



Module

3

Lecture
2

Asansol Engineering College
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Thermodynamics

Properties of Pure Substances

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Saturation Temperature and Saturation Pressure

- Strictly speaking, the statement “water boils at 100°C” is incorrect. The correct statement is “water boils at 100°C at 1 atm. pressure.” The only reason the water started boiling at 100°C was because we held the pressure constant at 1 atm. (101.325 kPa).
- If the pressure inside the cylinder were raised to 500 kPa by adding weights on top of the piston, the water would start boiling at 151.9°C.
- That is, *the temperature at which water starts boiling depends on the pressure; therefore, if the pressure is fixed, so is the boiling temperature.*

- ❖ At a given pressure, the temperature at which a pure substance changes phase is called *saturation temperature (T_{sat})*.
- ❖ At a given temperature, the pressure at which a pure substance changes phase is called *saturation pressure (P_{sat})*.
- ❖ At a pressure of 101.325 kPa, T_{sat} is 99.97 °C.
- ❖ Conversely, at a temperature of 99.97 °C, P_{sat} is 101.325 kPa .

- Saturation tables that list the saturation pressure against the temperature (or the saturation temperature against the pressure) are available for practically all substances.
- A partial listing of such a table is given in **Table 3–1** for water.
- This table indicates that the pressure of water changing phase (boiling or condensing) at 25°C must be 3.17 kPa, and the pressure of water must be maintained at 3973 kPa (about 40 atm) to have it boil at 250°C. Also, water can be frozen by dropping its pressure below 0.61 kPa.

TABLE 3–1

Saturation (or vapor) pressure of water at various temperatures

Temperature $T, ^\circ\text{C}$	Saturation Pressure $P_{\text{sat}}, \text{kPa}$
–10	0.260
–5	0.403
0	0.611
5	0.872
10	1.23
15	1.71
20	2.34
25	3.17
30	4.25
40	7.38
50	12.35
100	101.3 (1 atm)
150	475.8
200	1554
250	3973
300	8581

- It takes a large amount of energy to melt a solid or vaporize a liquid.
- The amount of energy absorbed or released during a phase-change process is called the *latent heat*.
- More specifically, the amount of energy absorbed during melting is called the *latent heat of fusion* and is equivalent to the amount of energy released during freezing.
- Similarly, the amount of energy absorbed during vaporization is called the *latent heat of vaporization* and 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 2257.1 kJ/kg.

- During a phase-change process, pressure and temperature are obviously dependent properties, and there is a definite relation between them, that is, $T_{\text{sat}} = f(P_{\text{sat}})$.
- A plot of T_{sat} versus P_{sat} , such as the one given for water in Fig. 3.8, is called a *liquid–vapor saturation curve*. A curve of this kind is characteristic of all pure substances.

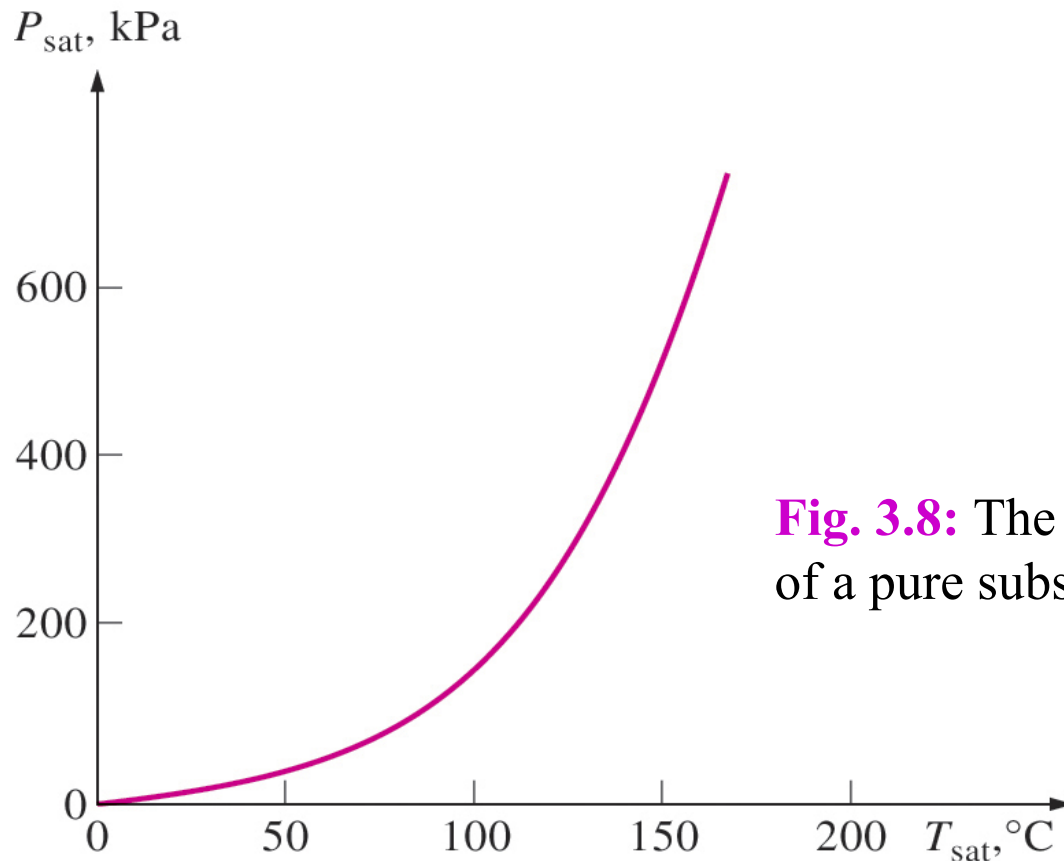


Fig. 3.8: The liquid–vapor saturation curve of a pure substance (water)

- It is clear from Fig. 3.8 that T_{sat} increases with P_{sat} . Thus, a substance at higher pressures will boil at higher temperatures.
- In the kitchen, higher boiling temperatures mean shorter cooking times and energy savings.
- A beef stew, for example, may take 1 to 2 h to cook in a regular pan that operates at 1 atm. pressure, but only 20 min in a pressure cooker operating at 3 atm. absolute pressure (corresponding boiling temperature: 134°C).
- The atmospheric pressure, and thus the boiling temperature of water, decreases with elevation.
- Therefore, it takes longer to cook at higher altitudes than it does at sea level (unless a pressure cooker is used).
- For example, the standard atmospheric pressure at an elevation of 2000 m is 79.50 kPa, which corresponds to a boiling temperature of 93.2°C as opposed to 100°C at sea level (zero elevation).

Property Diagrams For Phase Change Processes

T - v Diagram

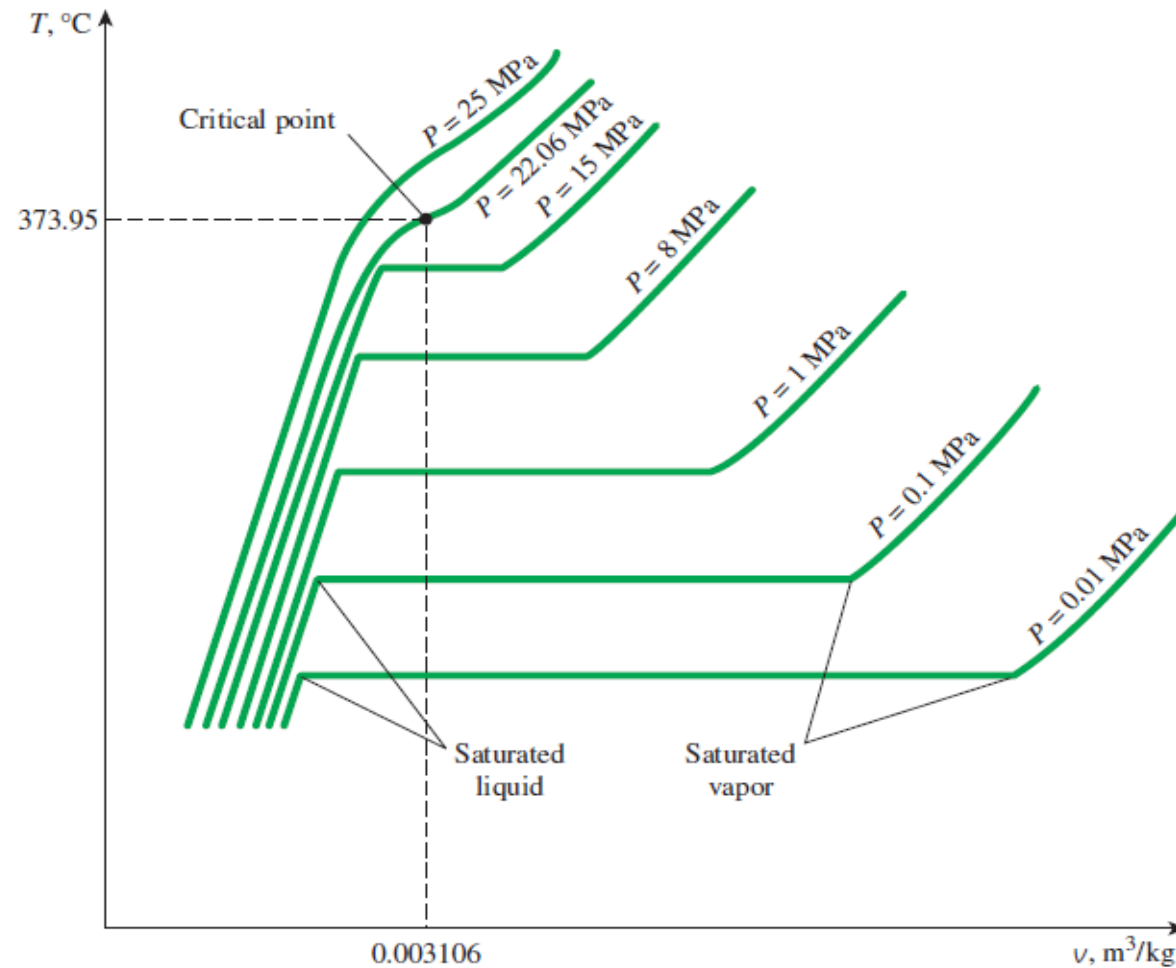


Fig. 3.9: T - v diagram of constant-pressure phase-change processes of a pure substance at various pressures

- The phase-change process of water at 1 atm. pressure was described in detail on a T - v diagram in Fig. 3.4. Now we repeat the same process at different pressures to develop the T - v diagram.
- Let us add weights on top of the piston until the pressure inside the cylinder reaches 1 MPa. At this pressure, water will have a somewhat smaller specific volume than it did at 1 atm. pressure.
- As heat is transferred to the water at this new pressure, the process will follow a path that looks very much like the process path at 1 atm. pressure, as shown in Fig. 3.4, but there are some noticeable differences.
- First, water will start boiling at a much higher temperature (179.9°C) at this pressure.
- Second, the specific volume of the saturated liquid is larger and the specific volume of the saturated vapor is smaller than the corresponding values at 1 atm. pressure.
- That is, the horizontal line that connects the saturated liquid and saturated vapor states is much shorter.

- As the pressure is increased further, this saturation line will continue to get shorter, as shown in Fig. 3.9, and it will become a point when the pressure reaches 22.09 MPa for the case of water.
- This point is called the *critical point*, and it is defined as *the point at which the saturated liquid and saturated vapor states are identical*.
- The temperature, pressure, and specific volume of a substance at the critical point are called, respectively, the *critical temperature T_{cr}* , *critical pressure P_{cr}* , and *critical specific volume v_{cr}* .
- The critical-point properties of water are P_{cr} 22.09 MPa, T_{cr} 374.14°C, and v_{cr} 0.003155 m³/kg. For helium, they are 0.23 MPa, 267.85°C, and 0.01444 m³/kg.

- At pressures above the critical pressure, there will not be a distinct phase change process (Fig. 3.10). Instead, the specific volume of the substance will continually increase, and at all times there will be only one phase present.
- Eventually, it will resemble a vapor, but we can never tell when the change has occurred. Above the critical state, there is no line that separates the compressed liquid region and the superheated vapor region.
- However, it is customary to refer to the substance as *superheated vapor* at temperatures above the critical temperature and as *compressed liquid* at temperatures below the critical temperature.

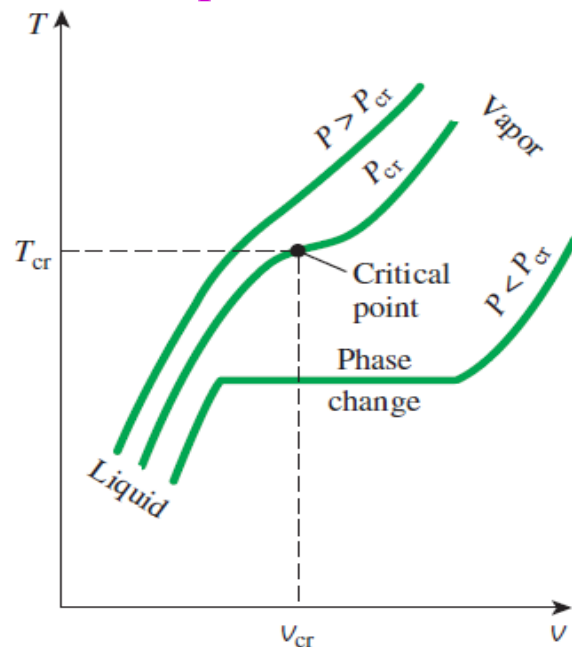
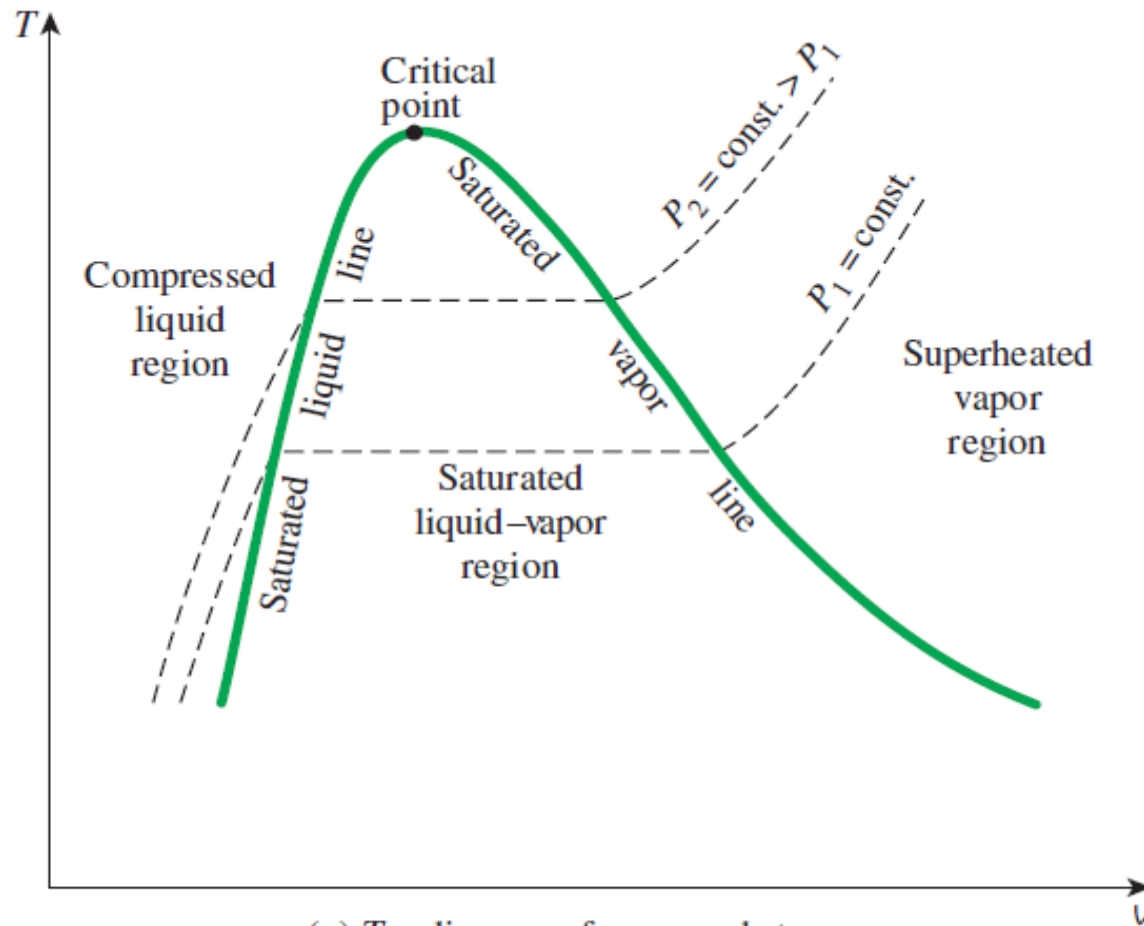


Fig. 3.10: At supercritical pressures ($P > P_{cr}$), there is no distinct phase-change (boiling) process.

- The saturated liquid states in Fig. 3.9 can be connected by a line called the *saturated liquid line*, and saturated vapor states in the same figure can be connected by another line, called the *saturated vapor line*.
- These two lines meet at the critical point, forming a dome as shown in Fig. 3.11. All the compressed liquid states are located in the region to the left of the saturated liquid line, called the *compressed liquid region*. All the superheated vapor states are located to the right of the saturated vapor line, called the *superheated vapor region*. In these two regions, the substance exists in a single phase, a liquid or a vapor.
- All the states that involve both phases in equilibrium are located under the dome, called the *saturated liquid–vapor mixture region*, or the *wet region*.



(a) T - v diagram of a pure substance

Fig. 3.11: T - v diagram of a pure substance

@ Constant Pressure

$T > T_{\text{sat}} \Rightarrow$ “superheated vapor”

$T = T_{\text{sat}} \Rightarrow$ “two-phase liquid-vapor”

$T < T_{\text{sat}} \Rightarrow$ “compressed liquid”

The P - v Diagram

- The general shape of the P - v diagram of a pure substance is very much like the T - v diagram, but the constant temperature lines on this diagram have a downward trend, as shown in Fig. 3.12.
- Consider again a piston-cylinder device that contains liquid water at 1 MPa and 150°C. Water at this state exists as a compressed liquid. Now the weights on top of the piston are removed one by one so that the pressure inside the cylinder decreases gradually (Fig. 3.11).

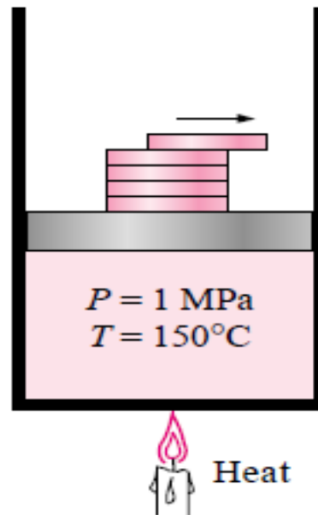


Fig. 3.11: The pressure in a piston-cylinder device can be reduced by reducing the weight of the piston.

- The water is allowed to exchange heat with the surroundings so its temperature remains constant. As the pressure decreases, the volume of the water will increase slightly.
- When the pressure reaches the saturation-pressure value at the specified temperature (0.4758 MPa), the water will start to boil.
- During this vaporization process, both the temperature and the pressure remain constant, but the specific volume increases.
- Once the last drop of liquid is vaporized, further reduction in pressure results in a further increase in specific volume.
- Notice that during the phase change process, we did not remove any weights. Doing so would cause the pressure and therefore the temperature to drop [since $T_{\text{sat}} = f(P_{\text{sat}})$], and the process would no longer be isothermal.
- If the process is repeated for other temperatures, similar paths will be obtained for the phase-change processes. Connecting the saturated liquid and the saturated vapor states by a curve, we obtain the P - v diagram of a pure substance, as shown in Fig. 3.12.

P - v Diagram

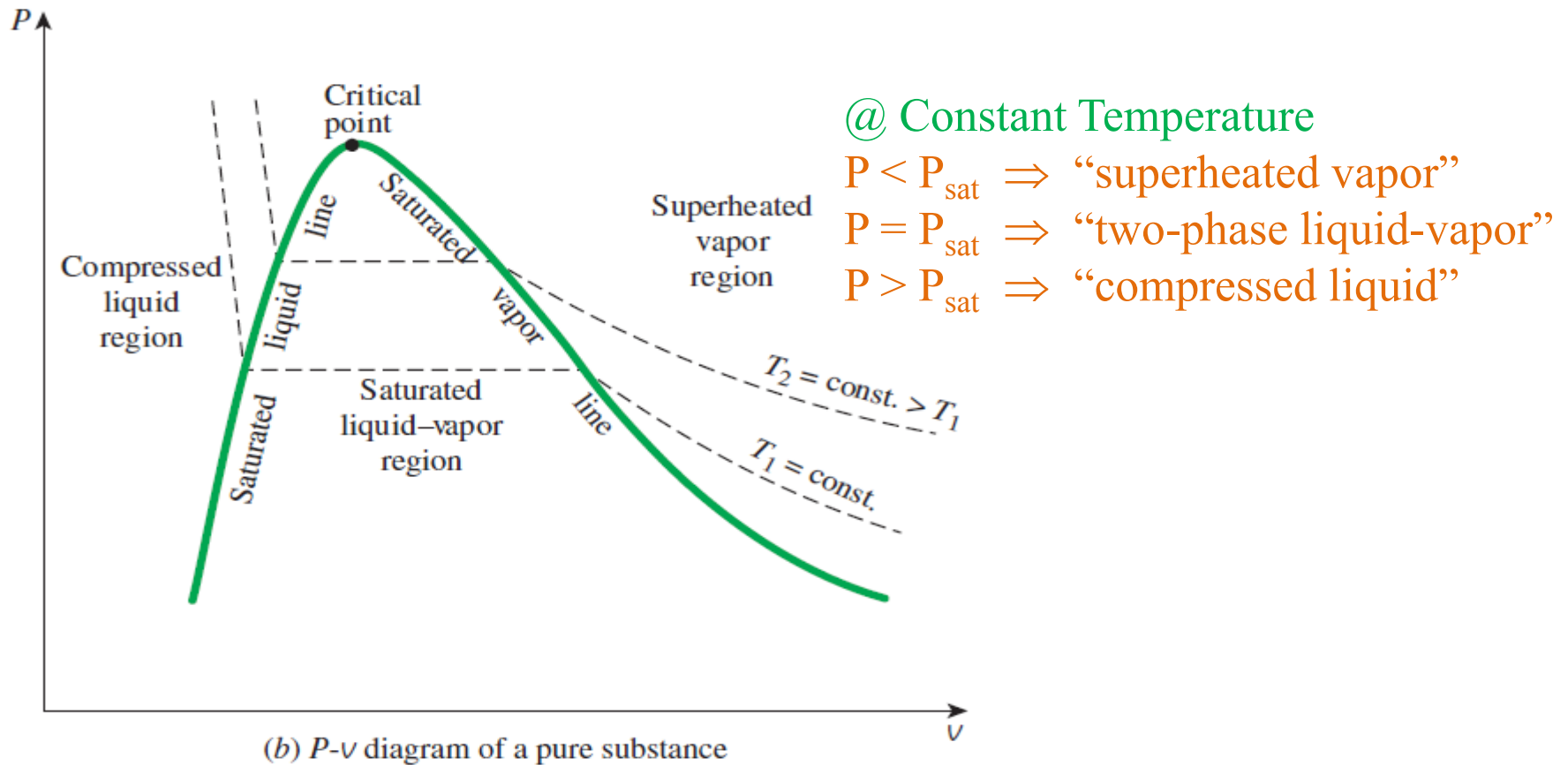


Fig. 3.12: P - v diagram of a pure substance

Thank You