

**Thermodynamics**  
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**Lecture No 26**  
**Tutorial problem - Part 2**

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Air and  $N_2$  are contained in an insulated piston cylinder apparatus as shown in the figure. The thin rigid wall that separates the two chambers is perfectly thermally conducting. Initially, the air is at 500 kPa and 473 K and  $N_2$  is at 1500 kPa and they each occupy 0.01 m<sup>3</sup>. The air is now compressed slowly till the pressure of  $N_2$  reaches 1580 kPa. Determine the work and heat interaction for the air and its final temperature. For air and  $N_2$ ,  $pv = 288 T$ ,  $C_v = 742$  J/kg K, where  $p$  is in N/m<sup>2</sup>,  $v$  is in m<sup>3</sup>/kg, and  $T$  is in K. Neglect any internal energy changes in the partition wall.

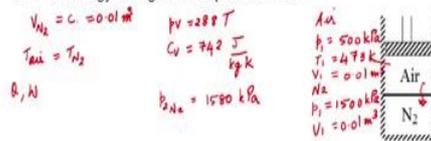


Figure 1.

**Solution of the problem in Fig. 1:**

$$p_{1,air} = 500 \text{ kPa}, T_{1,air} = 473 \text{ K}, V_{1,air} = 0.01 \text{ m}^3$$

$$p_{1,N_2} = 1500 \text{ kPa}, V_{1,N_2} = 0.01 \text{ m}^3$$

$$pv = 288 T, C_v = 742 \frac{J}{kgK},$$

$$p_{2,N_2} = 1580 \text{ kPa}, V_{2,N_2} = 0.01 \text{ m}^3 \text{ (as the separating wall is rigid)}$$

Since the separating wall is perfectly conducting, the temperature of air and nitrogen is equal all the time,  $T_{air} = T_{N_2}$ . Also,  $T_{1,air} = T_{1,N_2} = 473 \text{ K}$ .

As the air gets compressed, it gets heated and transfers some amount of heat to nitrogen. There is no work interaction for nitrogen as the separating wall is rigid.

Using  $pv = 288 T$ , we can calculate  $T_{2,N_2}$ .

$$\frac{p_{1,N_2} v_{1,N_2}}{T_{1,N_2}} = \frac{p_{2,N_2} v_{2,N_2}}{T_{2,N_2}} \rightarrow \frac{p_{1,N_2} V_{1,N_2}}{T_{1,N_2}} = \frac{p_{2,N_2} V_{2,N_2}}{T_{2,N_2}} \quad (\text{since } m_{1,N_2} = m_{2,N_2})$$

Also,  $V_{1,N_2} = V_{2,N_2}$ .

Therefore,  $T_{2,N_2} = 498.2 \text{ K} = T_{2,air}$

For nitrogen, the first law is  $dU = \delta Q - \delta W$ . As the work interaction is zero for nitrogen,  $dU = \delta Q$ .

After integration,  $\Delta U = Q$ .  $\Delta U = m_{N_2} C_v \Delta T$ . Hence, we need the mass of nitrogen.

$$\text{Now, } \frac{p_{1,N_2} V_{1,N_2}}{m_{1,N_2}} = 288 T_{1,N_2} \rightarrow m_{N_2} = 0.11 \text{ kg}$$

For nitrogen,  $Q = \Delta U = 0.11 \times 742 \times (498.2 - 473) = 2 \text{ kJ}$

Heat interaction for nitrogen is positive as it is receiving heat from air. The heat interaction for the air is negative of the heat interaction for nitrogen (air is losing heat to nitrogen).

The first law for air in the integrated form is  $\Delta U = Q - W$ . We are asked to find out  $W$ .

For air,  $\Delta U = m_{air} C_v \Delta T$ . We need the mass of air.

$$\text{Now, } \frac{p_{1,air} V_{1,air}}{m_{1,air}} = 288 T_{1,air} \rightarrow m_{air} = 0.036 \text{ kg}$$

Now,  $\Delta U = m_{air} C_v \Delta T = 0.036 \times 742 \times (498.2 - 473) = 686 \text{ J}$

Therefore, for air,  $W = Q - \Delta U = (-2000 \text{ J}) - 686 \text{ J} = -2686 \text{ J}$

Work interaction for air is negative as work is being done on the system (air).

**Therefore, for air,  $Q = -2 \text{ kJ}$ ,  $W = -2.686 \text{ kJ}$ ,  $T_2 = 498.2 \text{ K}$**

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$$\frac{p_1 v_1}{T_1} = 288$$

$$N_2: \frac{1500 \text{ kPa} \times 0.01 \text{ m}^3}{473} = \frac{1580 \text{ kPa} \times 0.01 \text{ m}^3}{T_2}$$

$$T_{2, N_2} = \frac{1580 \times 473}{1500} = 498.2 \text{ K}$$

$$T_{2, \text{air}} = 498.2 \text{ K}$$

$$m_{N_2} = ? \quad p_1 v_1 = 288 T_1$$

$$p_1 \frac{V_1}{m} = 288 T_1$$

$$\Rightarrow m = \frac{p_1 V_1}{288 T_1} = \frac{1500 \times 10^3 \times 0.01 \text{ m}^3}{288 \times 473}$$

$$m = 0.11 \text{ kg}$$

$$\Delta U = 0.11 \times 742 \times (498.2 - 473)$$

$$\Delta U = 2 \text{ kJ}$$

$$Q_2 = 2 \text{ kJ}$$

First law  
air:  $dU = \delta Q - \delta W$

$$N_2: dU = \delta Q - \frac{\delta W}{\gamma}$$

$$dU = \delta Q$$

$$Q_2 = \Delta U$$

$$\Delta U = m C_v \Delta T$$



Air and  $N_2$  are contained in an insulated piston cylinder apparatus as shown in the figure. The thin rigid wall that separates the two chambers is perfectly thermally conducting. Initially, the air is at 500 kPa and 473 K and  $N_2$  is at 1500 kPa and they each occupy 0.01 m<sup>3</sup>. The air is now compressed slowly till the pressure for  $N_2$  reaches 1580 kPa. Determine the work and heat interaction for the air and its final temperature. For air and  $N_2$ ,  $p v = 288 T$ ,  $C_v = 742 \text{ J/kg K}$ , where  $p$  is in  $\text{N/m}^2$ ,  $v$  is in  $\text{m}^3/\text{kg}$ , and  $T$  is in K. Neglect any internal energy changes in the partition wall.

$$v_{N_2} = v = 0.01 \text{ m}^3$$

$$T_{\text{air}} = T_{N_2}$$

$$p v = 288 T$$

$$C_v = 742 \frac{\text{J}}{\text{kg K}}$$

$$p_{N_2} = 1580 \text{ kPa}$$

$$p_1 = 500 \text{ kPa}$$

$$T_1 = 473 \text{ K}$$

$$v_1 = 0.01 \text{ m}^3$$

$$N_2: p_2 = 1500 \text{ kPa}$$

$$v_2 = 0.01 \text{ m}^3$$



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$$m_{\text{air}} = \left( \frac{p_1 V_1}{288 T_1} \right)_{\text{air}} = \frac{500 \times 10^3 \times 0.01}{288 \times 473} = 0.036 \text{ kg}$$

$$\Delta U_{\text{air}} = m_{\text{air}} \times C_{v,\text{air}} \times \Delta T_{\text{air}} = 0.036 \times 742 \times (498.2 - 473) = 686 \text{ J}$$

$$8Q = dU + \delta W$$

$$\delta W = 8Q - dU = -2000 - 686$$

$${}_1W_2 = -2686 \text{ J}$$



$$\frac{p_1 V_1}{T_1} = 288$$

$$N_2: \frac{1500 \text{ kPa} \times 0.01 \text{ m}^3}{473} = \frac{1580 \text{ kPa} \times 0.01 \text{ m}^3}{T_2}$$

$$T_{2,N_2} = \frac{1580 \times 473}{1500} = 498.2 \text{ K}$$

$$T_{2,\text{air}} = 498.2 \text{ K}$$

$$m_{N_2} = ? \quad \frac{p_1 V_1}{T_1} = 288 T_1$$

$$\frac{p_1 V_1}{m} = 288 T_1$$

$$\Rightarrow m = \frac{p_1 V_1}{288 T_1} = \frac{1500 \times 10^3 \times 0.01 \text{ m}^3}{288 \times 473}$$

$$m = 0.11 \text{ kg}$$

$$\Delta U = 0.11 \times 742 \times (498.2 - 473)$$

$$\Delta U = 2 \text{ kJ}$$

$${}_1Q_2 = 2 \text{ kJ}$$

First law  
air:  $dU = \delta Q - \delta W$

$N_2: dU = \delta Q - \frac{\delta W}{\rho}$

$dU = \delta Q$

${}_1Q_2 = \Delta U$

$\Delta U = m C_v \Delta T$



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$$V_{N_2} = v = 0.01 \text{ m}^3$$

$$T_{\text{air}} = T_{N_2}$$

$$p_1 = 500 \text{ kPa}$$

$$T_1 = 473 \text{ K}$$

$$V_1 = 0.01 \text{ m}^3$$

$$p_2 = 1500 \text{ kPa}$$

$$V_2 = 0.01 \text{ m}^3$$

$$p_{N_2} = 1580 \text{ kPa}$$

