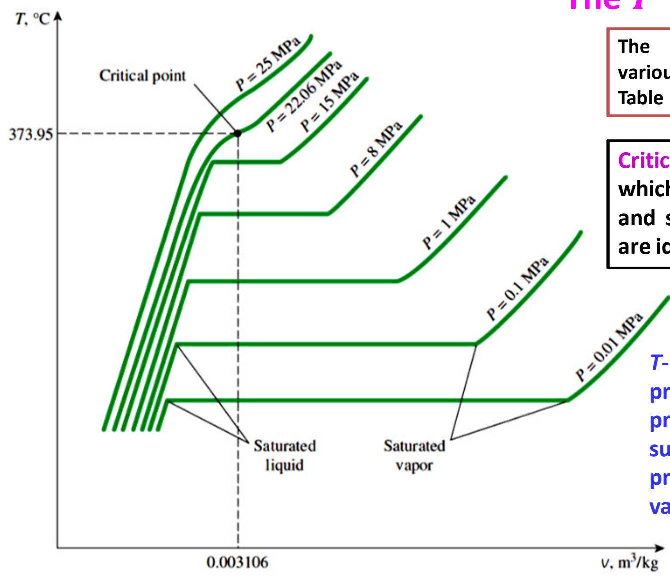
## Property Diagrams For Phase-Change Processes

**The variations of properties during phase-change processes are best studied and understood with the help of property diagrams such as the $T-v$, $P-v$, and $P-T$ diagrams for pure substances.**

### The $T-v$ Diagram

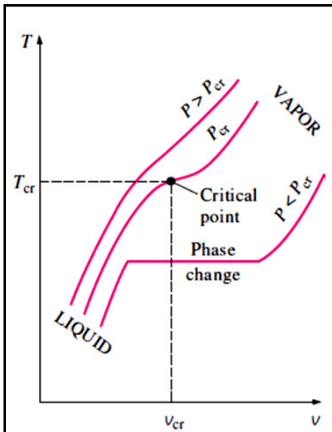



**The critical properties for various substances are given in Table A–1 in the appendix.**

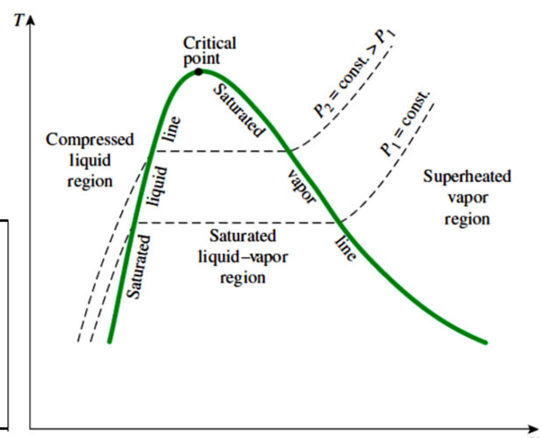
**Critical point: The point at which the saturated liquid and saturated vapor states are identical.**

***T-v* diagram of constant-pressure phase-change processes of a pure substance at various pressures (numerical values are for water).**





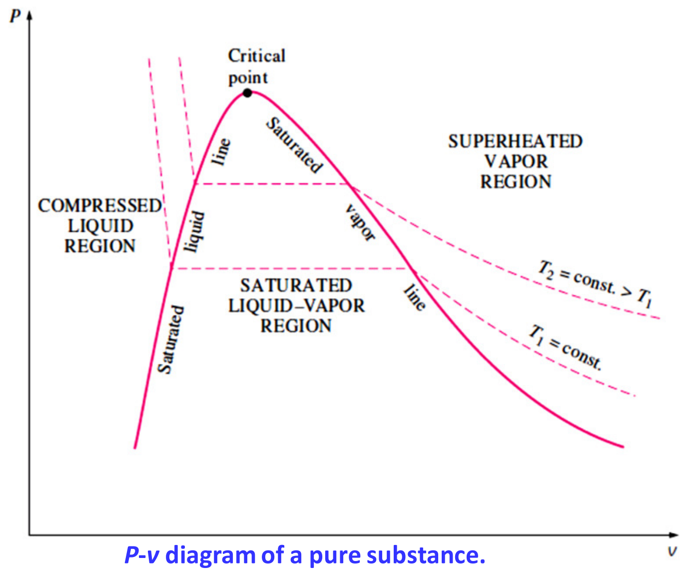

**At supercritical pressures ($P > P_{cr}$), there is no distinct phase-change (boiling) process. Thus, it is superheated vapor at temperatures above the critical temperature and compressed liquid at temperatures below the critical temperature.**



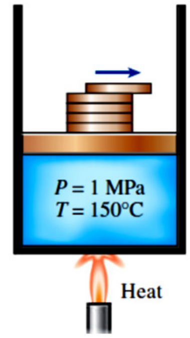

(*a*) *T-v* diagram of a pure substance

- **Saturated Liquid Line**
- **Saturated Vapor Line**
- **Compressed Liquid Region**
- **Superheated Vapor Region**
- **Saturated Liquid–Vapor Mixture Region (Wet Region)**

## The $P - v$ Diagram




***P-v* diagram of a pure substance.**




**The pressure in a piston–cylinder device can be reduced by reducing the weight of the piston.**

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