PROPERTIES OF PURE SUBSTANCES

1: **PURE SUBSTANCE**: A substance that has a fixed chemical composition throughout a process. Water, nitrogen, helium, and carbon dioxide, for example, are all pure substances. A mixture of various chemical elements or compounds also qualifies as a pure substance as long as the mixture is homogeneous. Air, for example, is a mixture of several gases, but it is often considered to be a pure substance because it has a uniform chemical composition. However, a mixture of oil and water is not a pure substance. Since oil is not soluble in water, it will collect on top of the water, forming two chemically dissimilar regions.

2: PHASES OF A PURE SUBSTANCE

At room temperature and pressure, copper is a solid, mercury is a liquid, and nitrogen is a gas. Under different conditions, each may appear in a different phase.
The molecules in a solid are arranged in a three-dimensional pattern (lattice) that is repeated throughout. Because of the small distances between molecules in a solid, the attractive forces of molecules on each other are large and keep the molecules at fixed positions.
The molecular spacing in the liquid phase is not much different from that of the solid phase, except the molecules are no longer at fixed positions relative to each other and they can rotate and translate freely.
In the gas phase, the molecules are far apart from each other, and a molecular order is nonexistent. Gas molecules move about at random, continually colliding with each other and the walls of the container they are in.

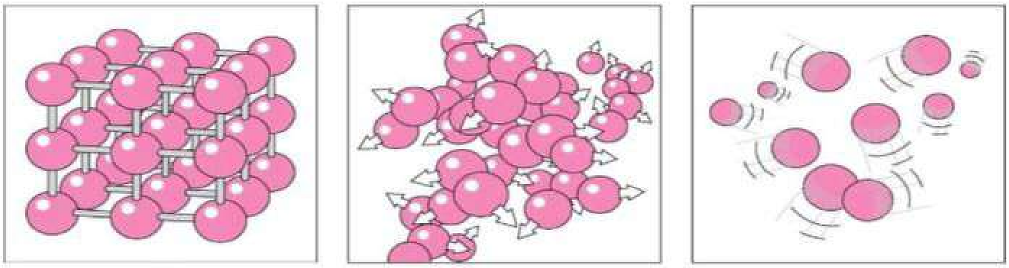


Figure 1: The arrangement of atoms in different phases: (a) molecules are at relatively fixed positions in a solid, (b) groups of molecules move about each other in the liquid phase, and (c) molecules move about at random in the gas phase.

3:PHASE-CHANGE PROCESSES OF PURE SUBSTANCES

A piston–cylinder device containing liquid water at 20°C and 1 atm pressure (state 1). Under these conditions, water exists in the liquid phase, and it is called a compressed liquid, or a subcooled liquid, meaning that it is not about to vaporize.
As more heat is transferred, the temperature keeps rising until it reaches 100C (state 2). At this point water is still a liquid, but any heat addition will cause some of the liquid to vaporize. That is, a phase-change process from liquid to vapor is about to take place. A liquid

that is about to vaporize is called a saturated liquid. Therefore, state 2 is a saturated liquid state.

Once boiling starts, the temperature stops rising until the liquid is completely vaporized. That is, the temperature will remain constant during the entire phase-change process if the pressure is held constant.

Midway about the vaporization line (state 3), the cylinder contains equal amounts of liquid and vapor.

As we continue transferring heat, the vaporization process continues until the last drop of liquid is vaporized (state 4). At this point, the entire cylinder is filled with vapor that is on the borderline of the liquid phase. A vapor that is about to condense is called a saturated vapor. Therefore, state 4 is a saturated vapor state. A substance at states between 2 and 4 is referred to as a saturated liquid–vapor mixture since the liquid and vapor phases coexist in equilibrium at these states.

further transfer of heat results in an increase in both the temperature and the specific volume (state 5), A vapor that is not about to condense (i.e., not a saturated vapor) is called a superheated vapor. This constant-pressure phase-change process is illustrated on a T-v diagram in Fig.2. If the entire process described here is reversed by cooling the water while maintaining the pressure at the same value, the water will go back to state 1.

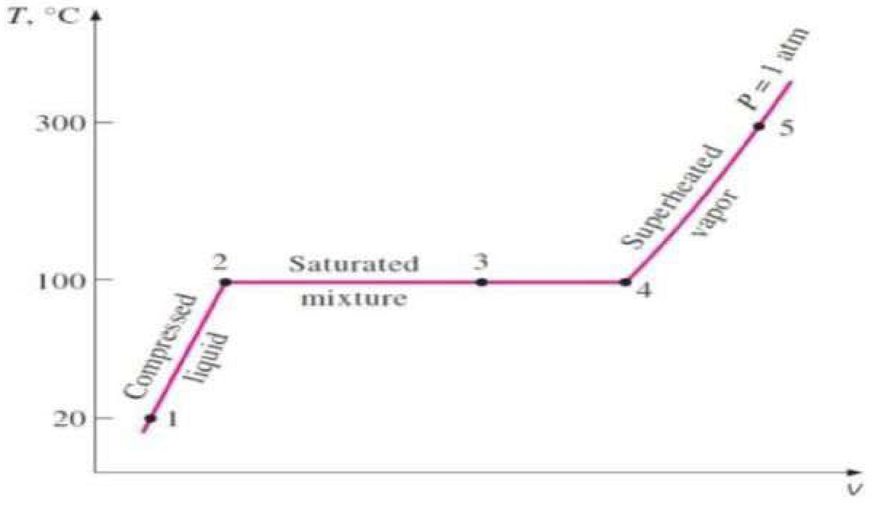


FIGURE 2: T-v diagram for the heating process of water at constant pressure.

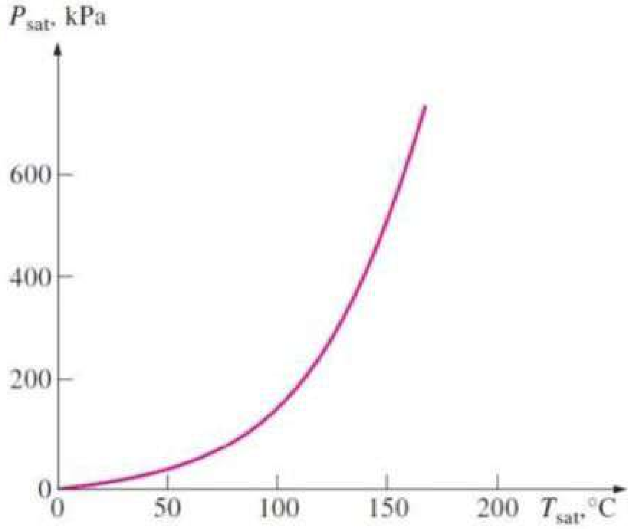
<u>4:Saturation Temperature and Saturation Pressure</u>

At a given pressure, the temperature at which a pure substance changes phase is called the saturation temperature Tsat. Likewise, at a given temperature, the pressure at which a pure substance changes phase is called the saturation pressure Psat. A plot of Tsat versus Psat , such as the one given for water in is called a liquid–vapor saturation curve. A curve of this kind is characteristic of all pure substances.

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



5: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. We develop and discuss the T-v, P-v, diagrams for pure substances.

1- **T-υ Diagram**

2-

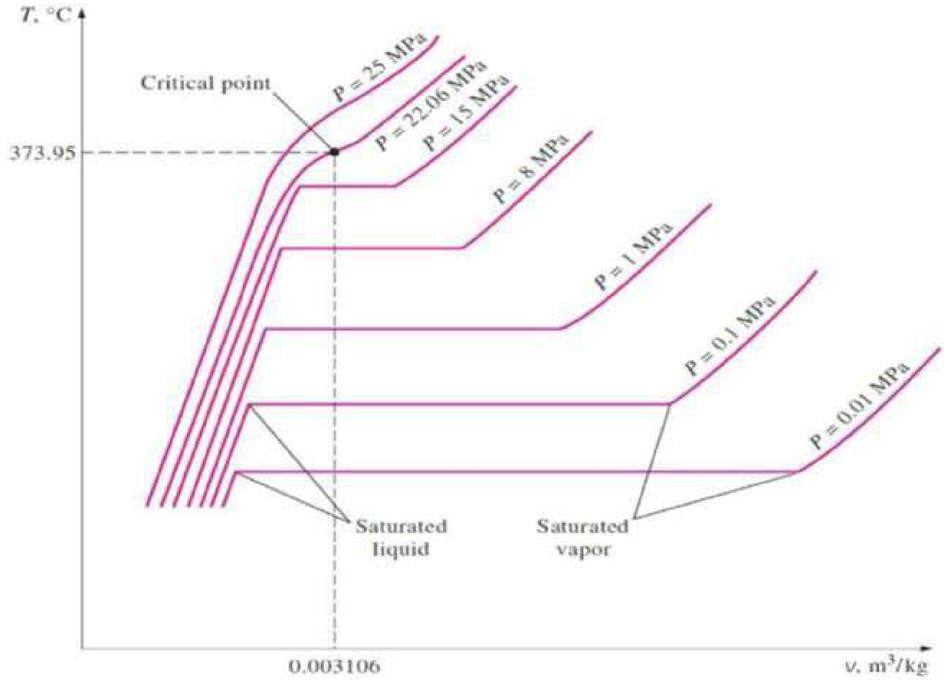


Figure 3: T-v diagram of constant-pressure phase-change processes of a pure substance at various pressures (numerical values are for water).

- water starts boiling at a much higher temperature when pressure increased.
- the specific volume of the saturated liquid is larger and the specific volume of the saturated vapor is smaller than the corresponding values at lower pressure.
- the horizontal line that connects the saturated liquid and saturated vapor states is much shorter when pressure increased.
- As the pressure is increased further, this saturation line continues to shrink, as shown in and it becomes a point when the pressure reaches 22.06 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 Tcr, critical pressure Pcr, and critical specific volume vcr

-The saturated liquid states in Figure 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 figure 4-4. 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.

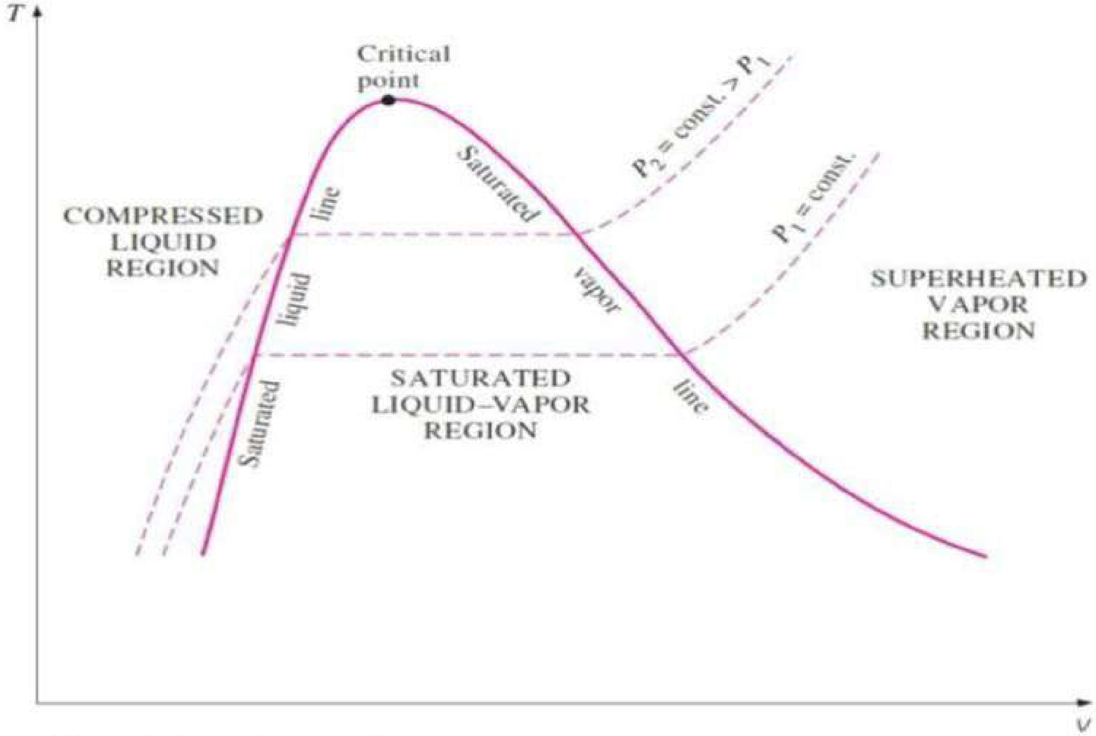


Figure 4: T- v diagram of a pure substance.