

Thermodynamics
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Lecture 38
Tutorial problem - Part 1

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Q A cylinder contains 70 g of Oxygen and 300 g of Helium. The volume of the cylinder is 10 L. Calculate the partial pressure and volume of each gas and the total pressure in the cylinder at 25 °C.

$m_{O_2} = 70g = 0.07 kg$
 $m_{He} = 300g = 0.3 kg$
 $V = 10 L = 10 \times 10^{-3} m^3$
 $T = 25^\circ C = 298 K$
 $1L = 1000 cm^3$
 $cm = 0.01 m$
 $1000 L = 1 m^3$
 $y_{O_2} = \frac{m_{O_2}}{m_{O_2} + m_{He}} = \frac{0.07}{0.07 + 0.3} = 0.18$
 $y_{He} = 1 - y_{O_2} = 0.82$
 $M_{O_2} = 32 kg/kmol$
 $M_{He} = 4 kg/kmol$
 $p_{O_2} = x_{O_2} p$
 $p_{He} = x_{He} p$

Figure 1.

Solution of the problem given in Fig. 1:

$$m_{O_2} = 70 g = 0.07 kg, m_{He} = 0.3 kg, V = 10 L = 10 \times 10^{-3} m^3, T = 298 K$$

Partial pressure of gases, $p_{O_2} = x_{O_2} p_{mix}$ and $p_{He} = x_{He} p_{mix}$ where x and p_{mix} represent the mole fraction and mixture pressure. Also, $V_{O_2} = x_{O_2} V$ and $V_{He} = x_{He} V$.

We can find mole fraction using molecular weight of the mixture which in turn needs mass fractions.

$$y_{O_2} = \frac{m_{O_2}}{m_{O_2} + m_{He}} = \frac{0.07}{0.07 + 0.3} = 0.18, y_{He} = 1 - y_{O_2} = 0.82$$

$$\text{Molecular weight of the mixture, } M_{mix} = \frac{1}{\sum y_i / M_i} = \frac{1}{\frac{y_{O_2}}{M_{O_2}} + \frac{y_{He}}{M_{He}}} = \frac{1}{\frac{0.18}{32} + \frac{0.82}{4}} = 4.74 kg/kmol$$

$$\text{Now, } x_{O_2} = \frac{y_{O_2}}{M_{O_2}} M_{mix} = \frac{0.18}{32} \times 4.74 = 0.026 \text{ and } x_{He} = 1 - x_{O_2} = 0.974$$

$$\text{Hence, } V_{O_2} = x_{O_2} V = 0.026 \times 10 = 0.26 L \text{ and } V_{He} = x_{He} V = 0.974 \times 10 = 9.74 L.$$

To calculate partial pressures, we need mixture pressure.

Assume that both the gases are ideal gases. Hence, the mixture is also an ideal gas.

Now, $m_{mix} = 0.37 \text{ kg}, T_{mix} = 298 \text{ K}, V_{mix} = 10^{-2} \text{ m}^3, R_{mix} = \frac{\bar{R}}{M_{mix}} = \frac{8314.5 \frac{\text{kJ}}{\text{kmol}\cdot\text{K}}}{4.74 \frac{\text{kg}}{\text{kmol}}} = 1754.1 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$

Hence, $p_{mix}V_{mix} = m_{mix}R_{mix}T_{mix} \rightarrow p_{mix} = 193 \text{ bar}$

Hence, $p_{O_2} = x_{O_2}p_{mix} = 5 \text{ bar}, p_{He} = x_{He}p_{mix} = 187.2 \text{ bar}$

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$$M_{mix} = \frac{1}{\sum \frac{y_i}{M_i}} = \frac{1}{\frac{y_{O_2}}{M_{O_2}} + \frac{y_{He}}{M_{He}}}$$

$$= \frac{1}{\frac{0.18}{32} + \frac{0.82}{4}}$$

$$M_{mix} = 4.74 \text{ kg/kmol}$$

$$x_{O_2} = \frac{0.18}{32} \times 4.74 = 0.026$$

$$x_{He} = \frac{0.82}{4} \times 4.74 = 0.974$$

$$m = 0.37 \text{ kg}$$

$$V = 10 \text{ L} = 10 \times 10^{-3} \text{ m}^3$$

$$T = 298 \text{ K}$$

$$p = ?$$

$$p_{mix} V_{mix} = m_{mix} \times R_{mix} \times T_{mix}$$

$$p = \frac{0.37 \times 8314.5 \times 298}{4.74 \times 10 \times 10^{-3}} = 193 \text{ bar}$$

$$p_{O_2} = x_{O_2} p = 5 \text{ bar}$$

$$p_{He} = x_{He} p = 187.2 \text{ bar}$$

$$V_{O_2} = 10 \text{ L} \times 0.026 = 0.26 \text{ L}$$

$$V_{He} = 10 \text{ L} \times 0.974 = 9.7 \text{ L}$$

$$R = \frac{\bar{R}}{M_{mix}}$$