

**Problem 1:** A closed system contains 1 mol of nitrogen (molar mass of  $28 \text{ g.mol}^{-1}$ ). Using the ideal gas law ( $PV^t = nRT$ ), calculate the missing *PVT* parameter for the following data given. Give your results in **SI units**. The universal gas constant is  $R = 8.314 \text{ J.mol}^{-1}.\text{K}^{-1}$ .

- (a)  $P = 1 \text{ atm}, T = 0^\circ\text{C}$
- (b)  $V^t = 12.85 \text{ ft}^3; T = 59^\circ\text{F}$
- (c)  $P = 2.5 \times 10^9 \text{ g.m}^{-1}.\text{s}^{-2}; T = 650.50^\circ\text{R}$
- (d)  $V^t = 1.3 \times 10^{-12} \text{ Gl}; P = 500 \text{ psi}$

**Problem 2:** In a coal-fired power station water-steam system is used to produce electricity. Determine the enthalpy ( $\text{kJ.kg}^{-1}$ ) and entropy ( $\text{kJ.kg}^{-1}.\text{K}^{-1}$ ) of the system under the following conditions (a-h):

Pressure (bar)	Temperature	Enthalpy	Entropy	State
		$\text{kJ.kg}^{-1}$	$\text{kJ.kg}^{-1}.\text{K}^{-1}$	
160.0	720.65 K	(a)	(b)	(c)
38.2	–	(d)	(e)	liquid water
140.0	440.00°C	(f)	(g)	(h)

**Problem 3:** The *Angel Falls* in Venezuela are the world's highest waterfalls ( $\sim 1000 \text{ m}$ ). Take the amount of 1 kg of water as the system flowing over the waterfall. Assume that it does not exchange energy with its surroundings.

- (a) Calculate the potential energy of the water at the top of the falls with respect to the base of the falls. Assume gravity acceleration as  $9.81 \text{ m.s}^{-2}$ .
- (b) What is the energy balance that applies during the water falling down? What is the kinetic energy of the water just before it strikes down?
- (c) When striking down the energy is converted to internal energy. Calculate the temperature change with the heat capacity  $4184 \text{ J.kg}^{-1}.\text{K}^{-1}$ .

**Problem 4:** A hydroturbine operates with a head of 160 ft of water. Inlet and outlet conduits are 78.74 inches in diameter. Calculate the maximum mechanical power (in kW) that can be developed by the turbine for an inlet velocity of  $18 \text{ km.h}^{-1}$ .

**Problem 5:** Given  $Ar$  at  $P_1 = 140 \text{ kPa}, T_1 = 10^\circ\text{C}, V_1 = 200 \text{ liters}$  which undergoes a polytropic compression to  $P_2 = 700 \text{ kPa}, T_2 = 180^\circ\text{C}$ , find  $Q_{1-2}$ . Given  $MW = 39.948 \text{ kg.kgmole}^{-1}$ ,  $R = 0.2081 \text{ kJ.kg}^{-1}.\text{K}^{-1}$  and  $C_V = 0.312 \text{ kJ.kg}^{-1}.\text{K}^{-1}$ .

**Problem 6:** Given air (assuming ideal gas behaviour) expanding reversibly and adiabatically from  $T_1 = 450K$  and  $V_1 = 3.0 \times 10^{-3}m^3$  to the final volume,  $V_2 = 5.0 \times 10^{-3}m^3$ .  $T$  and  $V$  relationship for constant heat capacities is represented by  $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$ .

- Derive a relationship between  $T$  and  $P$ ; Assuming that  $C_p = 5.0 \text{ cal. (mol.K)}^{-1}$  and  $C_v = 3.0 \text{ cal. (mol.K)}^{-1}$ ;
- Calculate  $T_2$ ;
- Calculate the work done during the process and;
- Determine the enthalpy change.

**Problem 7:** Gaseous  $\text{CO}_2$  ( $m_{\text{CO}_2} = 4g$ ) is contained in a vertical piston-cylinder assembly by a piston of mass 50 kg and having a face area of  $1.0 \times 10^{-2}\text{m}^2$ . The  $\text{CO}_2$  initially occupies a volume of  $5 \times 10^{-3}\text{m}^3$  and has a specific internal energy of  $657 \text{ kJ.kg}^{-1}$ . The atmosphere exerts a pressure of 100 kPa on the top of the piston. Heat transfer in the amount of 1.95 kJ occurs slowly from the  $\text{CO}_2$  to the surroundings, and the volume of the  $\text{CO}_2$  decreases to  $2.5 \times 10^{-3}\text{m}^3$ . Friction between the piston and the cylinder wall can be neglected. The local acceleration of gravity is  $9.81 \text{ m.s}^{-2}$ . For the  $\text{CO}_2$ , determine (a) the pressure in kPa and (b) the final specific internal energy in  $\text{kJ.kg}^{-1}$ .

**Problem 8:** CO gas contained within a piston-cylinder assembly undergoes three processes in series:

- Process 1-2: expansion from  $p_1 = 5 \text{ bar}$ ,  $V_1 = 0.2 \text{ m}^3$  to  $V_2 = 1.0 \text{ m}^3$ , during which the pressure-volume relationship is  $pV = \text{constant}$ .
- Process 2-3: constant volume heating from state 2 to state 3, where  $p_3 = 5 \text{ bar}$ .
- Process 3-1: constant pressure compression to the initial state.

Sketch the processes in series on p-V coordinates and evaluate the work for each process, in kJ.

# Tutorial 03

Problem 1:

$$PV = mRT$$

$$R = 8.314 \text{ J/mol.K}$$

$$m = 1 \text{ mol}$$

(a)  $P = 1 \text{ atm}$ ;  $T = 0^\circ\text{C} \therefore V^t = ?$

$$V^t = \frac{mRT}{P} = \frac{1 \text{ mol} \times 8.314 \frac{\text{J}}{\text{mol.K}} \times (0 + 273.15) \text{ K}}{1 \text{ atm}} \times \frac{1}{101325 \times 10^3 \text{ Pa}} \times \frac{1 \text{ Pa}}{1 \text{ N/m}^2}$$

$$\downarrow$$
  
$$V^t = 2270.9693 \frac{\text{J}}{\text{atom}} \times \frac{1 \text{ N.m}}{1 \text{ J}} \times \frac{1 \text{ atm}}{1.01325 \times 10^5 \text{ Pa}} \times \frac{1 \text{ Pa}}{1 \text{ N/m}^2}$$

$$\begin{bmatrix} \text{[m}^3\text{]} \\ (\text{SI}) \end{bmatrix} \boxed{V^t = 2.2413 \times 10^{-2} \text{ m}^3}$$

(b)  $V^t = 12.85 \text{ ft}^3$ ;  $T = 59^\circ\text{F} \therefore P = ?$

$$\hookrightarrow 288.15 \text{ K}$$

$$P = \frac{mRT}{V^t} = \frac{1 \text{ mol} \times 8.314 \frac{\text{J}}{\text{mol.K}} \times 288.15 \text{ K}}{12.85 \text{ ft}^3} \times \frac{1}{101325 \times 10^3 \text{ Pa}}$$

$$\downarrow$$
  
$$P = 186.43 \frac{\text{J}}{\text{ft}^3} \times \frac{35.313 \text{ ft}^3}{1 \text{ m}^3} \times \frac{1 \text{ N.m}}{1 \text{ J}} = \boxed{\begin{array}{l} 6583.40 \text{ N/m}^2 \\ = 6.58 \text{ kPa} \end{array}}$$

$$\boxed{[\text{Pa} = \text{N/m}^2]}$$

(c)  $P = 2.5 \times 10^9 \text{ g/m.s}^2$ ;  $T = 650.50^\circ\text{R} \therefore V^t = ?$

$$\hookrightarrow 363.39 \text{ K}$$

$$V^t = \frac{mRT}{P} = 1\text{mol} \times 8.314 \frac{\text{J}}{\text{mol.K}} \times 361.39 \text{K} \times \frac{1}{2.5 \times 10^9 \frac{\text{g}}{\text{m.s}^2}}$$

$$V^t = 1.2018 \times 10^{-6} \frac{\text{J}}{\text{g.m.s}^2} \times \frac{1\text{N.m}}{1\text{J}} \times \frac{1\text{Kg m/s}^2}{1\text{N}} \times \frac{1000\text{g}}{1\text{Kg}}$$

↓

$$[m^3] \quad \boxed{V^t = 1.2018 \times 10^{-3} m^3}$$

(d)  $V^t = 1.3 \times 10^{-12} \text{Gl}; P = 500 \text{ psi} \therefore T = ?$

$$T = \frac{PV}{mR} = 500 \text{ psi} \times 1.3 \times 10^{-12} \text{Gl} \times \frac{1}{1\text{mol}} \times \frac{1}{8.314 \frac{\text{J}}{\text{mol.K}}}$$

↓

$$[K] \quad T = 7.8181 \times 10^{-11} \frac{\text{psi.Gl.K}}{\text{J}} \times \frac{1\text{N/m}^2}{1.4504 \times 10^{-4} \text{psi}} \times \frac{10^9 \text{J}}{1\text{Gl}} \times$$

$$\times \frac{10^{-3} m^3}{1\text{L}} \times \frac{1\text{J}}{1\text{N.m}}$$

$$\boxed{T = 0.5390 \text{ K}}$$

## Problem 2 :

(1) At 160 bar, the saturation temperature ( $T_{sat}$ ) is  $347.4^\circ\text{C} \ll T = 720.65\text{K} (= 447.50^\circ\text{C})$ . Thus the water is at superheated steam state (c). From the superheated steam table (SST) at 160 bar,

	440°C	480°C	
$h$ (kJ/kg)	3103.7	3234.4	But we want to determine $h^*$ and $s$ at 447.50°C therefore we need
$s$ (kJ/kg.K)	6.0429	6.2215	

To perform a linear interpolation between 440°C and 480°C:

$$\frac{\frac{T_2 - T_1}{(480 - 440)}^{\circ\text{C}}}{\frac{T_2 - T^*}{(480 - 447.50)}^{\circ\text{C}}} = \frac{\frac{h_2 - h_1}{(3234.4 - 3103.7) \text{ kJ/kg}}}{\frac{(3234.4 - h^*)}{(3234.4 - h^*) \text{ kJ/kg}}}$$

$$(480 - 447.50)(3234.4 - 3103.7) = (480 - 440)(3234.4 - h^*)$$

$$\boxed{h^* = 3128.21 \text{ kJ/kg}} \quad (\text{a})$$

Now using the same procedure for entropy:

$$(480 - 440)^\circ\text{C} \quad (6.0015 - 6.0429) \text{ kJ/kg.K}$$

$$(480 - 447.50)^\circ\text{C} \quad (6.2285 - S^*) \text{ kJ/kg.K}$$

$$S^* = 6.0764 \text{ kJ/kg.K} \quad (\text{b})$$

(2) At 38.2 bar and considering that the fluid is liquid, we obtain from the saturated water (liquid-vapor) table:

P(bar)	Enthalpy (kJ/kg)		Entropy (kJ/kg.K)	
	$h_f$	$h_g$	$S_f$	$S_g$
35	1049.8	2803.4	2.7253	6.1253
40	1087.3	2805.4	2.7964	6.0705

Enthalpy and entropy of liquid water at 38.2 bar can be obtained through linear interpolation

$$(40 - 35) \text{ bar} \quad (1087.3 - 1049.8) \text{ kJ/kg}$$

$$(40 - 38.2) \text{ bar} \quad (1087.3 - h^*) \text{ kJ/kg}$$

$$h^* = 1073.8 \text{ kJ/kg} \quad (\text{a})$$

Similarly for entropy

$$(S^* = 2.7708 \text{ kJ/kg.K}) \quad (e)$$

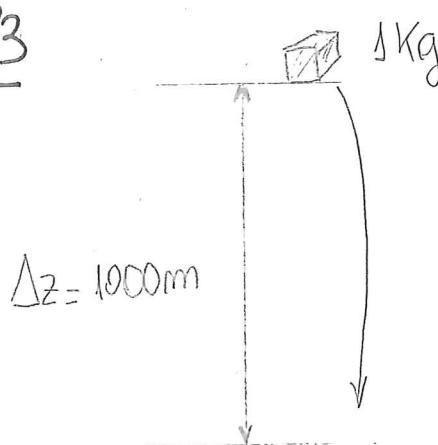
(3) At 140 bar, the saturation temperature ( $T_{\text{sat}}$ ) is  $336.8^\circ\text{C} \ll T = 440^\circ\text{C}$ , therefore <sup>The</sup> water is at superheated steam state (h). From SST (by simple inspection):

$$h^* = 3142.2 \text{ kJ/kg} \quad (f)$$

$$S^* = 6.1474 \text{ kJ/kg.K} \quad (g)$$

P3

6



(a)  $E_p \leftarrow \text{potential energy}$

$$(a) E_p = m \cdot g \cdot \Delta z$$

$$E_p = 1 \text{ Kg} \times 9.81 \frac{\text{m}}{\text{s}^2} \times 1000 \text{ m}$$

$$E_p = 9810 \frac{\text{kg} \cdot \text{m}^2}{\text{s}^2} = 9.81 \text{ kJ}$$

$$\text{N} \cdot \text{m} = \text{J}$$

internal energy  
Kinetic energy

(b)  $\Delta U + \Delta E_p + \Delta E_k = 0$  (energy conservation)

↳ during fall down:  $\Delta U = 0$

$$E_p + E_k = \text{const.} \Rightarrow E_p(z) + E_k(z) = E_p(\Delta z)$$

Just before hitting the bottom:  $z = 0$

$$E_k = E_p(\Delta z) = 9.81 \text{ kJ}$$

(c)  $E_k = \Delta U$

$$\Delta U = m C_p \Delta T = Q$$

$$\Delta T = \frac{\Delta U}{m C_p} = \frac{9810 \text{ J}}{1 \text{ Kg} \times 4184 \frac{\text{J}}{\text{K}}} \therefore \Delta T = 234 \text{ K}$$

P4

$$\left\{ \begin{array}{l} \Delta z = 160 \text{ ft} \\ \rho_{\text{water}} = 1000 \text{ kg/m}^3 \\ D = 78.74 \text{ in} \\ v = 18 \text{ km/h} \end{array} \right.$$

The mechanical power can be defined here as,

$$\dot{\omega} = \dot{m} g \Delta z \quad [\text{KW}]$$

Thus, we first need to calculate

the mass flow rate:

$$\dot{m} = \rho v A = 1000 \frac{\text{kg}}{\text{m}^3} \times \frac{18 \frac{\text{km}}{\text{h}}}{\frac{1}{4} \pi D^2} \times \frac{\pi \times (78.74 \text{ in})^2}{3.1415}$$

converting units to S.I.:

$$\dot{m} = \frac{1000 \text{ kg}}{\text{m}^3} \times \frac{18 \frac{\text{km}}{\text{h}}}{\frac{1}{4} \pi} \times 78.74^2 \frac{\text{in}^2}{\text{m}^2} \times \frac{1000 \text{ m}}{1 \text{ km}} \times \frac{6.452 \times 10^{-4} \frac{\text{m}^2}{\text{s}}}{1 \text{ min}^2} \times \frac{1 \text{ k}}{3600 \text{ s}}$$

$$\dot{m} = 15708.41 \text{ kg/s}$$

The power is thus,

$$\dot{\omega} = 15708.41 \frac{\text{kg}}{\text{s}} \times 9.81 \frac{\text{m}}{\text{s}^2} \times 160 \frac{\text{ft}}{\text{s}} \times \frac{0.3048 \text{ m}}{1 \text{ ft}}$$

$$\dot{\omega} = 7515124.52 \frac{\text{kg} \cdot \text{m}^2}{\text{s}^3} \times \frac{1 \text{ J}}{1 \text{ Nm}} \times \frac{1 \text{ W}}{1 \text{ Nm/s}}$$

$$\dot{\omega} = 7515124.52 \text{ J/s} = 7515.12 \text{ kW}$$

P5

$$\text{Air} \left\{ \begin{array}{l} P_1 = 140 \text{ kPa} \\ T_1 = 10^\circ\text{C} \\ V_1 = 200 \text{ l} \end{array} \right. \xrightarrow[\text{expansion}]{\text{polytropic}} \left\{ \begin{array}{l} P_2 = 700 \text{ kPa} \\ T_2 = 180^\circ\text{C} \end{array} \right.$$

$$Q_{12} = ?$$

$$\text{From the 1st law } \Delta U = U_2 - U_1 = Q_{12} - W_{12}$$

For ideal gases, we need to calculate  $\Delta U = \Delta U(\Delta T)$  and we can easily compute  $W_{12}$  from its definition as  $\int_{V_1}^{V_2} P dV$ . Using the following data for noble gas Argon:

$$MW = 39.948 \text{ kg/mol} ; C_V = 0.312 \text{ kJ/kg.K}$$

The mass of Argon can be calculated from state 1:

$$m = \frac{m}{MW} = \frac{P_1 V_1}{RT_1} \therefore m = \frac{P_1 V_1}{RT_1} \times MW$$

$$m = \frac{140 \text{ kPa} \times 200 \text{ l}}{\frac{8.314 \text{ kJ}}{\text{mol.K}} \times 283.15 \text{ K}} \times \frac{39.948 \text{ kg}}{\text{mol}} \times \frac{1000 \text{ Pa}}{1 \text{ kPa}} \times \frac{1 \text{ N/m}^2}{1 \text{ Pa}} \times \frac{1 \text{ K}}{1000}$$

$$[kg] \times \frac{1 \text{ J}}{1 \text{ kJ}} \times \frac{10^{-3} \text{ m}^3}{1 \text{ l}} = 0.475 \text{ kg}$$

Now, the volume at state 2:

$$P_2 \sqrt{2} = \frac{m}{MW} RT_2$$

$$\begin{aligned} V_2 &= \frac{m}{MW} \frac{RT_2}{P_2} = \frac{0.4751 \text{ kg}}{39.948 \text{ kg/mol}} \times 8.314 \frac{\text{J/K}}{\text{mol.K}} \times 463.15 \text{ K} \times \frac{1}{700 \text{ kPa}} \times \frac{1 \text{ kPa}}{1000 \text{ Pa}} \times \\ &\quad \times \frac{1 \text{ Pa}}{10^5 \text{ N/m}^2} \times \frac{1000 \text{ J} \times 1 \text{ km}}{1 \text{ N} \times 1 \text{ J}} = 6.40 \times 10^{-2} \text{ m}^3 \end{aligned}$$

Now, for polytropic processes,

$$P_i V_i^n = \text{constant} = C$$

$$\frac{P_1}{P_2} = \left( \frac{V_2}{V_1} \right)^n$$

$$\ln(P_1/P_2) = \ln(V_2/V_1)^n$$

$$n = \frac{\ln(P_1/P_2)}{\ln(V_2/V_1)} = 1.412$$

Thus, the work in polytropic processes can be described as

$$W_{12} = \int_{V_1}^{V_2} P dV = \int_{V_1}^{V_2} \frac{C}{V^n} dV = \frac{C}{1-n} \left[ V^{1-n} \right]_{V_1}^{V_2}$$

$$W_{12} = \frac{C}{1-n} \left[ V_2^{1-n} - V_1^{1-n} \right]$$

$$\text{As } Q = P_1 V_1^n = P_2 V_2^n$$

$$W_{s2} = \frac{P_2 V_2^n \sqrt[1-n]{V_2} - P_1 V_1^n \sqrt[1-n]{V_1}}{1-n} = \frac{P_2 \sqrt{V_2} - P_1 \sqrt{V_1}}{1-n}$$

$$W_{s2} = \frac{1}{1-1.412} \left[ (700 \times 6.40 \times 10^{-2}) - (140 \times 2 \times 10^{-3}) \right] \text{ kPa.m}^3 \times \\ \times \frac{1000 \text{ Pa}}{1 \text{ MPa}} \times \frac{1 \text{ N/mm}^2}{1 \text{ Pa}} \times \frac{1 \text{ J}}{1 \text{ Nm}} = -40776.70 \text{ J}$$

$$W_{s2} = -40.78 \text{ kJ}$$

The work is negative  $\Rightarrow A_C$  was worked upon in compression.  
From the 1st law,

$$U_2 - U_1 = Q_{s2} - W_{s2}$$

$$Q_{s2} = U_2 - U_1 + W_{s2}$$

Assuming that  $A_C$  behaves like an ideal gas, i.e.,  $u = u(T)$  (with  $u = U/m$ )

$$\frac{du}{dT} = C_v \therefore du = C_v dT \therefore \Delta u = \frac{\Delta U}{m} = C_v \Delta T$$

$$\text{Thus, } Q_{s2} = m C_v (T_2 - T_1) + W_{s2}$$

$$Q_{s2} = 0.475 \text{ kg} \times 0.312 \frac{\text{kJ}}{\text{kg.K}} \times 170 \text{ K} + (-40.78 \text{ kJ}) = -15.58 \text{ kJ}$$

heat was lost from the system although temperature increased. This is because the rise in internal energy was mainly due to work.

P6

$$\left. \begin{array}{l} T_1 = 450K \\ V_1 = 3 \times 10^{-3} m^3 \end{array} \right\} \Rightarrow V_2 = 5 \times 10^{-3} m^3$$

The total change in energy,  $\Delta E$ , can be split into

$$\Delta E = \Delta E_k + \Delta E_p + \Delta U = Q - W$$

↑                      ↑                      ↑  
 Kinetic      potential      internal  
 energy        energy        energy

Assuming that in the expansion process, Kinetic and potential energies do not change

$$\Delta E = \Delta U = Q - W$$

In differential form

$$dU = dQ - dW$$

As the process is adiabatic, i.e.,  $dQ = 0$

$$dU = -dW = -PdV$$

Since the gas is ideal,  $dU = C_V dT = -PdV$  and  $V = RT/P$ , and applying the chain rule to  $V = \sqrt{(T, P)}$

$$dV = \frac{\partial V}{\partial T} dT + \frac{\partial V}{\partial P} dP = \frac{R}{P} dT - \frac{RT}{P^2} dP$$

Thus replacing  $dV$ ,

$$C_V dT = -P dV = -P \left[ \frac{R}{P} dT - \frac{RT}{P^2} dP \right]$$

$$C_V dT = -R dT + \frac{RT}{P} dP$$

Since  $C_p - C_v = R$ , replacing  $C_V$  in the equation above

$$C_p dT = \frac{RT}{P} dP$$

$$\frac{dT}{T} = \frac{R}{C_p} \frac{dP}{P} = \frac{C_p - C_v}{C_p} \frac{dP}{P} = \frac{\gamma - 1}{\gamma} \frac{dP}{P} \quad (\gamma = C_p/C_v)$$

Now integrating from state 1 to 2:

$$\ln \frac{T_2}{T_1} = \left( \frac{\gamma - 1}{\gamma} \right) \ln \frac{P_2}{P_1}$$

$$\frac{T_2}{T_1} = \left( \frac{P_2}{P_1} \right)^{\frac{\gamma - 1}{\gamma}} \quad (\underline{a})$$

(b)  $T_2$  is obtained from (see lecture notes)

$$\frac{T_2}{T_1} = \left( \frac{V_1}{V_2} \right)^{\gamma - 1} \therefore \frac{T_2}{450K} = \left( \frac{3 \times 10^{-3} m^3}{5 \times 10^{-3} m^3} \right)^{\frac{5 \text{ cal}/\text{mol}\cdot K - 1}{3 \text{ cal}/\text{mol}\cdot K}}$$

$$T_2 = 320.12 K$$

The work done during the process is

13

$$W = -\Delta U = -C_V \Delta T = -\frac{3 \text{ cal}}{\text{mol.K}} (320.12 - 450) \text{ K}$$

$$W = 389.64 \text{ cal/mol} \times \frac{4.186 \text{ J}}{1 \text{ cal}}$$

$$W = 1631.03 \text{ J/mol} \quad (\text{c})$$

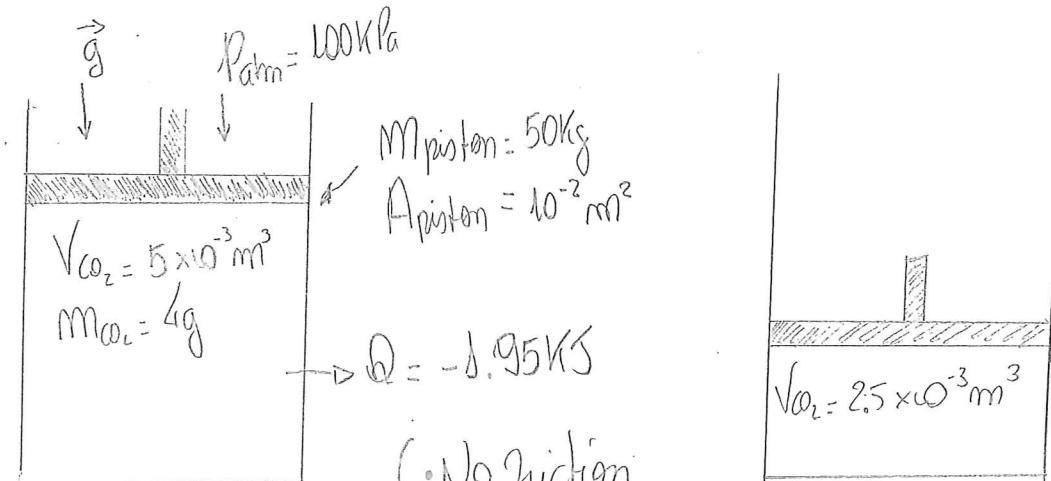
↳  $W > 0$  indicates that in the expansion process, work is done by the system.

(d) The enthalpy change of the gas can be calculated as,

$$\Delta H = C_p \Delta T = 5 \frac{\text{cal}}{\text{mol.K}} \times (320.12 - 450) \text{ K} \times \frac{4.186 \text{ J}}{1 \text{ cal}}$$

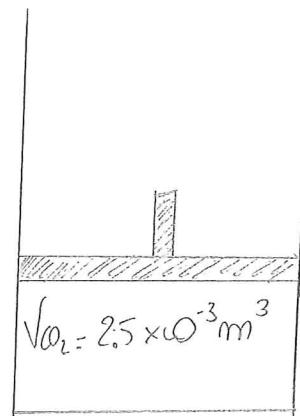
$$\Delta H = -2718.39 \text{ J/mol}$$

P7

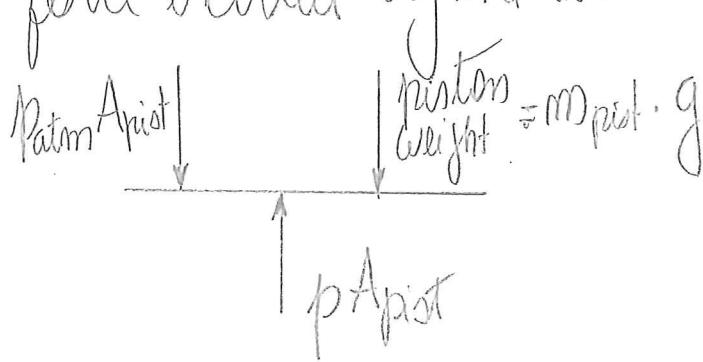


$$\Rightarrow Q = -1.95 \text{ kJ}$$

- {  
• No friction  
(piston x cylinder)  
•  $g = 9.8 \text{ m s}^{-2}$



Let's assume that potential and kinetic energy are negligible. Then, as there is no friction and the piston is NOT accelerated, the force exerted by the  $\text{CO}_2$  in the cylinder on the bottom of the piston is equal to the weight of the piston + the force exerted by the atmosphere on the top of the piston:



The force balance at the surface of the piston is:

$$p A_{piston} = p_{atm} A_{piston} + M_{piston} g \times (1/A_{piston})$$

$$p = p_{atm} + \frac{M_{piston}}{A_{piston}} g = 100 \text{ kPa} + \frac{50 \text{ kg}}{10^{-2} \text{ m}^2} \times \frac{9.8 \text{ m/s}^2}{\text{N/m}^2} \times \frac{1 \text{ Pa}}{\text{N}} \times \frac{1 \text{ N}}{1 \text{ kg m/s}^2} \times \frac{1 \text{ kPa}}{1000 \text{ Pa}}$$

$$p = 149.05 \text{ kPa} \quad (\text{a})$$

$$(b) V_1 = 5 \times 10^{-3} \text{ m}^3 \quad V_2 = 2.5 \times 10^{-3} \text{ m}^3$$

$$U_1 = 657 \text{ kJ/kg} \quad \Rightarrow \quad U_2 = ?$$

15

The work can be calculated through (assuming constant pressure)

$$W_{12} = \int_{V_1}^{V_2} p dV = p(V_2 - V_1) = 149.05 \text{ kPa} \times (2.5 - 5) \times 10^{-3} \text{ m}^3 \times \frac{1000 \text{ Pa}}{1 \text{ kPa}} \times \frac{1 \text{ J}}{1 \text{ Nm}} \times \frac{1 \text{ J}}{1 \text{ Nm}} = -372.63 \text{ J}$$

The energy balance for  $\text{CO}_2$ :

$$\Delta U = Q - W = -1.95 \times 10^3 \text{ J} - (-372.63) \text{ J}$$

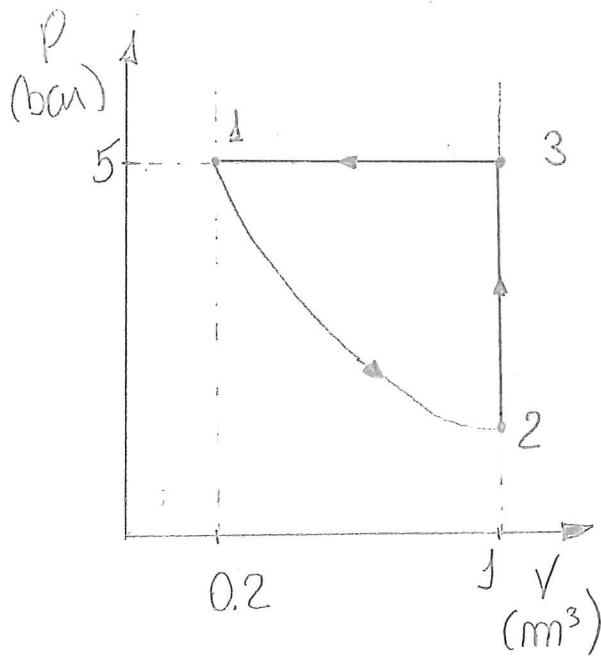
$$\Delta U = -1577.25 \text{ J}$$

$$\text{Then with } \Delta U = m(U_2 - U_1) \therefore U_2 = \frac{\Delta U}{m} + U_1$$

$$U_2 = \frac{-1577.25 \text{ J}}{4 \times 10^{-3} \text{ kg}} + 657 \times 10^3 \frac{\text{ J}}{\text{ kg}}$$

$$U_2 = 262687.5 \frac{\text{ J}}{\text{ kg}} = 262.69 \frac{\text{ kJ}}{\text{ kg}}$$

P8



(a) 1-2:  $PV = \text{constant} = \frac{K}{V}$

$$P = K/V$$

$$\begin{aligned} W_{12} &= \int_{V_1}^{V_2} P dV = \int_{V_1}^{V_2} \frac{K}{V} dV = \\ &= K \ln \frac{V_2}{V_1} = P_1 V_1 \ln \frac{V_2}{V_1} \\ &= 5 \text{ bar} \times 0.2 \text{ m}^3 \times \ln \frac{1}{0.2} \end{aligned}$$

$$\begin{aligned} W_{12} &= 1.609 \text{ bar} \cdot \text{m}^3 \times \frac{10^5 \text{ N/m}^2}{1 \text{ bar}} \times \\ &\quad \times \frac{\Delta J}{\Delta N \text{ nm}} \end{aligned}$$

$$W_{12} = 1.63 \times 10^5 \text{ J}$$

$W_{23} = 0$

c) 3-1:  $W_{31} = \int_{V_3}^{V_1} P dV$

As pressure is constant between  
3-1 (i.e.,  $P_3 = P_1 = 5 \text{ bar}$ )

$$W_{31} = P_1 (\sqrt{V_1} - \sqrt{V_3}) = 5 \text{ bar} (0.2 - 1) \text{ m}^3 \times \frac{10^5 \text{ N/m}^2}{1 \text{ bar}} \times \frac{\Delta J}{\Delta N \text{ nm}}$$

$$W_{31} = -4 \times 10^5 \text{ J}$$