

## Soal-soal Bab 5

**Example 4.8.** For metallic copper at 300 K the following values are known:

$$C_P = 24.5 \text{ J/mol K}$$

$$\beta = 50.4 \times 10^{-6} \text{ K}^{-1}$$

$$\kappa = 7.78 \times 10^{-12} \text{ Pa}^{-1}$$

$$V = 7.06 \text{ cm}^3/\text{mol}$$

Determine  $C_V$ .

Direct substitution into (4.12) gives

$$C_P - C_V = \frac{300 \times 7.06 \times 10^{-6} \times (50.4 \times 10^{-6})^2}{7.78 \times 10^{-12}}$$

$$= 0.692 \text{ J/mol K}$$

$$C_V = 24.5 - 0.69 = 23.8 \text{ J/mol K}$$

**Example 4.9.** The heat capacity of quartz ( $\text{SiO}_2$ ) at 100 kPa between 298 and 848 K is given by the equation

$$C_P(\text{J/mol K}) = 46.98 + 34.33 \times 10^{-3} \times (T/\text{K}) - 11.3 \times 10^5 \times (T/\text{K})^{-2}$$

If 1000 kg of quartz is heated from 300 K to 700 K at 100 kPa how much heat is required?

For a constant-pressure process it was shown in Example 1.7 that  $\Delta H = Q$ . Furthermore, (1.11) gives  $dH = C_P dT$  for a constant-pressure process. As a result, we have

$$Q = \int_{T_1}^{T_2} C_P dT$$

Substitution for  $C_P$  and integration provide the equation:

$$Q = 46.98 \times (T_2 - T_1) + \frac{34.33 \times 10^{-3}}{2} \times (T_2^2 - T_1^2) - 11.3 \times 10^5 \times \left( \frac{1}{T_1} - \frac{1}{T_2} \right)$$

Substitution of numerical values for the temperatures gives the result:

$$Q = 23\,506 \text{ J/mol}$$

The molar mass of  $\text{SiO}_2$  is 0.052 kg/mol and therefore

$$Q = \frac{23\,506}{0.052} = 452\,040 \text{ J/kg}$$

This gives a total heat requirement for 1000 kg of

$$Q^t = 1000 \times 452 \times 10^3 = 452 \times 10^6 \text{ J or } 452 \text{ MJ}$$

**Example 4.11.** One gram mole of nitrogen is contained in a constant-volume tank at low pressure. Assuming nitrogen to be an ideal gas, calculate the amount of heat required to raise its temperature from 300 to 1000 K. For nitrogen

$$C'_p / (\text{J/mol K}) = 27.336 + 5.233 \times 10^{-3} \times (T/\text{K})$$

For a constant-volume process there is no work and the first law becomes  $\Delta U = Q$ . Since we have taken nitrogen to be an ideal gas,

$$Q = \Delta U = \int_{T_1}^{T_2} C'_v dT$$

To get  $C'_v$ , we use the relation  $C'_p - C'_v = R$ , and our equation becomes

$$Q = \int_{T_1}^{T_2} (C'_p - R) dT$$

where  $R$  has the value 8.314 J/mol K. Substitution for  $C'_p$  and  $R$  gives

$$Q = \int_{300}^{1000} (19.022 + 5.223 \times 10^{-3} \times T) dT$$

Integrating,

$$Q = 19.022 \times 700 + \frac{5.223 \times 10^{-3}}{2} \times 91 \times 10^4 = 15\,696 \text{ J}$$

- 4.5. Steam at a pressure of 35 bar is known to have a specific volume of 50 dm<sup>3</sup>/kg. What is its enthalpy?

Examination of the steam tables for values of  $V$  at a pressure of 35 bar shows the given value of  $V$  lies between  $V_f = 1.2347$  and  $V_g = 57.03$  dm<sup>3</sup>/kg. The steam is therefore "wet," consisting of a mixture of saturated vapor and saturated liquid. In order to find the enthalpy we must determine the quality of the steam, and this is done through use of the known volume data. From Example 4.5 we have

$$V = V_f + xV_{fg} \quad \text{where } V_{fg} = V_g - V_f$$

Solving for the quality (mass fraction of vapor)  $x$ ,

$$x = \frac{V - V_f}{V_{fg}} = \frac{50.0 - 1.2347}{57.03 - 1.2347} = 0.874$$

The enthalpy is given by

$$H = H_f + xH_{fg}$$

From the saturation steam tables at 35 bar

$$H_f = 1049.7 \quad \text{and} \quad H_{fg} = 1752.2 \text{ kJ/kg}$$

Thus

$$H = 1049.7 + 0.874 \times 1752.2 = 2581.4 \text{ kJ/kg}$$

- 4.6. A tank contains exactly one kilogram of H<sub>2</sub>O consisting of liquid and vapor in equilibrium at 10 bar. If the liquid and vapor each occupy one-half the volume of the tank, what is the enthalpy of the contents of the tank?

For saturated liquid and vapor at 10 bar the steam tables provide the values

$$V_f = 1.127 \text{ dm}^3/\text{kg} \quad V_g = 194.3 \text{ dm}^3/\text{kg}$$

$$H_f = 762.6 \text{ kJ/kg} \quad H_g = 2776.2 \text{ kJ/kg}$$

If  $x$  is the mass of vapor, then the volume of vapor is  $xV_g$  and similarly the volume of liquid is  $(1-x)V_f$ . However, these two volumes are equal, and therefore

$$xV_g = (1-x)V_f$$

or

$$\frac{x}{1-x} = \frac{V_f}{V_g} = \frac{1.127}{194.4}$$

Solution for  $x$  gives

$$x = 0.00576 \text{ kg} \quad \text{and} \quad 1-x = 0.99424 \text{ kg}$$

Then by (4.8)

$$H = (1-x)H_f + xH_g = 0.99424 \times 762.6 + 0.00576 \times 2776.2 = 774.2 \text{ kJ/kg}$$

47. A rigid tank having a total volume of  $1 \text{ m}^3$  contains  $0.05 \text{ m}^3$  of saturated liquid water and  $0.95 \text{ m}^3$  of saturated vapor steam at 1 bar pressure. How much heat must be added to the water so that the liquid is just vaporized?

The system is closed, and the first-law energy equation is simply  $Q = \Delta U^t = m \Delta U$ , because there is no work. In its initial state the system contains saturated liquid and saturated vapor in equilibrium at 1 bar. Property values from the steam tables are:

$$\begin{aligned} V_{f_1} &= 1.043 & V_{g_1} &= 1694.0 \text{ dm}^3/\text{kg} \\ U_{f_1} &= 417.4 & U_{g_1} &= 2506.0 & U_{fg_1} &= 2088.6 \text{ kJ/kg} \end{aligned}$$

The latter values are obtained by use of the equation  $U = H - PV$ . The final state is saturated vapor at a pressure yet to be determined. This is done through use of the given volumes. The initial mass of liquid is

$$m_{f_1} = \frac{V_{\text{liquid}}}{V_{f_1}} = \frac{0.05}{1.043 \times 10^{-3}} = 47.94 \text{ kg}$$

Similarly

$$m_{g_1} = \frac{V_{\text{vapor}}}{V_{g_1}} = \frac{0.95}{1694 \times 10^{-3}} = 0.561 \text{ kg}$$

The total mass of the system is

$$m = m_{f_1} + m_{g_1} = 47.94 + 0.56 = 48.50 \text{ kg}$$

The final state of the system is saturated vapor occupying the full  $1 \text{ m}^3$  of tank volume and consisting of the total mass of the system. Thus

$$V_{g_2} = \frac{V_{\text{tank}}}{m} = \frac{1}{48.5} = 0.02062 \text{ m}^3/\text{kg} \quad \text{or} \quad 20.62 \text{ dm}^3/\text{kg}$$

Saturated vapor with this specific volume occurs at just one pressure, which may be found by interpolation in the steam tables for saturated vapor. This pressure is  $P_2 = 89.5 \text{ bar}$  and at this pressure the internal energy of saturated vapor is

$$\begin{aligned} U_2 = U_{g_2} &= H_{g_2} - P_2 V_{g_2} = 2745.4 - \frac{89.5 \times 10^5 \times 0.02062}{1000} \\ &= 2560.9 \text{ kJ/kg} \end{aligned}$$

The initial internal energy is

$$U_1 = U_{f_1} + x_1 U_{fg_1}$$

where  $x_1$  is the initial quality, given by

$$x_1 = \frac{m_{g_1}}{m} = \frac{0.561}{48.5} = 0.01157$$

(Note that although the system is 95% vapor by volume initially, it is only a little more than 1% vapor on a mass basis.) Substitution of values in the expression for  $U_1$  gives

$$U_1 = 417.4 + 0.01157 \times 2088.6 = 441.6 \text{ kJ/kg}$$

We may now solve for  $Q$  by our original equation:

$$Q = m \Delta U = 48.5 \times (2560.9 - 441.6) = 102\,790 \text{ kJ}$$