Some Consequences of T_{sat} and P_{sat} Dependence

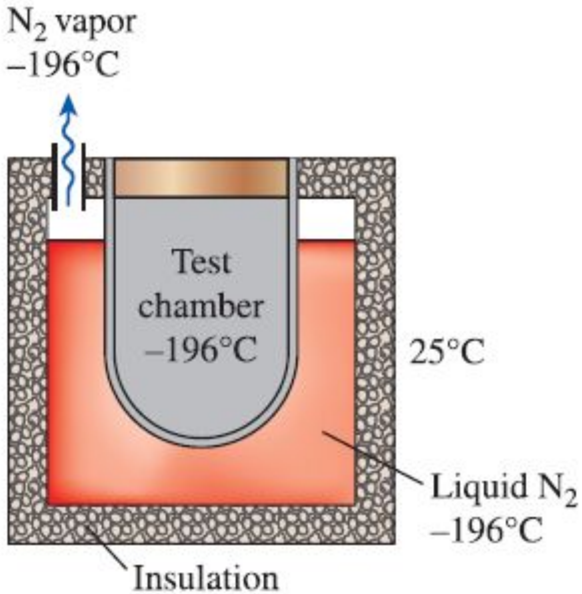
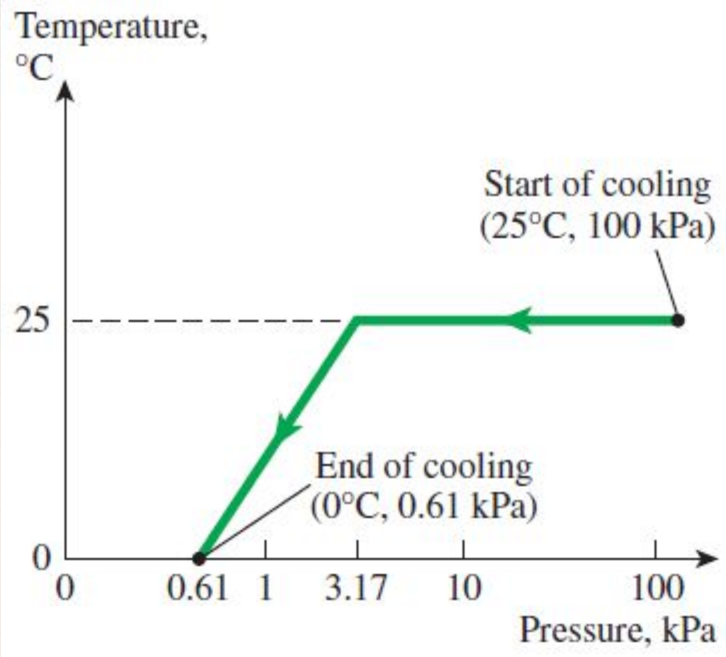
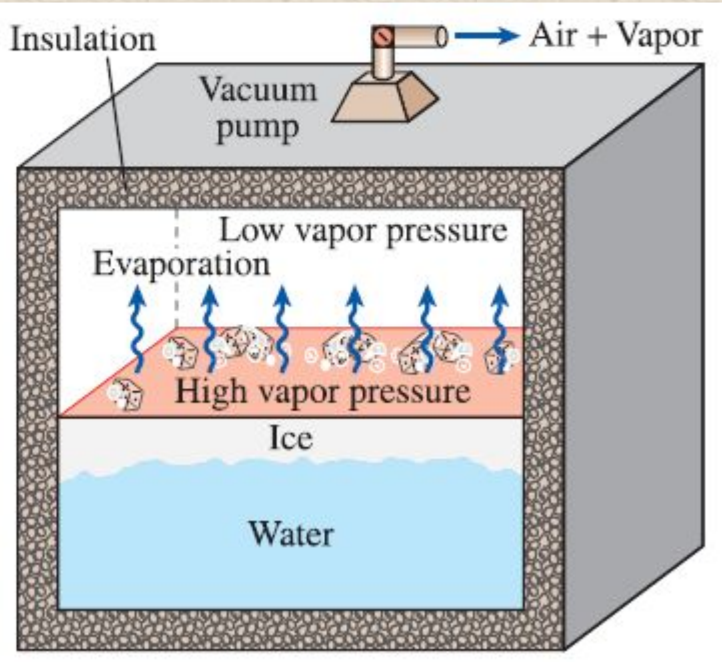


FIGURE 3–12
The temperature of liquid nitrogen exposed to the atmosphere remains constant at −196°C, and thus it maintains the test chamber at −196°C.

The variation of the temperature of fruits and vegetables with pressure during vacuum cooling from 25°C to 0°C.

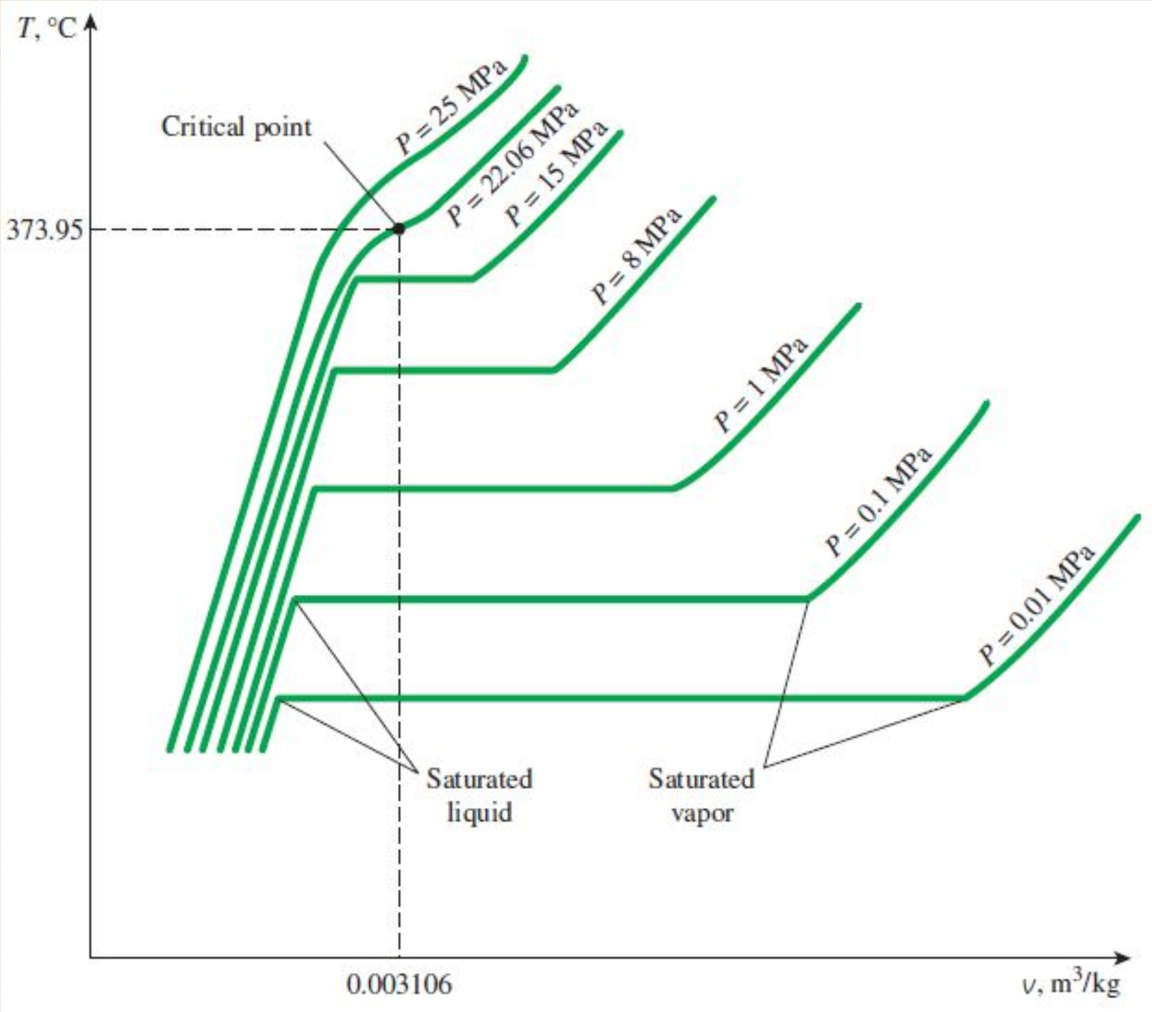


In 1775, ice was made by evacuating the air space in a water tank.



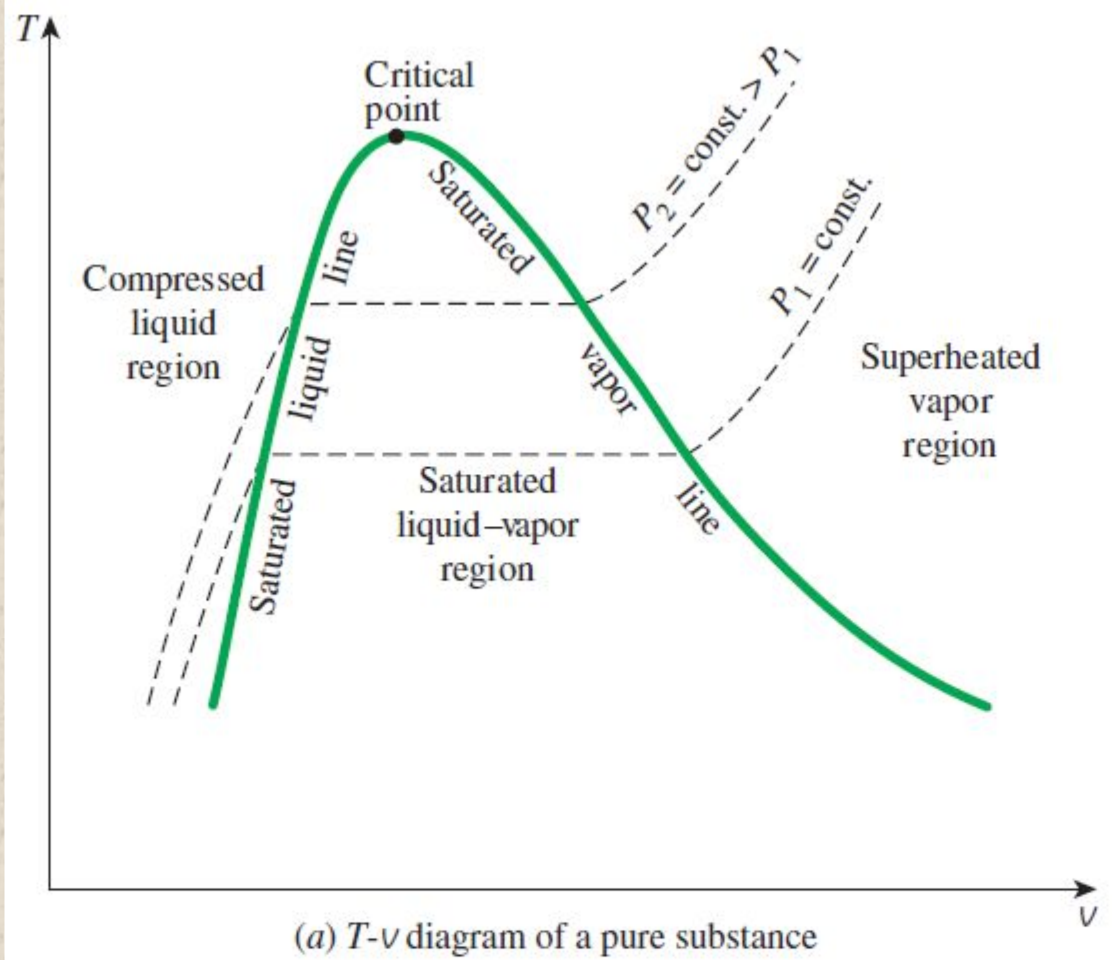
PROPERTY DIAGRAMS FOR PHASE-CHANGE PROCESSES

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.



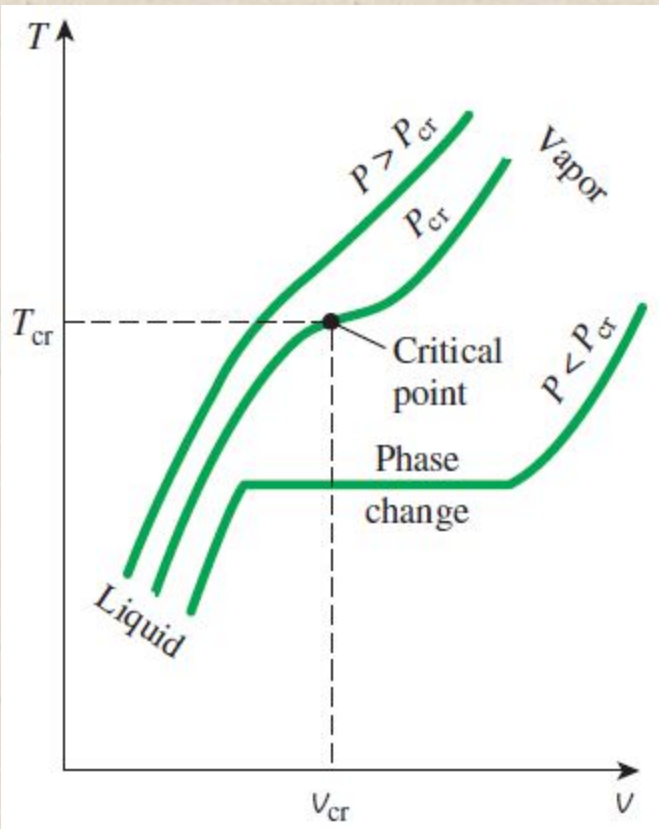
T-*v* diagram of constant-pressure phase-change processes of a pure substance at various pressures (numerical values are for water).

- saturated liquid line
- saturated vapor line
- compressed liquid region
- superheated vapor region
- saturated liquid–vapor mixture region (wet region)



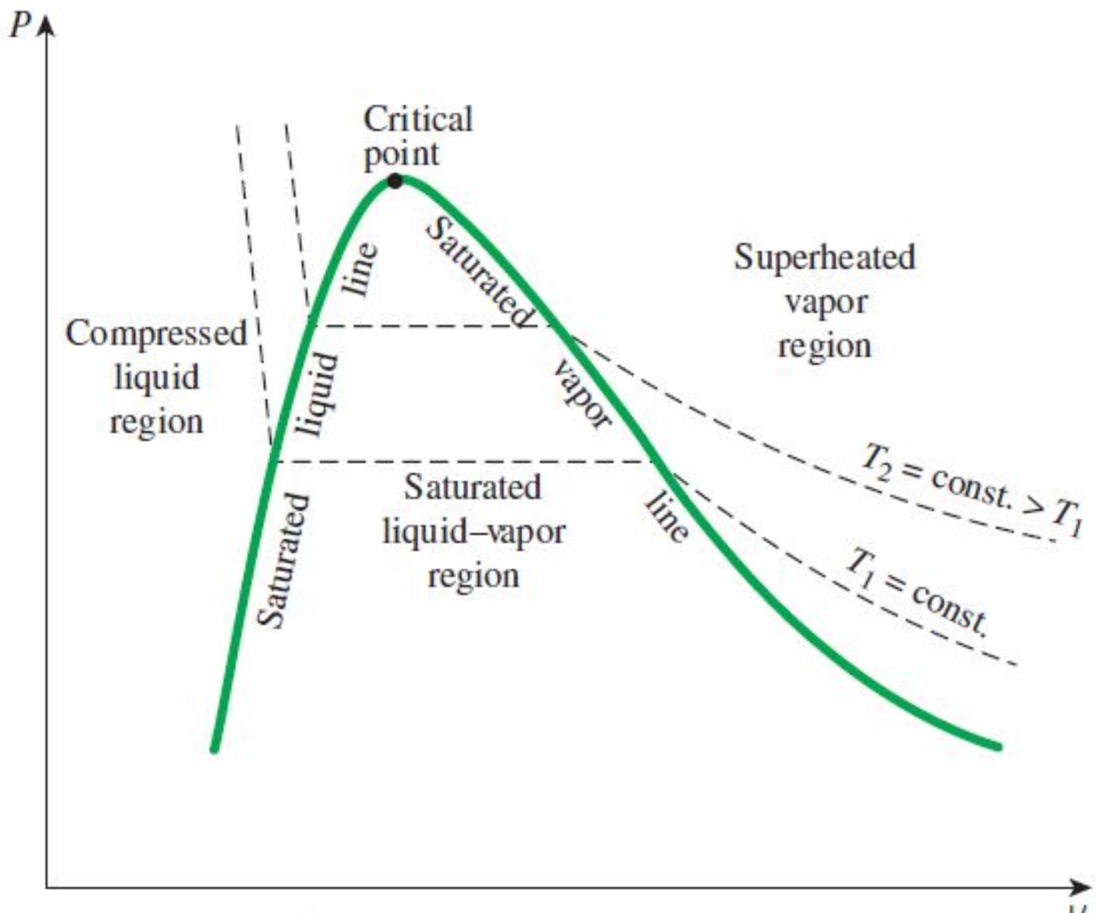
(a) T-v diagram of a pure substance

FIGURE 3–17
Property diagrams of a pure substance.



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

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



(*b*) *P*-v diagram of a pure substance

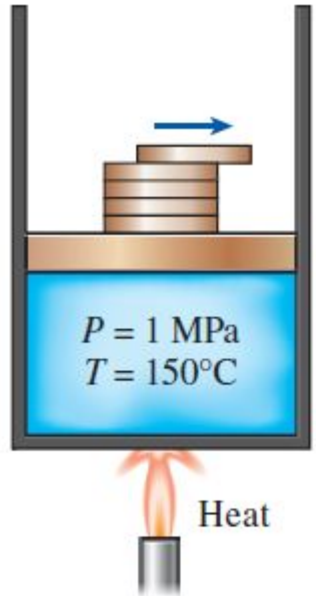
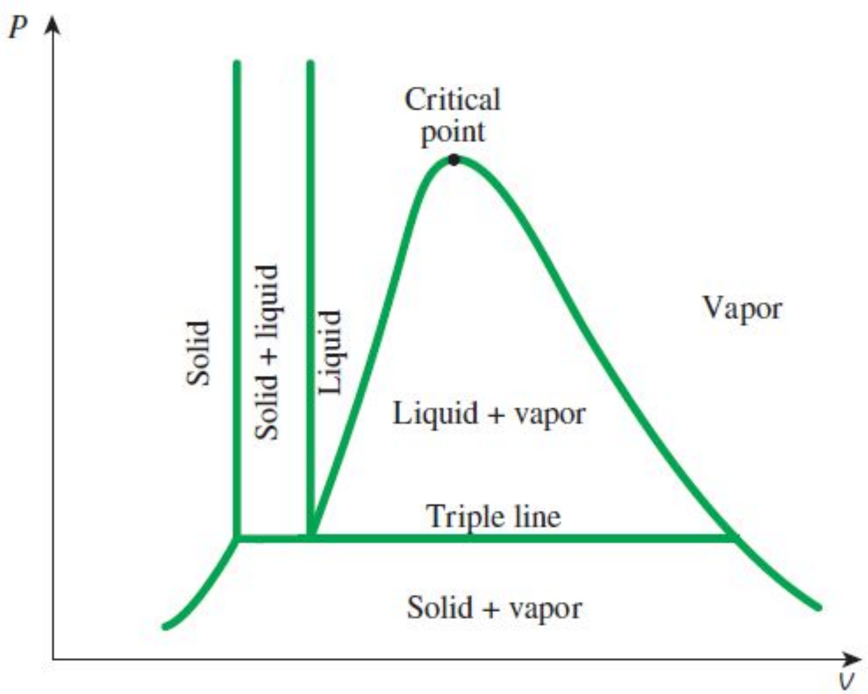


FIGURE 3–18
The pressure in a piston–cylinder device can be reduced by reducing the weight of the piston.

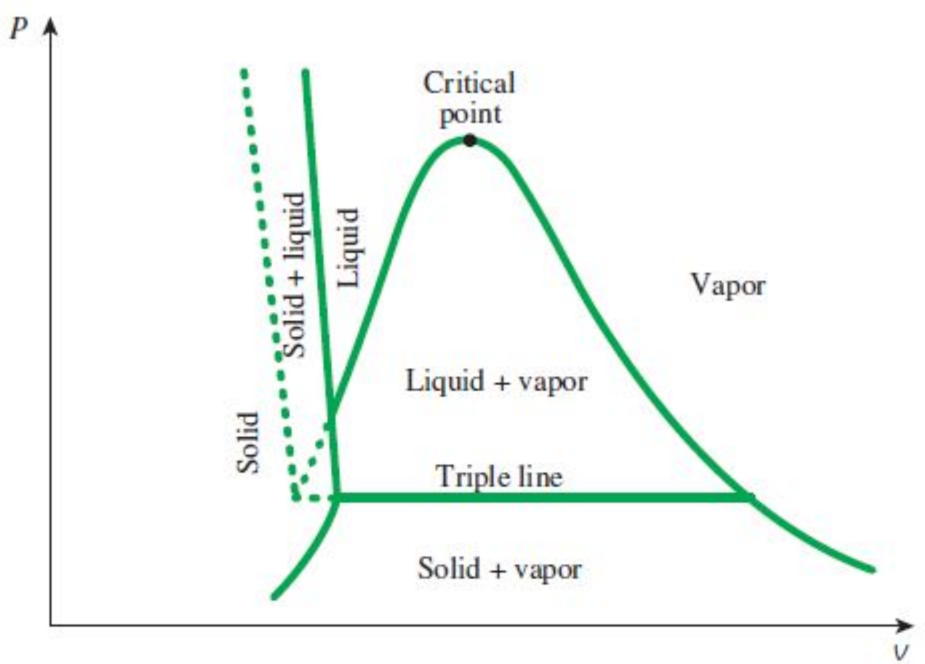
Extending the Diagrams to Include the Solid Phase

For water,
$T_{tp} = 0.01°C$
$P_{tp} = 0.6117$ kPa

At triple-point pressure and temperature, a substance exists in three phases in equilibrium.



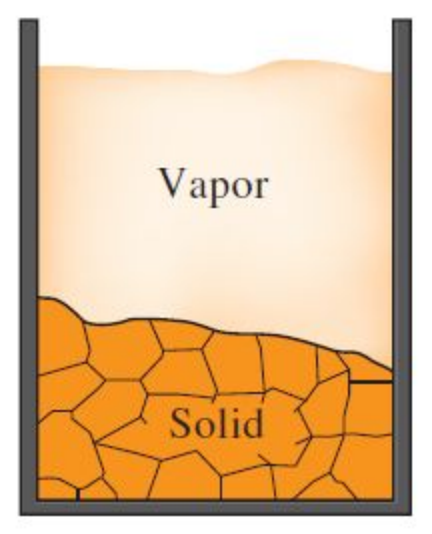
(*a*) *P*-*v* diagram of a substance that contracts on freezing



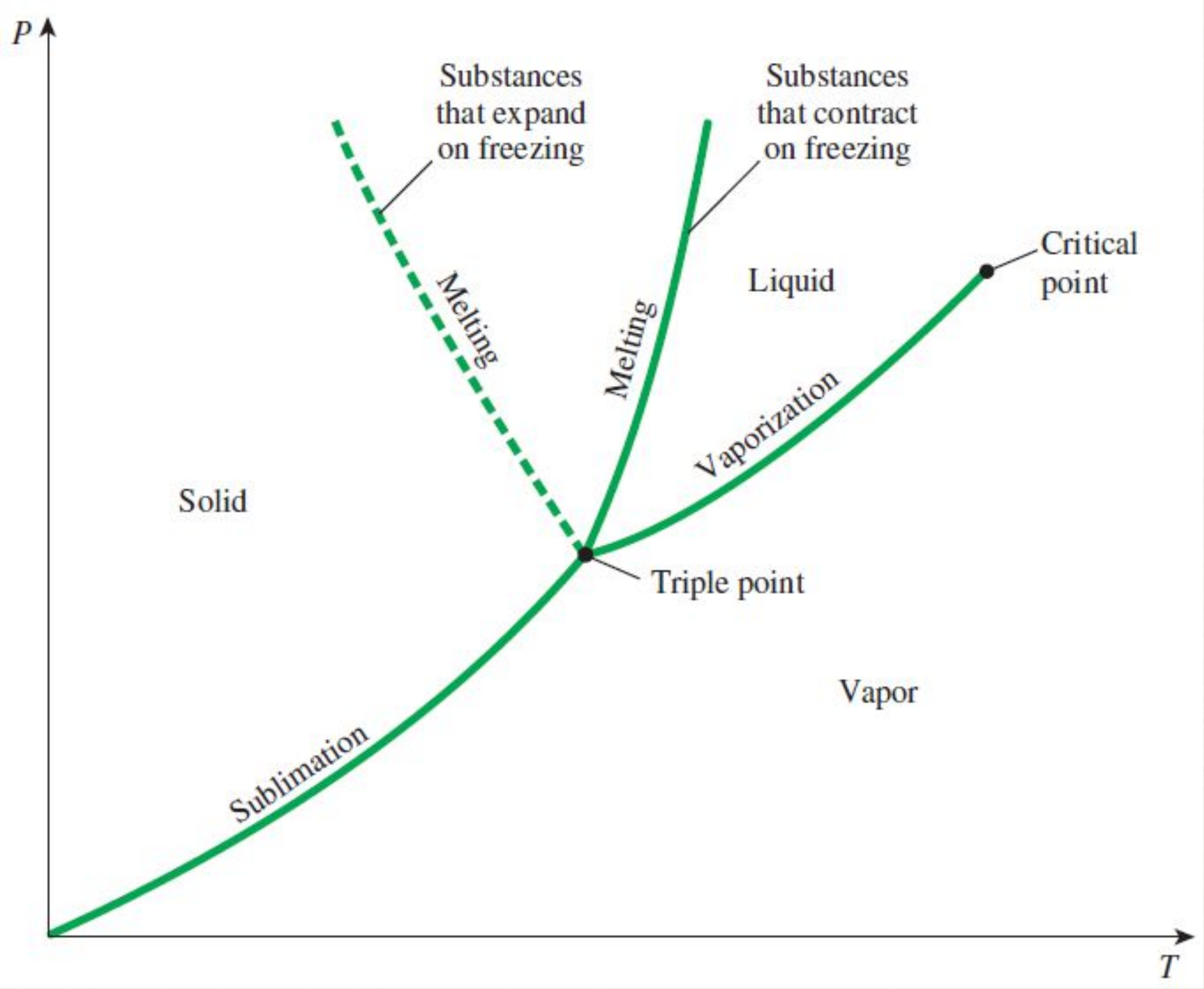
(*b*) *P*-*v* diagram of a substance that expands on freezing (such as water)

Phase Diagram

Sublimation: Passing from the solid phase directly into the vapor phase.



At low pressures (below the triple-point value), solids evaporate without melting first (*sublimation*).



P-T diagram of pure substances.

The *P*-*v*-*T* surfaces present a great deal of information at once, but in a thermodynamic analysis it is more convenient to work with two-dimensional diagrams, such as the *P*-*v* and *T*-*v* diagrams.

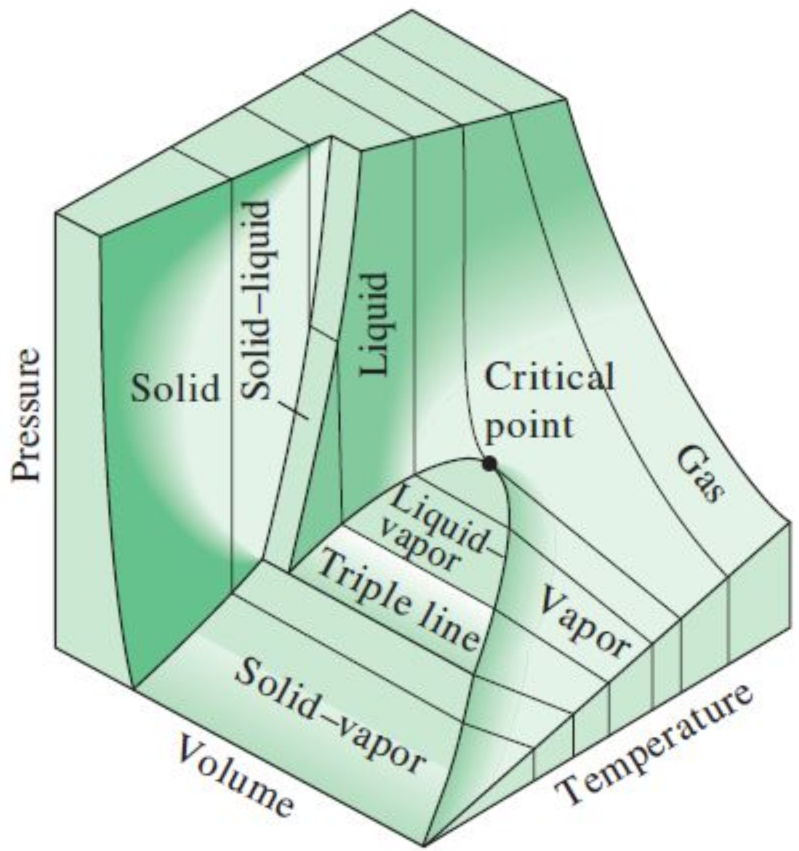


FIGURE 3–23

P-*v*-*T* surface of a substance that *contracts* on freezing.

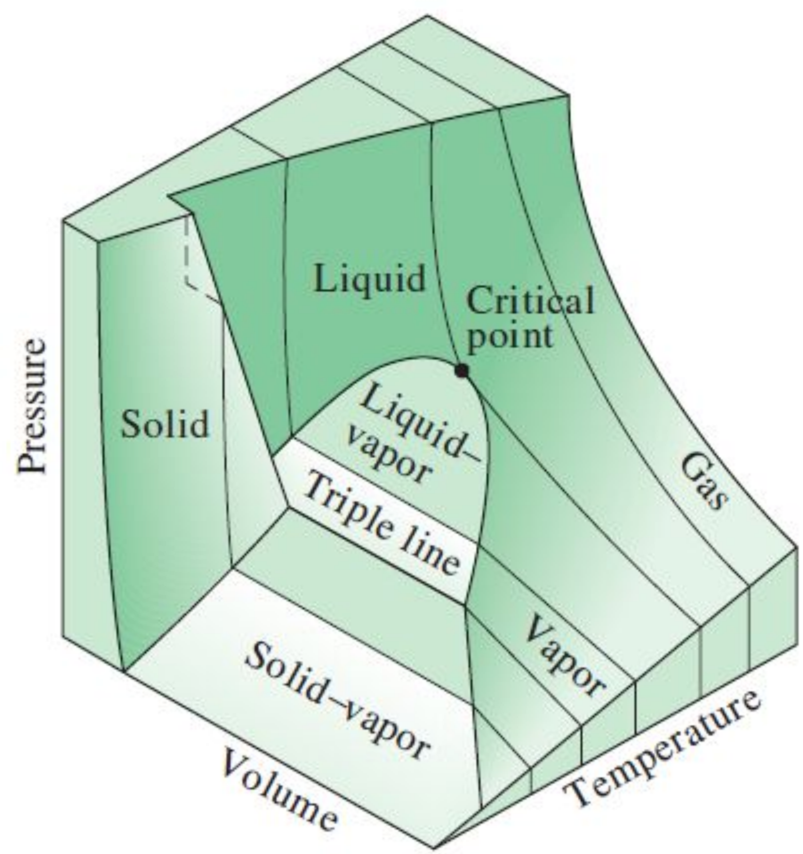


FIGURE 3–24

P-*v*-*T* surface of a substance that *expands* on freezing (like water).

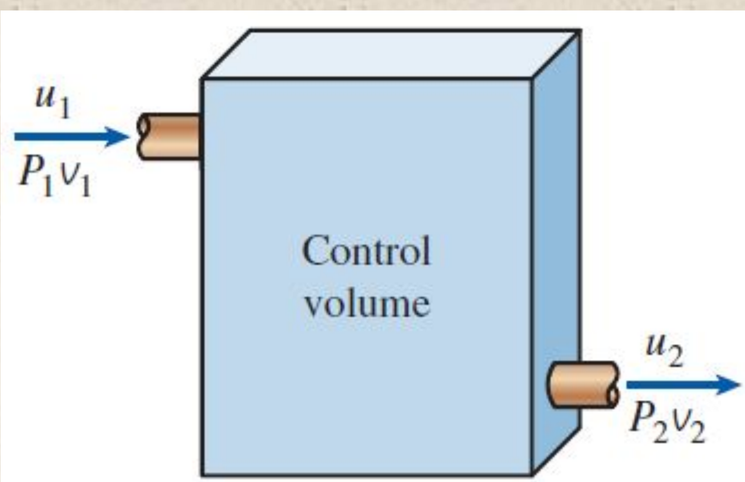
PROPERTY TABLES

- For most substances, the relationships among thermodynamic properties are too complex to be expressed by simple equations.
- Therefore, properties are frequently presented in the form of tables.
- Some thermodynamic properties can be measured easily, but others cannot and are calculated by using the relations between them and measurable properties.
- The results of these measurements and calculations are presented in tables in a convenient format.

Enthalpy—A Combination Property

$$h = u + Pv \qquad (\text{kJ/kg})$$

$$H = U + PV \qquad (\text{kJ})$$



The combination $u + Pv$ is frequently encountered in the analysis of control volumes.

$$\text{kPa}\cdot\text{m}^3 \equiv \text{kJ}$$
$$\text{kPa}\cdot\text{m}^3/\text{kg} \equiv \text{kJ/kg}$$
$$\text{bar}\cdot\text{m}^3 \equiv 100\ \text{kJ}$$
$$\text{MPa}\cdot\text{m}^3 \equiv 1000\ \text{kJ}$$
$$\text{psi}\cdot\text{ft}^3 \equiv 0.18505\ \text{Btu}$$

The product *pressure* × *volume* has energy units.

Saturated Liquid and Saturated Vapor States

v_f = specific volume of saturated liquid

v_g = specific volume of saturated vapor

v_{fg} = difference between v_g and v_f (that is $v_{fg} = v_g - v_f$)

A partial list of Table A–4.

Temp. °C T	Sat. press. kPa P_{sat}	Specific volume m^3/kg Sat. liquid v_f	Sat. vapor v_g
85	57.868	0.001032	2.8261
90	70.183	0.001036	2.3593
95	84.609	0.001040	1.9808

Specific temperature

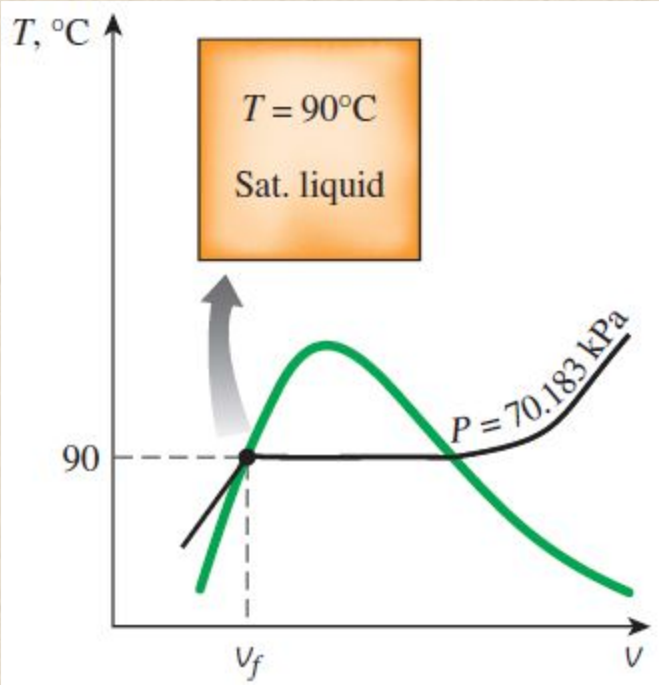
Corresponding saturation pressure

Specific volume of saturated liquid

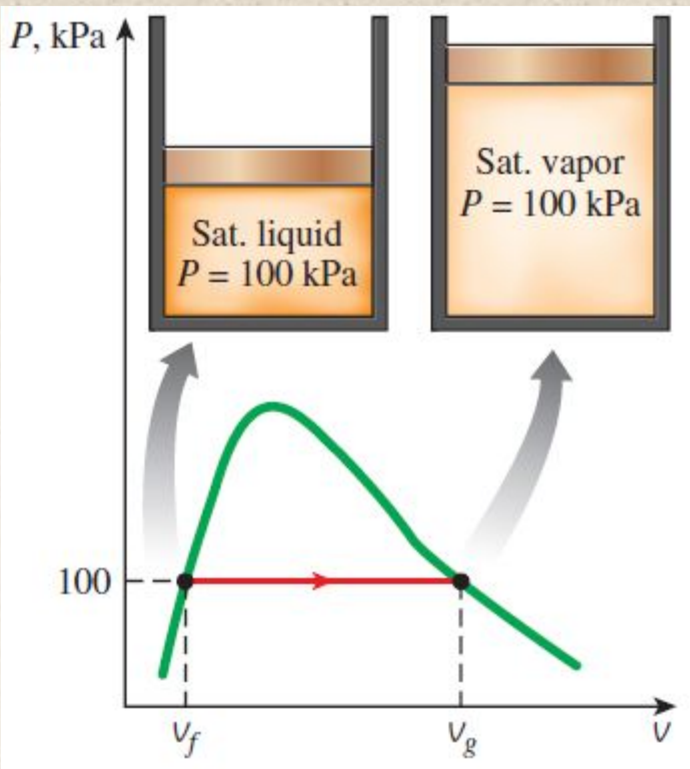
Specific volume of saturated vapor

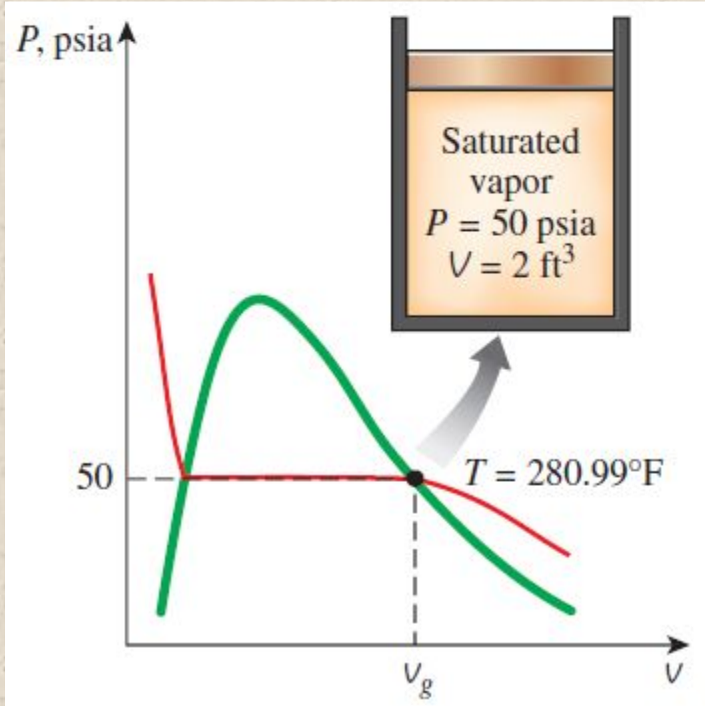
- **Table A–4**: Saturation properties of water under temperature.
- **Table A–5**: Saturation properties of water under pressure.

Enthalpy of vaporization, h_{fg} **(Latent heat of vaporization)**: The amount of energy needed to vaporize a unit mass of saturated liquid at a given temperature or pressure.



Examples:
Saturated liquid and saturated vapor states of water on *T-v* and *P-v* diagrams.





Saturated Liquid–Vapor Mixture

Quality, *x* : The ratio of the mass of vapor to the total mass of the mixture.

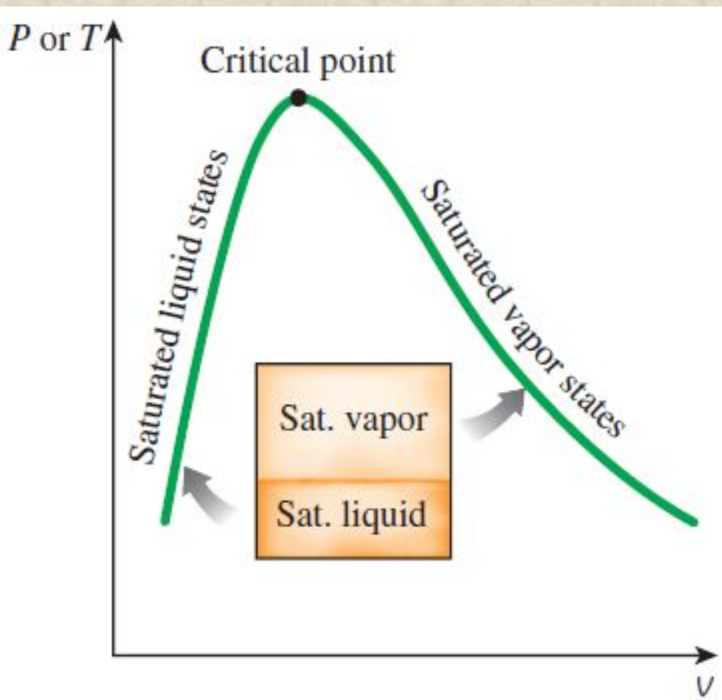
Quality is between 0 and 1 ➤ 0: sat. liquid, 1: sat. vapor.

The properties of the saturated liquid are the same whether it exists alone or in a mixture with saturated vapor.

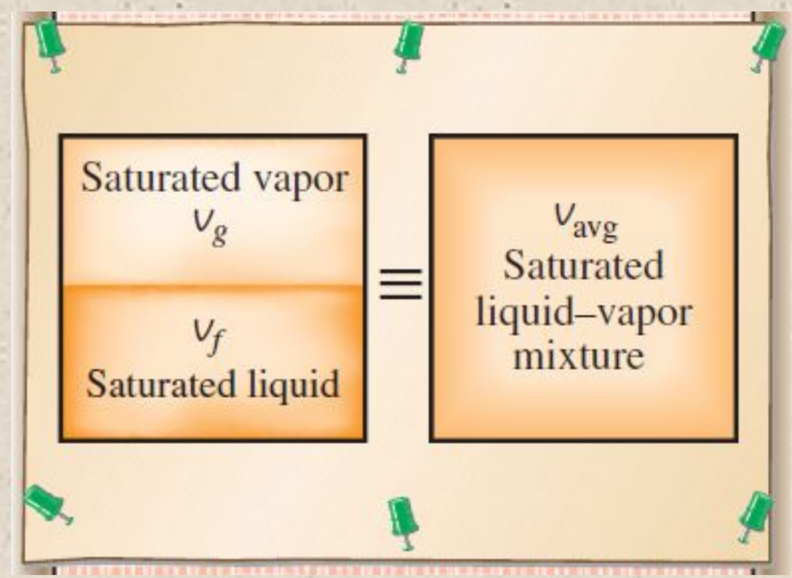
$$x = \frac{m_{\text{vapor}}}{m_{\text{total}}}$$

$$m_{\text{total}} = m_{\text{liquid}} + m_{\text{vapor}} = m_f + m_g$$

Temperature and pressure are dependent properties for a mixture.



The relative amounts of liquid and vapor phases in a saturated mixture are specified by the ***quality x***.



A two-phase system can be treated as a homogeneous mixture for convenience.

$$v_{avg} = v_f + x v_{fg} \qquad (\mathrm{m^3/kg})$$

$$x = m_g / m_t$$

$$x = \frac{v_{avg} - v_f}{v_{fg}}$$

$$u_{avg} = u_f + x u_{fg} \qquad (\mathrm{kJ/kg})$$

$$h_{avg} = h_f + x h_{fg} \qquad (\mathrm{kJ/kg})$$

y → *v*, *u*, or *h*.

$$y_{avg} = y_f + x y_{fg}$$

$$y_f \leq y_{avg} \leq y_g$$

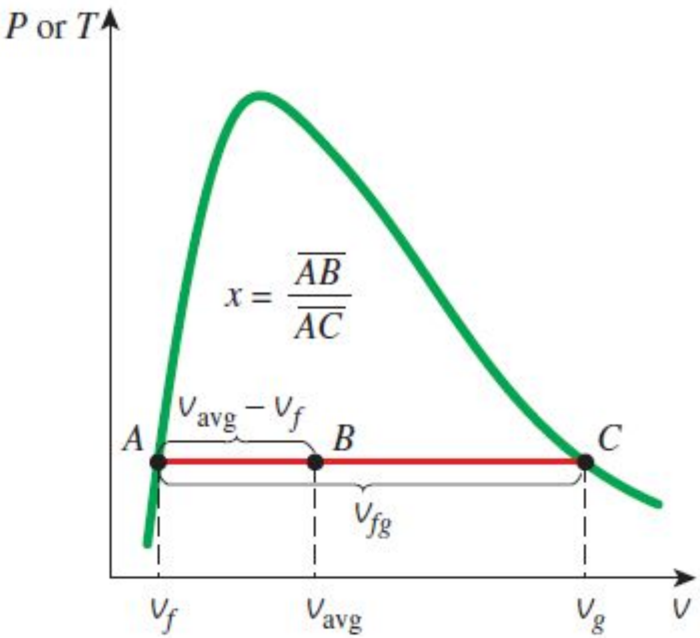


FIGURE 3–33
Quality is related to the horizontal distances on P-v and T-v diagrams.

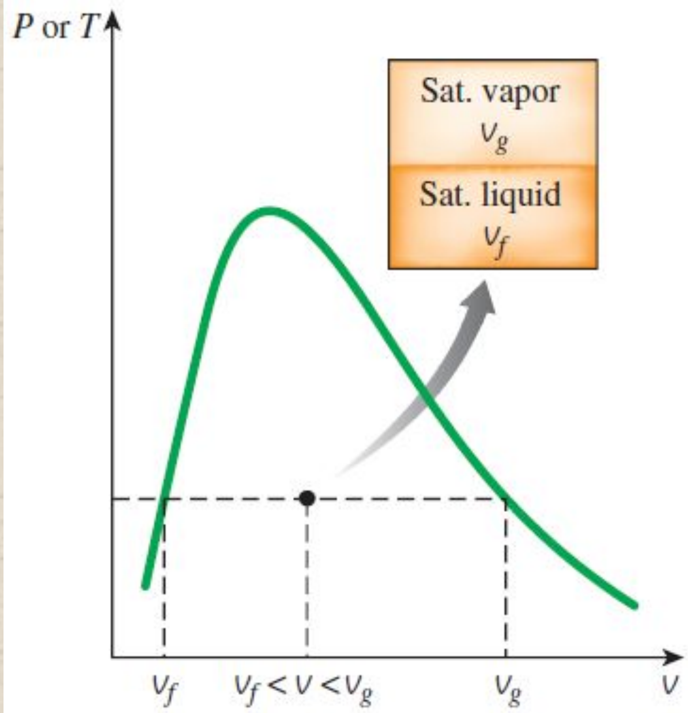


FIGURE 3–34
The v value of a saturated liquid–vapor mixture lies between the v_f and v_g values at the specified T or P.

Examples: Saturated liquid-vapor mixture states on *T-v* and *P-v* diagrams.