

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

- (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 (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 kJ.kg^{-1}	Entropy $\text{kJ.kg}^{-1}.\text{K}^{-1}$	State
160.0	733.15 K	(a)	(b)	(c)
37.5	–	(d)	(e)	liquid water
140.0	375.00°C	(f)	(g)	(h)

Problem 3: The *Angle Falls* in Venezuela are the worlds 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 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 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 $T_1 = 450\text{K}$ and $V_1 = 3.0 \times 10^{-3}\text{m}^3$ to the final volume, $V_2 = 5.0 \times 10^{-3}\text{m}^3$. T and V relationship for constant heat capacities is represented by $\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$.

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

Problem 7: Gaseous CO_2 ($m_{\text{CO}_2} = 4\text{g}$) 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 CO_2 initially occupies a volume of $5 \times 10^{-3}\text{m}^3$ and has a specific internal energy of 657kJ.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 CO_2 to the surroundings, and the volume of the 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 9.81m.s^{-2} . For the CO_2 , determine (a) the pressure in kPa and (b) the final specific internal energy in 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 01

P1 ($PV^t = nRT$) $n=1 \text{ gmol}$ $R=8.314 \text{ J/gmol.K}$

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

$$V^t = \frac{nRT}{P} = 1 \text{ gmol} \times 8.314 \frac{\text{J}}{\text{gmol.K}} \times (0+273.15)\text{K} \times \frac{1}{1 \text{ atm}}$$

$$V^t = 2270.9691 \frac{\text{J}}{\text{atm}} \times \frac{1 \text{ N.m}}{1 \text{ J}} \times \frac{1 \text{ atm}}{1.01325 \times 10^5 \text{ N/m}^2}$$

\downarrow
[m³] $V^t = 2.2412 \times 10^{-2} \text{ m}^3$

(b) $V^t = 12.85 \text{ ft}^3$; $T = 59^\circ\text{F} \therefore P = ?$
 $\hookrightarrow 288.15 \text{ K}$

$$P = \frac{nRT}{V^t} = 1 \text{ gmol} \times 8.314 \frac{\text{J}}{\text{gmol.K}} \times 288.15 \text{ K} \times \frac{1}{12.85 \text{ ft}^3}$$

$$P = 186.43 \frac{\text{J}}{\text{ft}^3} \times \frac{1 \text{ N.m}}{1 \text{ J}} \times \frac{1 \text{ ft}^3}{2.832 \times 10^{-2} \text{ m}^3}$$

\swarrow
[Pa = N/m²]

$$P = 6582.98 \text{ N/m}^2 = 6.58 \text{ kPa}$$

(c) $P = 2.5 \times 10^9 \text{ g/ms}^2$; $T = 650.50^\circ\text{R} \therefore V^t = ?$
 $\hookrightarrow 361.39 \text{ K}$

$$V^t = \frac{nRT}{P} = 1 \text{ gmol} \times 8.314 \frac{\text{J}}{\text{gmol.K}} \times 361.39 \text{ K} \times \frac{1}{2.5 \times 10^9 \frac{\text{g}}{\text{ms}^2}}$$

$$\downarrow \quad \sqrt{t} = 1.2018 \times 10^{-6} \frac{\cancel{\text{J}}}{\cancel{\text{g}}/\cancel{\text{m}}/\cancel{\text{s}}^2} \times \frac{1 \text{ N} \cdot \cancel{\text{m}}}{1 \cancel{\text{J}}} \times \frac{1 \cancel{\text{kg}} \text{ m}/\cancel{\text{s}}^2}{1 \cancel{\text{N}}} \times \frac{1000 \cancel{\text{g}}}{1 \cancel{\text{kg}}}$$

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

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

$$T = \frac{PV}{nR} = 500 \text{ psi} \times 1.3 \times 10^{-12} \text{ Gl} \times \frac{1}{\text{g/mol}} \times \frac{\text{g/mol} \cdot \text{K}}{8.3145}$$

$$\downarrow \quad T = 7.81814 \times 10^{-11} \cancel{\text{psi}} \times \cancel{\text{Gl}} \times \frac{\cancel{\text{K}}}{\cancel{\text{J}}} \times \frac{6.895 \times 10^3 \cancel{\text{N}}/\cancel{\text{m}}^2}{1 \cancel{\text{psi}}} \times \frac{10^3 \cancel{\text{L}}}{1 \cancel{\text{Gl}}} \times \frac{10^{-3} \text{ m}^3}{\cancel{\text{L}}} \times \frac{1 \cancel{\text{J}}}{1 \cancel{\text{Nm}}}$$

$$T = 0.5391 \text{ K}$$

P2

(1) At 160 bar, the saturation temperature (T_{sat}) is $347.4^\circ\text{C} \ll T = 733.15\text{ K} (= 460^\circ\text{C})$. Thus the water is at superheated steam (e) state.

The superheated steam table (SST) at 160 bar looks like:

	440	480
h (KJ/Kg)	3103.7	3234.4
s (KJ/Kg.K)	6.0429	6.2215

But we want h and s at 460°C .

A linear interpolation between 440 and 480°C

$$\frac{T_2 - T_1}{480 - 440} = \frac{h_2 - h_1}{3234.4 - 3103.7}$$

$$\frac{480 - 460}{480 - 440} = \frac{3234.4 - h^*}{3234.4 - 3103.7}$$

$$\frac{T_2 - T^*}{480 - 440} = \frac{h_2 - h^*}{3234.4 - 3103.7}$$

$$(3234.4 - h^*)(480 - 440) = (3234.4 - 3103.7)(480 - 460)$$

$$h^* = 3169.05 \text{ KJ/Kg (a)}$$

Using the same procedure for entropy (s):

$$s^* = 6.1322 \text{ KJ/Kg.K (b)}$$

(2) At 37.5 bar and considering that the fluid is liquid, the saturated water-steam table

gives:

P (bar)	h_f (KJ/kg)	s_f (KJ/kg.K)
35	1049.8	2.7253
40	1087.3	2.7964

By linear interpolation

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

$$(40-37.5) \text{ bar} \quad \text{---} \quad (1087.3 - h^*) \text{ KJ/kg}$$

$$(40-37.5) \text{ bar} \times (1087.3 - 1049.8) \text{ KJ/kg} = (40-35) \text{ bar} \times (1087.3 - h^*) \text{ KJ/kg}$$

$$\underline{h^* = 1068.55 \text{ KJ/kg}} \quad (d)$$

$$(40-35) \text{ bar} \quad \text{---} \quad (2.7964 - 2.7253) \text{ KJ/kg.K}$$

$$(40-37.5) \text{ bar} \quad \text{---} \quad (2.7964 - s^*) \text{ KJ/kg.K}$$

$$\underline{s^* = 2.7609 \text{ KJ/kg.K}} \quad (e)$$

(3) At 140 bar, the saturation temperature is $T_{\text{sat}} = 336.8^\circ\text{C} < T (= 375^\circ\text{C})$. Thus, the fluid is superheated steam^(h). From the superheated steam table

$T(^{\circ}\text{C})$	$h (\text{KJ/kg})$	$s (\text{KJ/kgK})$
360	2895.7	5.8361
400	3051.3	6.0747

Through linear interpolation:

$$(400 - 360)^{\circ}\text{C} \text{ — } (3051.3 - 2895.7) \text{ KJ/kg}$$

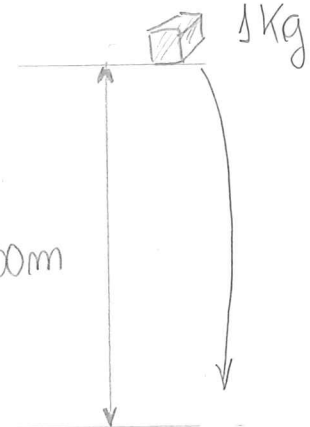
$$(400 - 375)^{\circ}\text{C} \text{ — } (3051.3 - h^*) \text{ KJ/kg}$$

$$\underline{h^* = 2954.05 \text{ KJ/kg} \quad (g)}$$

$$\underline{s^* = 5.9256 \text{ KJ/kgK} \quad (g)}$$

P3

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$$\Delta z = 1000 \text{ m}$$

potential energy

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

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

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

N.m = J

internal energy kinetic energy

$$(b) \Delta U + \Delta E_p + \Delta E_k = 0 \quad (\text{energy conservation})$$

$$\Leftrightarrow \text{during fall down: } \Delta U = 0$$

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

Just before hitting the bottom: $z = 0$

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

$$(c) E_k = \Delta U$$

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

$$\Delta T = \frac{\Delta U}{m c_p} = \frac{9810 \text{ J}}{1 \text{ kg} \times 4184 \frac{\text{J}}{\text{kg K}}} \therefore \Delta T = 2.34 \text{ K}$$

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

The mechanical power can be defined here as,

$$\dot{W} = \dot{m} g \Delta z \quad [\text{kW}]$$

Thus, we first need to calculate

the mass flow rate:

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

converting units to SI:

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

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

The power is thus,

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

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

$$\dot{W} = 7515124.52 \frac{\text{J}}{\text{s}} = 7515.12 \text{ kW}$$

P5

$$\text{Ar} \left\{ \begin{array}{l} P_1 = 140 \text{ kPa} \\ T_1 = 10^\circ\text{C} \\ V_1 = 200 \text{ l} \end{array} \right. \xrightarrow[\text{expansion}]{\text{polytropic}} \left\{ \begin{array}{l} P_2 = 700 \text{ kPa} \\ T_2 = 180^\circ\text{C} \end{array} \right. \quad \underline{8}$$

$$Q_{12} = ?$$

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:

$$MW = 39.948 \text{ kg/mol} ; C_v = 0.312 \text{ kJ/kg}\cdot\text{K}$$

The mass of Argon can be calculated from state 1:

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

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

\downarrow

[kg]

$$\times \frac{1 \text{ J}}{1 \text{ N}\cdot\text{m}} \times \frac{10^{-3} \text{ m}^3}{1 \text{ l}} = 0.4751 \text{ kg}$$

Now, the volume at state 2:

$$P_2 V_2 = \frac{m}{MW} RT_2$$

$$V_2 = \frac{m}{MW} \frac{RT_2}{P_2} = \frac{0.4751 \text{ kg}}{39.948 \frac{\text{kg}}{\text{mol}}} \times \frac{8.314 \frac{\text{kJ}}{\text{mol} \cdot \text{K}}}{1} \times 453.15 \text{ K} \times \frac{1}{700 \text{ kPa}} \times \frac{1 \text{ kPa}}{1000 \text{ Pa}} \times \frac{1000 \text{ J}}{1 \text{ kJ}} \times \frac{1 \text{ m}^3}{1 \text{ J}} = 6.40 \times 10^{-2} \text{ m}^3$$

Now, for polytropic processes,

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

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

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

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

Thus, the work in polytropic processes can be described as

$$W_{12} = \int_{V_1}^{V_2} P dV = \int_{V_1}^{V_2} \frac{C}{V^m} dV = \frac{C}{1-m} V^{(1-m)} \Big|_{V_1}^{V_2}$$

$$W_{12} = \frac{C}{1-m} [V_2^{(1-m)} - V_1^{(1-m)}]$$

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$$\text{As } C = P_1 V_1^m = P_2 V_2^m$$

$$W_{12} = \frac{P_2 V_2^m V_2^{1-m} - P_1 V_1^m V_1^{1-m}}{1-m} = \frac{P_2 V_2 - P_1 V_1}{1-m}$$

$$W_{12} = \frac{1}{1-1.412} \left[(700 \times 6.40 \times 10^{-2}) - (140 \times 2 \times 10^{-3}) \right] \text{ kPa} \cdot \text{m}^3 \times$$

$$\times \frac{1000 \text{ Pa}}{1 \text{ kPa}} \times \frac{1 \text{ N/m}^2}{1 \text{ Pa}} \times \frac{1 \text{ J}}{1 \text{ Nm}} = -40776.70 \text{ J}$$

$$W_{12} = -40.78 \text{ kJ}$$

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

$$U_2 - U_1 = Q_{12} - W_{12}$$

$$Q_{12} = U_2 - U_1 + W_{12}$$

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

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

Thus, $Q_{12} = m C_v (T_2 - T_1) + W_{12}$

$$Q_{12} = 0.4751 \text{ kg} \times 0.312 \frac{\text{kJ}}{\text{kg} \cdot \text{K}} \times 170 \text{ K} + (-40.78 \text{ kJ}) = -15.58 \text{ kJ}$$

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

P6

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

The total change in energy, ΔE , can be split into

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

$\begin{array}{ccc} \nearrow & \nearrow & \nwarrow \\ \text{kinetic} & \text{potential} & \text{internal} \\ \text{energy} & \text{energy} & \text{energy} \end{array}$

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

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

or in differential form

$$dU = dQ - dW$$

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

$$dU = -dW = -P dV$$

Since the gas is ideal, $dU = C_V dT = -P dV$ and $V = RT/P$,

and applying the chain rule to $V = V(T, P)$

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

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)

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

$$T_2 = 320.12 \text{ K}$$

The work done during the process is

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

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

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

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

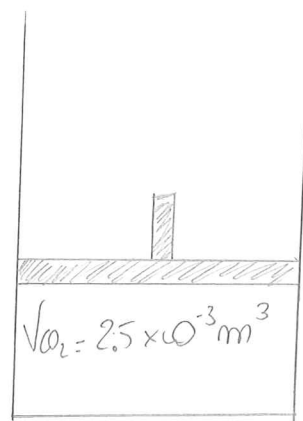
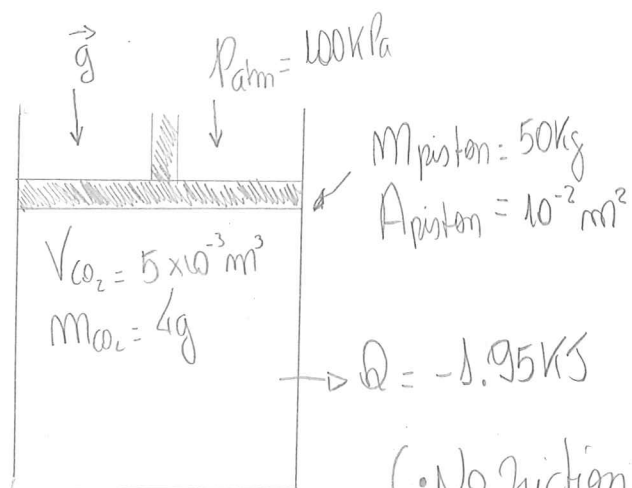
(d) The enthalpy change of the gas can be calculated as,

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

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

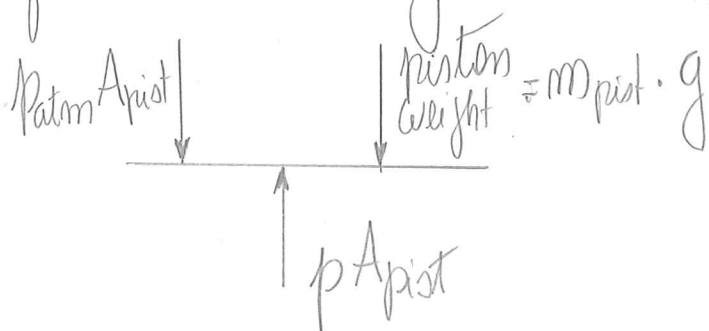
P7

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- No friction (piston \times cylinder)
- $g = 9.81 \text{ m/s}^2$

Let's assume that potential and kinetic energy are negligible. Also, as there is no friction and the piston is NOT accelerated, the force exerted by the CO_2 in the cylinder on the bottom of the piston is equal to the weight of the piston \oplus the force exerted by the atmosphere on the top of the piston:



The force balance at the surface of the piston is:

$$p A_{pist} = P_{atm} A_{pist} + m_{pist} g \times (1/A_{pist})$$

$$p = P_{atm} + \frac{m_{pist}}{A_{pist}} g = 100 \text{ kPa} + \frac{50 \text{ kg}}{10^{-2} \text{ m}^2} \times 9.81 \frac{\text{m}}{\text{s}^2} \times \frac{1 \text{ Pa}}{1 \text{ N/m}^2} \times \frac{1 \text{ N}}{1 \text{ kg} \frac{\text{m}}{\text{s}^2}} \times \frac{1 \text{ kPa}}{1000 \text{ Pa}}$$

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

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

$$u_1 = 657 \text{ kJ/kg}$$

$$V_2 = 2.5 \times 10^{-3} \text{ m}^3$$

$$u_2 = ?$$



The work can be calculated through (assuming constant pressure):

$$W_{12} = \int_{V_1}^{V_2} p dV = p(V_2 - V_1) = 149.05 \text{ kPa} \times (2.5 - 5) \times 10^{-3} \text{ m}^3 \times \frac{1000 \text{ Pa}}{1 \text{ kPa}} \times \frac{1 \text{ kJ/m}^2}{1 \text{ Pa}} \times \frac{1 \text{ J}}{1 \text{ kJ}} = -372.63 \text{ J}$$

The energy balance for CO_2 :

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

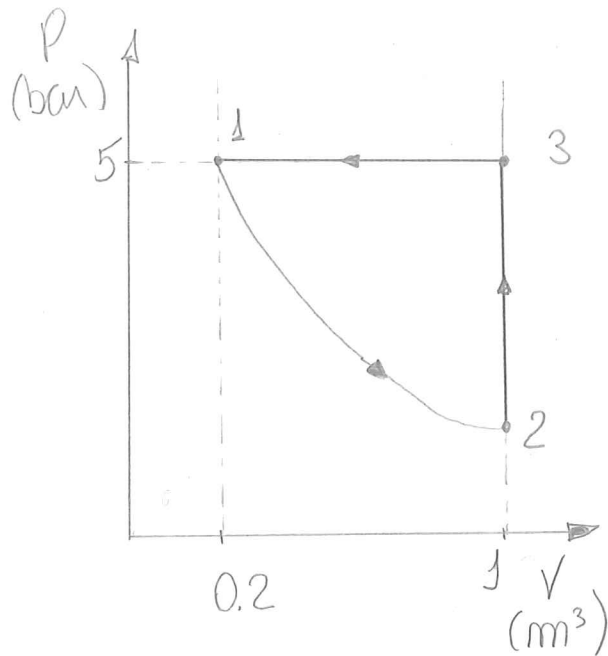
$$\Delta U = -1577.25 \text{ J}$$

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 : $PV = \text{constant} = \frac{16}{K}$

$$p = K/V$$

$$W_{12} = \int_{V_1}^{V_2} P dV = \int_{V_1}^{V_2} \frac{K}{V} dV =$$

$$= K \ln \frac{V_2}{V_1} = p_3 V_3 \ln \frac{V_2}{V_1}$$

$$= 5 \text{ bar} \times 0.2 \text{ m}^3 \times \ln \frac{1}{0.2}$$

$$W_{12} = 1.609 \text{ bar} \cdot \text{m}^3 \times \frac{10^5 \text{ N/m}^2}{1 \text{ bar}} \times$$

$$\times \frac{1 \text{ J}}{1 \text{ Nm}}$$

$$W_{12} = 1.61 \times 10^5 \text{ J} \times \frac{1 \text{ KS}}{1000 \text{ J}}$$

$$= 1.61 \times 10^2 \text{ KS}$$

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

As pressure is constant between

3-1 (i.e., $p_3 = p_1 = 5 \text{ bar}$)

$$W_{31} = p_1 (V_1 - V_3) = 5 \text{ bar} (0.2 - 1) \text{ m}^3 \times \frac{10^5 \text{ N/m}^2}{1 \text{ bar}} \times \frac{1 \text{ J}}{1 \text{ Nm}}$$

$$W_{31} = -4 \times 10^5 \text{ J} = -4 \times 10^2 \text{ KS}$$