

**Chapter 1 Solutions**  
***Engineering and Chemical Thermodynamics 2e***

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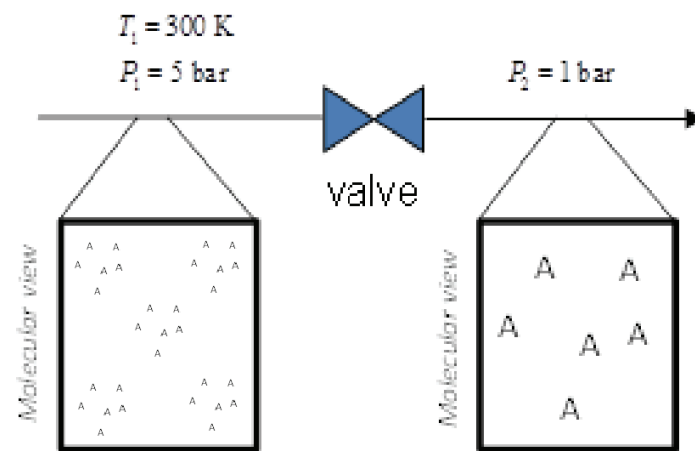
**1.1**

(b) The volume of water contaminating the wine is equal to the volume of wine contaminating the water.

**1.2** (b) The amount of pennies in the jar of mostly nickels is the equal to the amount of nickels in the jar of mostly pennies.

After step (1) there are 10 pennies and 90 nickels in the first jar. We can reason this problem assuming the jars get well mixed. After step (2) there are 9 nickels and 1 penny transferred back to the other jar. That leaves 9 pennies in the first jar and 9 nickels in the second jar. Even if it is not perfectly mixed, the same type of reasoning leads to choice (b).

1.3



$$PV = nRT \rightarrow \frac{P}{RT} = \frac{n}{V} \text{ \& } RT \text{ is constant, so } \frac{n}{V} \propto P$$

### 1.5

Derive the following expressions by combining Equations 1.4 and 1.5:

$$\overline{\vec{v}_a^2} = \frac{3kT}{m_a} \qquad \overline{\vec{v}_b^2} = \frac{3kT}{m_b}$$

Therefore,

$$\frac{\overline{\vec{v}_a^2}}{\overline{\vec{v}_b^2}} = \frac{m_b}{m_a}$$

Since  $m_b$  is larger than  $m_a$ , the molecules of species A move faster on average.

## 1.6

**(a)**

After a short time, the temperature gradient in the copper block is changing (unsteady state), so the system is not in equilibrium.

**(b)**

After a long time, the temperature gradient in the copper block will become constant (steady state), but because the temperature is not uniform everywhere, the system is not in equilibrium.

**(c)**

After a very long time, the temperature of the reservoirs will equilibrate; The system is then homogenous in temperature. The system is in thermal equilibrium.

### **1.7**

The amount of water in the liquid will decrease. The vapor pressure of water increases with temperature and the energy delivered to the system will cause some of the water molecules to enter the vapor phase.

## 1.9

The saturation pressure is the pressure at which a pure substance boils at a given temperature. Vapor pressure is a substance's contribution to the total pressure in a mixture at a given temperature, assuming ideal gases. Saturation pressure is used to describe a pure substance while vapor pressure is used to describe a substance's contribution to an ideal gas mixture.



## **1.10**

It is not a mistake.

### **1.11**

Assuming a closed system, as the temperature decreases the pressure decreases and the lid is forced down by atmospheric pressure.

### 1.12

We consider the air inside the soccer ball as the system. We can answer this question by looking at the ideal gas law:

$$Pv = RT$$

If we assume it is a closed system, it will have the same number of moles of air in the winter as the summer. However, it is colder in the winter ( $T$  is lower), so the ideal gas law tells us that  $Pv$  will be lower and the balls will be under inflated.

Alternatively, we can argue that the higher pressure inside the ball causes air to leak out over time. Thus we have an open system and the number of moles decrease with time – leading to the under inflation.

### 1.13

As defined in the problem statement, the relative humidity can be calculated as follows

$$\text{Relative Humidity} = \frac{\text{mass of water}}{\text{mass of water at saturation}}$$

We can obtain the saturation pressure at each temperature from the steam tables. At 10 [°C], the saturation pressure of water is 1.22 [kPa]. This value is proportional to the mass of water in the vapor at saturation. For 90% relative humidity, the partial pressure of water in the vapor is:

$$p_{\text{Water}} = 0.9 \times 1.22 = 1.10 \text{ [kPa]}$$

This value represents the vapor pressure of water in the air. At 30 [°C], the saturation pressure of water is 4.25 [kPa]. For 50% relative humidity, the partial pressure of water in the vapor is:

$$p_{\text{Water}} = 0.5 \times 4.25 = 2.12 \text{ [kPa]}$$

Since the total pressure in each case is the same (atmospheric), the partial pressure is proportional to the mass of water in the vapor. We conclude there is about twice the amount of water in the air in the latter case.

## 1.14

**(a)**

When you have extensive variables, you do not need to know how many moles of each substance are present. The volumes can simply be summed.

$$V_1 = V_a + V_b$$

**(b)**

The molar volume,  $v_l$ , is equal to the total volume divided by the total number of moles.

$$v_l = \frac{V_1}{n_{tot}} = \frac{V_a + V_b}{n_a + n_b}$$

We can rewrite the above equation to include molar volumes for species  $a$  and  $b$ .

$$v_l = \frac{n_a v_a + n_b v_b}{n_a + n_b} = \frac{n_a}{n_a + n_b} v_a + \frac{n_b}{n_a + n_b} v_b$$
$$v_l = x_a v_a + x_b v_b$$

**(c)**

The relationship developed in Part (a) holds true for all extensive variables.

$$K_1 = K_a + K_b$$

**(d)**

$$k_1 = x_a k_a + x_b k_b$$

**1.15**

The molar density of the two systems would be the same.  $PV = nRT \rightarrow \frac{P}{RT} = \frac{n}{V}$

**1.16**

The mass density of system II would be larger than system I because both systems would have the same amount of moles, i.e.,  $PV = nRT \Rightarrow \frac{P}{RT} = \frac{n}{V}$

**1.17**

You can breathe in the same volume of helium because the system (your lungs) is at the same temperature and pressure. Assuming number of moles is constant



**1.18**

Increasing pressure will increase the boiling point temperature of the liquid, allowing you to cook food at a higher temperature.

**1.19**

The variables of the equation are thermodynamic properties. Two independent, intensive properties constrain the state of a pure substance. The equation relates thermodynamic properties in a given state.

## 1.20

To solve these problems, the steam tables were used. The values given for each part constrain the water to a certain state. In most cases we can look at the saturated table, to determine the state.

**(a)** Subcooled liquid

Explanation: the saturation pressure at  $T = 170$  [°C] is 0.79 [MPa] (see page 508); Since the pressure of this state, 10 [bar], is greater than the saturation pressure, water is a liquid.

**(b)** Saturated vapor-liquid mixture

Explanation: the specific volume of the saturated vapor at  $T = 70$  [°C] is 5.04 [m<sup>3</sup>/kg] and the saturated liquid is 0.001 [m<sup>3</sup>/kg] (see page 508); Since the volume of this state, 3 [m<sup>3</sup>/kg], is in between these values we have a saturated vapor-liquid mixture.

**(c)** Superheated vapor

Explanation: the specific volume of the saturated vapor at  $P = 60$  [bar] = 6 [MPa], is 0.03244 [m<sup>3</sup>/kg] and the saturated liquid is 0.001 [m<sup>3</sup>/kg] (see page 511); Since the volume of this state, 0.05 [m<sup>3</sup>/kg], is greater than this value, it is a vapor.

**(d)** Superheated vapor

Explanation: the specific entropy of the saturated vapor at  $P = 5$  [bar] = 0.5 [MPa], is 6.8212 [kJ/(kg K)] (see page 510); Since the entropy of this state, 7.0592 [kJ/(kg K)], is greater than this value, it is a vapor. In fact, if we go to the superheated water vapor tables for  $P = 500$  [kPa], we see the state is constrained to  $T = 200$  [°C].

### 1.21

An approximate solution can be found if we combine Equations 1.4 and 1.5:

$$\begin{aligned}\frac{1}{2}m\overline{\vec{v}^2} &= \overline{e_k^{molecular}} \\ \frac{3}{2}kT &= \overline{e_k^{molecular}} \\ \therefore \overline{\vec{v}} &\approx \sqrt{\frac{3kT}{m}}\end{aligned}$$

Assume the temperature is 22 °C. The mass of a single oxygen molecule is  $m = 5.14 \times 10^{-26}$  kg .  
Substitute and solve:

$$\overline{\vec{v}} = 487.6 \text{ [m/s]}$$

The molecules are traveling really, fast (around the length of five football fields every second).

Comment:

We can get a better solution by using the Maxwell-Boltzmann distribution of speeds that is sketched in Figure 1.4. Looking up the quantitative expression for this expression, we have:

$$f(v)dv = 4\pi \left( \frac{m}{2\pi kT} \right)^{3/2} \exp \left\{ -\frac{m}{2kT} v^2 \right\} v^2 dv$$

where  $f(v)$  is the fraction of molecules within  $dv$  of the speed  $v$ . We can find the average speed by integrating the expression above

$$\overline{\vec{v}} = \frac{\int_0^\infty f(v)v dv}{\int_0^\infty f(v) dv} = \sqrt{\frac{8kT}{\pi m}} = 449 \text{ [m/s]}$$

**1.22**

We have the following two points that relate the Reamur temperature scale to the Celsius scale:

$$(0^{\circ}\text{C}, 0^{\circ}\text{Reamur}) \text{ and } (100^{\circ}\text{C}, 80^{\circ}\text{Reamur})$$

Create an equation using the two points:

$$T(^{\circ}\text{Reamur}) = 0.8 T(^{\circ}\text{Celsius})$$

At  $22^{\circ}\text{C}$ ,

$$T = 17.6^{\circ}\text{Reamur}$$

### 1.23

We assume the temperature is constant at 0 °C. The molecular weight of air is

$$MW = 29 \text{ g/mol} = 0.029 \text{ kg/mol}$$

Find the pressure at the top of Mount Everest:

$$P = (1 \text{ atm}) \exp \left[ \frac{-(0.029 \text{ kg/mol})(9.81 \text{ [m/s]})(8848 \text{ m})}{\left(8.314 \left[ \frac{\text{J}}{\text{mol} \cdot \text{K}} \right] \right) (273.15 \text{ K})} \right]$$
$$P = 0.330 \text{ atm} = 33.4 \text{ kPa}$$

Interpolate steam table data:

$$T^{sat} = 71.4^\circ \text{C} \quad \text{for } P^{sat} = 33.4 \text{ kPa}$$

Therefore, the liquid boils at 71.4 °C. Note: the barometric relationship given assumes that the temperature remains constant. In reality the temperature decreases with height as we go up the mountain. However, a solution in which  $T$  and  $P$  vary with height is not as straight-forward.

### 1.24

From the steam tables in Appendix B.1:

$$\hat{v}^{critical} = 0.003155 \left[ \frac{\text{m}^3}{\text{kg}} \right] \quad (T = 374.15^\circ\text{C}, P = 22.089 \text{ MPa})$$

At 10 bar, we find in the steam tables

$$\hat{v}_l^{sat} = 0.001127 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$
$$\hat{v}_v^{sat} = 0.19444 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$

Because the total mass and volume of the closed, rigid system remain constant as the water condenses, we can develop the following expression:

$$\hat{v}^{critical} = (1-x)\hat{v}_l^{sat} + x\hat{v}_v^{sat}$$

where  $x$  is the quality of the water. Substituting values and solving for the quality, we obtain

$$x = 0.0105 \text{ or } 1.05 \%$$

A very small percentage of mass in the final state is vapor.

**1.25**

The calculation methods will be shown for part (a), but not parts (b) and (c)

**(a)**

Use the following equation to estimate the specific volume:

$$\hat{v}(1.9 \text{ MPa}, 250^\circ \text{C}) = \hat{v}(1.8 \text{ MPa}, 250^\circ \text{C}) + 0.5[\hat{v}(2.0 \text{ MPa}, 250^\circ \text{C}) - \hat{v}(1.8 \text{ MPa}, 250^\circ \text{C})]$$

Substituting data from the steam tables,

$$\hat{v}(1.9 \text{ MPa}, 250^\circ \text{C}) = 0.11821 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$

From the NIST website:

$$\hat{v}_{NIST}(1.9 \text{ MPa}, 250^\circ \text{C}) = 0.11791 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$

Therefore, assuming the result from NIST is more accurate

$$\% \text{ Difference} = \left( \frac{|\hat{v} - \hat{v}_{NIST}|}{\hat{v}_{NIST}} \times 100 \right) \% = 0.254 \%$$

**(b)**

Linear interpolation:

$$\hat{v}(1.9 \text{ MPa}, 300^\circ \text{C}) = 0.13284 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$

NIST website:

$$\hat{v}_{NIST}(1.9 \text{ MPa}, 300^\circ \text{C}) = 0.13249 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$

Therefore,

$$\% \text{ Difference} = 0.264 \%$$

**(c)**

Linear interpolation:

$$\hat{v}(1.9 \text{ MPa}, 270^\circ \text{C}) = 0.12406 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$



Note: Double interpolation is required to determine this value. First, find the molar volumes at 270 °C and 1.8 MPa and 2.0 MPa using interpolation. Then, interpolate between the results from the previous step to find the molar volume at 270 °C and 1.9 MPa.

NIST website:

$$\hat{v}_{NIST}(1.9 \text{ MPa}, 270 \text{ }^{\circ}\text{C}) = 0.12389 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$

Therefore,

$$\% \text{ Difference} = 0.137 \%$$

With regards to parts (a), (b), and (c), the values found using interpolation and the NIST website agree very well. The discrepancies will not significantly affect the accuracy of any subsequent calculations.

**1.26**

For saturated temperature data at 25 °C in the steam tables,

$$\hat{v}_l^{sat} = 0.001003 \left[ \frac{\text{m}^3}{\text{kg}} \right] = 1.003 \left[ \frac{\text{L}}{\text{kg}} \right]$$

Determine the mass:

$$m = \frac{V}{\hat{v}_l^{sat}} = \frac{1 [\text{L}]}{1.003 \left[ \frac{\text{L}}{\text{kg}} \right]} = 0.997 \text{ kg}$$

Because molar volumes of liquids do not depend strongly on pressure, the mass of water at 25 °C and atmospheric pressure in a one liter should approximately be equal to the mass calculated above unless the pressure is very, very large.

**1.27**

First, find the overall specific volume of the water in the container:

$$\hat{v} = \frac{1 \text{ m}^3}{5 \text{ kg}} = 0.2 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$

Examining the data in the saturated steam tables, we find

$$\hat{v}_l^{sat} < \hat{v} < \hat{v}_v^{sat} \quad \text{at } P^{sat} = 2 \text{ bar}$$

Therefore, the system contains saturated water and the temperature is

$$T = T^{sat} = 120.23^\circ \text{C}$$

Let  $m_l$  represent the mass of the water in the container that is liquid, and  $m_v$  represent the mass of the water in the container that is gas. These two masses are constrained as follows:

$$m_l + m_v = 5 \text{ kg}$$

We also have the extensive volume of the system equal the extensive volume of each phase

$$\begin{aligned} m_l \hat{v}_l^{sat} + m_v \hat{v}_v^{sat} &= V \\ m_l (0.001061 \text{ m}^3 / \text{kg}) + m_v (0.8857 \text{ m}^3 / \text{kg}) &= 1 \text{ m}^3 \end{aligned}$$

Solving these two equations simultaneously, we obtain

$$\begin{aligned} m_l &= 3.88 \text{ kg} \\ m_v &= 1.12 \text{ kg} \end{aligned}$$

Thus, the quality is

$$x = \frac{m_v}{m} = \frac{1.12 \text{ kg}}{5 \text{ kg}} = 0.224$$

The internal energy relative to the reference state in the saturated steam table is

$$U = m_l \hat{u}_l^{sat} + m_v \hat{u}_v^{sat}$$

From the steam tables:

$$\hat{u}_l^{sat} = 504.47 \text{ [kJ/kg]}$$

$$\hat{u}_v^{sat} = 2529.5 \text{ [kJ/kg]}$$

Therefore,

$$U = (3.88 \text{ kg})(504.47 \text{ [kJ/kg]}) + (1.12 \text{ kg})(2529.5 \text{ [kJ/kg]})$$

$$U = 4790.4 \text{ kJ}$$

**1.28**

First, determine the total mass of water in the container. Since we know that 10 % of the mass is vapor, we can write the following expression

$$V = m \left[ (0.9) \hat{v}_l^{sat} + (0.1) \hat{v}_v^{sat} \right]$$

From the saturated steam tables for  $P^{sat} = 1 \text{ MPa}$

$$\hat{v}_l^{sat} = 0.001127 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$

$$\hat{v}_v^{sat} = 0.1944 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$

Therefore,

$$m = \frac{V}{(0.9) \hat{v}_l^{sat} + (0.1) \hat{v}_v^{sat}} = \frac{1 \text{ m}^3}{0.9 \left( 0.001127 \left[ \frac{\text{m}^3}{\text{kg}} \right] \right) + 0.1 \left( 0.1944 \left[ \frac{\text{m}^3}{\text{kg}} \right] \right)}$$

$$m = 48.9 \text{ kg}$$

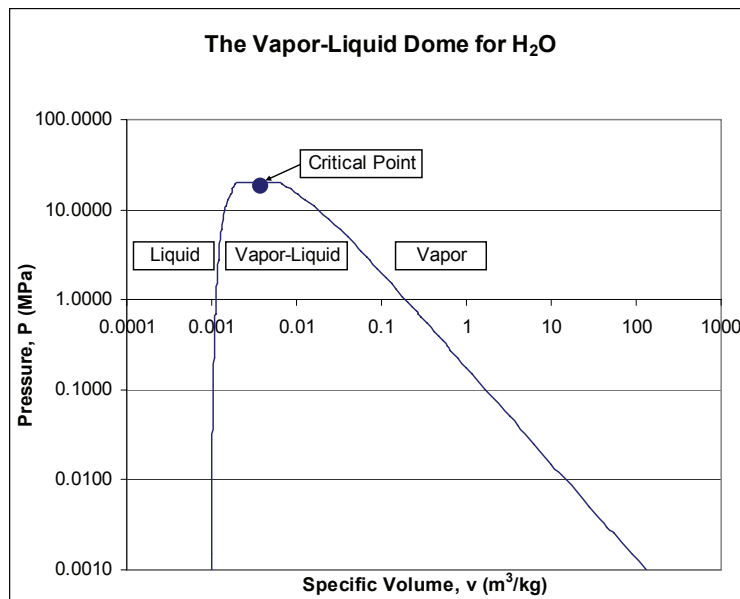
and

$$V_v = (0.1) m \hat{v}_v^{sat} = 0.1 (48.9 \text{ kg}) (0.1944 \text{ m}^3 / \text{kg})$$

$$V_v = 0.950 \text{ m}^3$$

### 1.29

In a spreadsheet, make two columns: one for the specific volume of water and another for the pressure. First, copy the specific volumes of liquid water from the steam tables and the corresponding saturation pressures. After you have finished tabulating pressure/volume data for liquid water, list the specific volumes and saturation pressures of water vapor. Every data point is not required, but be sure to include extra points near the critical values. The data when plotted on a logarithmic scale should look like the following plot.



### 1.30

The ideal gas law can be rewritten as

$$v = \frac{RT}{P}$$

For each part in the problem, the appropriate values are substituted into this equation where

$$R = 0.08314 \left[ \frac{\text{L} \cdot \text{bar}}{\text{mol} \cdot \text{K}} \right]$$

is used. The values are then converted to the units used in the steam table.

(a)

$$v = 30.7 \left[ \frac{\text{L}}{\text{mol}} \right]$$
$$\hat{v} = \frac{v}{MW} = \frac{30.7 \left[ \frac{\text{L}}{\text{mol}} \right]}{0.018 \left[ \frac{\text{kg}}{\text{mol}} \right]} 10^{-3} \left[ \frac{\text{m}^3}{\text{L}} \right] = 1.70 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$

For part (a), the calculation of the percent error will be demonstrated. The percent error will be based on percent error from steam table data, which should be more accurate than using the ideal gas law. The following equation is used:

$$\% \text{Error} = \left( \frac{|\hat{v}_{IG} - \hat{v}_{ST}|}{\hat{v}_{ST}} \times 100 \right) \%$$

where  $v_{IG}$  is the value calculated using the ideal gas law and  $v_{ST}$  is the value from the steam table.

$$\% \text{Error} = \left( \frac{\left| 1.70 \left[ \frac{\text{m}^3}{\text{kg}} \right] - 1.6729 \left[ \frac{\text{m}^3}{\text{kg}} \right] \right|}{1.6729 \left[ \frac{\text{m}^3}{\text{kg}} \right]} \right) \% = 1.62\%$$

This result suggests that you would introduce an error of around 1.6% if you characterize boiling water at atmospheric pressure as an ideal gas.

**(b)**

$$v = 64.3 \left[ \frac{\text{L}}{\text{mol}} \right]$$

$$\hat{v} = 3.57 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$

$$\% \text{Error} = 0.126\%$$

For a given pressure, when the temperature is raised the gas behaves more like an ideal gas.

**(c)**

$$v = 0.643 \left[ \frac{\text{L}}{\text{mol}} \right]$$

$$\hat{v} = 0.0357 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$

$$\% \text{Error} = 8.87\%$$

**(d)**

$$v = 1.06 \left[ \frac{\text{L}}{\text{mol}} \right]$$

$$\hat{v} = 0.0588 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$

$$\% \text{Error} = 0.823\%$$

The largest error occurs at high  $P$  and low  $T$ .



**1.31**

The room I am sitting in right now is approximately 16 ft long by 12 feet wide by 10 feet tall – your answer should vary. The volume of the room is

$$V = (12 \text{ ft})(16 \text{ ft})(10 \text{ ft}) = 1920 \text{ ft}^3 = 54.4 \text{ m}^3$$

The room is at atmospheric pressure and a temperature of 22 °C. Calculate the number of moles using the ideal gas law:

$$n = \frac{PV}{RT} = \frac{(1.01325 \times 10^5 \text{ Pa})(54.4 \text{ m}^3)}{\left(8.314 \left[ \frac{\text{J}}{\text{mol} \cdot \text{K}} \right] \right)(295.15 \text{ K})}$$
$$n = 2246 \text{ mol}$$

Use the molecular weight of air to obtain the mass:

$$m = n(MW) = (2246.27 \text{ mol})(0.029 \text{ kg/mol}) = 65.2 \text{ kg}$$

That's pretty heavy.

**1.32**

First, find the total volume that one mole of gas occupies. Use the ideal gas law:

$$v = \frac{RT}{P} = \frac{\left(8.314 \left[ \frac{\text{J}}{\text{mol} \cdot \text{K}} \right] \right) (293.15 \text{ K})}{(1 \times 10^5 \text{ Pa})} = 0.0244 \left[ \frac{\text{m}^3}{\text{mol}} \right]$$

Now calculate the volume occupied by the molecules:

$$v^{\text{occupied}} = \left( \frac{\text{Number of molecules}}{\text{per mole}} \right) \times \left( \frac{\text{Volume of}}{\text{one molecule}} \right) = N_A \left( \frac{4}{3} \pi r^3 \right)$$

$$v^{\text{occupied}} = \left( \frac{6.022 \times 10^{23} \text{ molecules}}{1 \text{ mol}} \right) \left[ \frac{4}{3} \pi (1.5 \times 10^{-10} \text{ m})^3 \right]$$

$$v^{\text{occupied}} = 8.51 \times 10^{-6} \left[ \frac{\text{m}^3}{\text{mol}} \right]$$

Determine the percentage of the total volume occupied by the molecules:

$$\text{Percentage} = \left[ \frac{v^{\text{occupied}}}{v} \times 100 \right] \% = 0.0349 \%$$

A very small amount of space, indeed.

### 1.33

Water condenses on your walls when the water is in liquid-vapor equilibrium. To find the maximum allowable density at 70 °F, we need to find the smallest density of water vapor at 40 °F which satisfies equilibrium conditions. In other words, we must find the saturation density of water vapor at 40 °F. From the steam tables,

$$\hat{v}_v^{sat} = 153.74 \left[ \frac{\text{m}^3}{\text{kg}} \right] \quad (\text{sat. water vapor at } 40^\circ\text{F} = 4.44^\circ\text{C})$$

We must correct the specific volume for the day-time temperature of 70 °F (21.1 °C ) with the ideal gas law.

$$\frac{\hat{v}_{v,277.6\text{ K}}^{sat}}{T_{277.6}} = \frac{\hat{v}_{294.3\text{ K}}}{T_{294.3}}$$
$$\hat{v}_{294.3\text{ K}} = \frac{T_{294.3}}{T_{277.6}} \left( \hat{v}_{v,277.6\text{ K}}^{sat} \right) = \frac{294.3\text{ K}}{277.6\text{ K}} \left( 153.74 \left[ \frac{\text{m}^3}{\text{kg}} \right] \right) = 163 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$

Therefore,

$$\hat{\rho} = \frac{1}{\hat{v}_v^{sat}} = 6.13 \times 10^{-3} \left[ \frac{\text{kg}}{\text{m}^3} \right]$$

If the density at 70 °F is greater than or equal to  $6.13 \times 10^{-3} \left[ \text{kg/m}^3 \right]$ , the density at night when the temperature is 40 °F will be greater than the saturation density, so water will condense onto the wall. However, if the density is less than  $6.13 \times 10^{-3} \left[ \text{kg/m}^3 \right]$ , then saturation conditions will not be obtained, and water will not condense onto the walls.

**1.34**

First, write an equation for the volume of the system in its initial state:

$$m_l \hat{v}_l^{sat} + m_v \hat{v}_v^{sat} = V$$

Substitute  $m_l = (1-x)m$  and  $m_v = xm$ :

$$m[(1-x)\hat{v}_l^{sat} + x\hat{v}_v^{sat}] = V$$

At the critical point

$$m\hat{v}^{critical} = V$$

Since the mass and volume don't change

$$\hat{v}^{critical} = (1-x)\hat{v}_l^{sat} + x\hat{v}_v^{sat}$$

From the steam tables in Appendix B.1:

$$\hat{v}^{critical} = 0.003155 \left[ \frac{\text{m}^3}{\text{kg}} \right] \quad (T = 374.15^\circ\text{C}, P = 22.089 \text{ MPa})$$

At 0.1 MPa, we find in the steam tables

$$\hat{v}_l^{sat} = 0.001043 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$

$$\hat{v}_v^{sat} = 1.6940 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$

Therefore, solving for the quality, we get

$$x = 0.00125 \text{ or } 0.125 \%$$

99.875% of the water is liquid.

**1.35**

**(a)** From the steam tables, this is superheated vapor (steam) and the value is  $\hat{v}_v = 1.080 \left[ \frac{\text{m}^3}{\text{kg}} \right]$

**(b)** This case is subcooled liquid water; however, the properties of a liquid do not vary much

with pressure, so we can use the saturated table at 100 °C:  $\hat{v}_l = 1.044 \times 10^{-3} \left[ \frac{\text{m}^3}{\text{kg}} \right]$

**1.36**

We need to specify two independent intensive properties to constrain the state of the system. We can use  $T = 90^\circ\text{C}$  and the quality  $x = 0.8$ . From the steam tables, we get:  $P = 70.1\text{ kPa}$  and

$$\hat{v} = (1-x)\hat{v}_l^{sat} + x\hat{v}_v^{sat} = 1.89 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$

**1.37**

We need two intensive properties. We can use the information in the problem statement to calculate the specific volume:

$$\hat{v} = \frac{V}{m} = 0.25 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$

From the steam tables, we see this corresponds to superheated steam at 300 °C. At P = 1

MPa  $\hat{v} = 0.25794 \left[ \frac{\text{m}^3}{\text{kg}} \right]$  while at 1.2 MPa  $\hat{v} = 0.21382 \left[ \frac{\text{m}^3}{\text{kg}} \right]$ . Thus we need to linearly

interpolate. As discussed in the text, following the ideal gas relation, it is most accurate to interpolate in terms of  $1/\hat{v}$

$$P = 1 \text{ MPa} + 0.2 \text{ MPa} \left[ \frac{1/0.25 - 1/0.25794}{1/0.21382 - 1/0.25794} \right] = 1.031 \text{ MPa}$$

**1.38**

The initial specific volume in the tank must match the value at the critical point,

$$\hat{v} = 0.003155 \left[ \frac{\text{m}^3}{\text{kg}} \right] = (1-x)\hat{v}_l^{sat} + x\hat{v}_v^{sat}$$

The value of mass can be found as:

$$m = \frac{V}{\hat{v}} = 31.7 \text{ kg}$$

For water at 100 °C,

$$\hat{v}_l^{sat} = 0.001044 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$

And

$$\hat{v}_v^{sat} = 1.673 \left[ \frac{\text{m}^3}{\text{kg}} \right]$$

Solving for  $x$ , we get

$$x = 0.0013$$

It is almost all liquid.



**1.39**

The final pressure is 500 kPa. Looking at the steam tables, the final temperature is 151.9 °C and

the final specific volume is  $\hat{v} = 0.3749 \left[ \frac{\text{m}^3}{\text{kg}} \right]$  and the final volume is  $V = m\hat{v} = 0.187 \text{ m}^3$