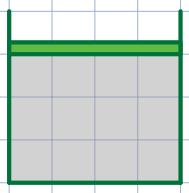
Piston-cylinder : air → compressed!
↳ ideal gas.



$V_1 = 0.4\,m^3$ $\quad V_2 = 0.1\,m^3$
$P_1 = 100\,kPa$ → $P_2 = ?$ ↑
$T_1 = 80°C$ $\quad T_2 = 80°C$ 등온과정 isothermal

· Determine the work done.

밀폐계 (closed system)

$W = m\int_1^2 P\,dv$ ← $w = \int P\,dv$ $\quad v = V/m$, $w = W/m$
$W = \int P\,dV$

$= m\int_1^2 RT/v\,dv$

air : ideal gas → $Pv = RT$
$P = RT/v$

$= mRT\int_1^2 1/v\,dv$

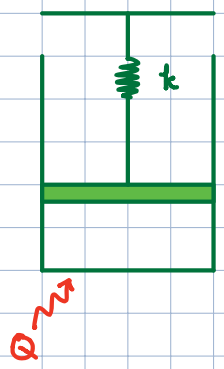
$= mRT\ln v_2/v_1$ ← $Pv = RT$ ← $v = V/m$
$PV/m = RT$
$PV = mRT = const$ $\quad P_1V_1 = P_2V_2 = const$

$= P_1V_1\ln v_2/v_1$

$= (100\,kPa)\cdot(0.4\,m^3)\cdot\ln\frac{0.1\,m^3}{0.4\,m^3}\,\frac{1\,kJ}{1\,kPa\cdot m^3}$ ← $v_2/v_1 = \frac{V_2/m}{V_1/m} = V_2/V_1$

$= -55.5\,kJ$ Ans.

A piston-cylinder (gas)



$V_1 = 0.05\,m^3$ → compress the spring until the volume doubles.

$P_1 = 200\,kPa$

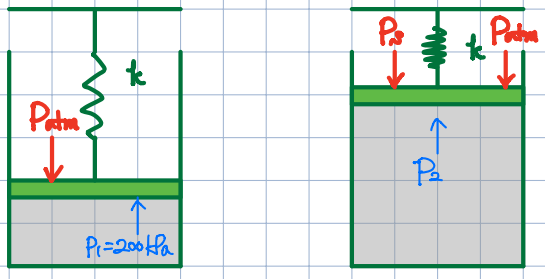
$k = 150\,kN/m$ $\qquad V_2 = 0.1\,m^3$

heat is transferred to the gas

$A = 0.25\,m^2$

(a) the final pressure
(b) the total work done by the gas
(c) the fraction of this work done against spring.

(a) initial 1. final 2.



$\Delta V = V_2 - V_1$

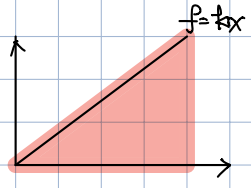
$P_s = F_s/A = kx/A \longleftarrow x = \Delta V/A = 0.05\,m^3/0.25\,m^2 = 0.2\,m$

$= \dfrac{(150\,kN/m)\cdot(0.2\,m)}{(0.25\,m^2)}$

$= 120\,kPa$

$P_1 = 200\,kPa = P_{atm}$ $\qquad P_2 = P_s + P_{atm} = 200 + 120 = 320\,kPa$ Ans.

(b) the total work done by the gas



$W_t = W_b + W_s$

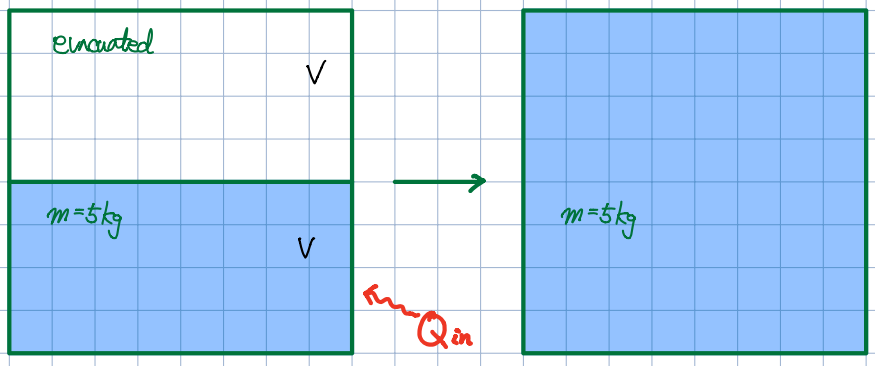
$= P_{atm}\cdot(V_2 - V_1) + \frac{1}{2}kx^2$

$= (200\,kPa)\cdot(0.05\,m^3)\cdot\dfrac{1\,kJ}{1\,kPa\cdot m^3} + \frac{1}{2}\cdot(150\,kN/m)\cdot(0.2\,m)^2$

$= 10\,kJ + 3\,kJ = 13\,kJ$ Ans.

$W_{spring} = 3\,kJ.$ Ans.

Rigid Tank (divided two equal parts)



$P_1 = 200\ kPa$
$T_1 = 25°C$

$T_f = 25°C$

(a) Determine the volume of tank.

(b) final pressure

(c) heat transfer ?

(a) Water

Sat. Water : Table > A-4 $T_1 = 25°C \longrightarrow v_f = 0.001003\ m^3/kg$

$P_{sat\ at\ 25°C} = 3.1698\ kPa \longleftrightarrow P_1 = 200\ kPa$

$V_t = 2 \times V = 2 \cdot v_f \times m$

$= 2 \cdot (0.001003\ m^3/kg) \cdot (5\ kg) \cdot \left(\frac{1000\ l}{1\ m^3}\right)$

$= 10.61\ l \approx 0.01\ m^3$ Ans.

(b) final pressure

$v_2 = V_2/m = \frac{0.01\ m^3}{5\ kg} = 0.002\ m^3/kg$

Table > A-4 $T_2 = 25°C \longrightarrow v_f = 0.001003\ m^3/kg$

$v_g = 43.340\ m^3/kg$

$v_f < v_2 < v_g$

$\longrightarrow$ lig-vapor mixture

$P = P_{sat\ at\ 25°C} = 3.1698\ kPa$ Ans.

(c) Q_{in} ?

$\Delta E = Q - W = \Delta U + \Delta KE + \Delta PE$

$Q_{in} = m(u_2 - u_1) \longrightarrow Q_{in} = (5kg) \cdot \{104.89 - 104.83\ kJ/kg\}$

$= 0.3\ kJ$ Ans.

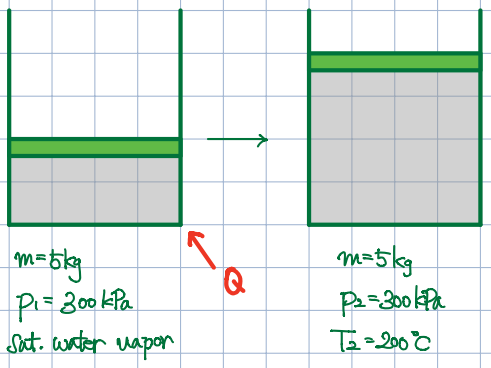
$u_2 = u_f + x_2 u_{fg} \longrightarrow x_2 = \frac{u_2 - u_f}{u_{fg}}$

Table > A-4 $T = 25°C \longrightarrow u_{fg} = 2304.3\ kJ/kg$

$u_f = 104.83$

$u_2 = u_f + x_2 \cdot u_{fg} = (104.83) + \frac{0.002 - 0.001003}{43.340} \cdot (2304.3)$

$= 104.89\ kJ/kg$



mass : 5 kg (Sat. water vapor) , 300 kP a

↓

(heated)

↓

p=const T_2 = 200°C

Calculate the work done by the steam

풀이 (closed system)

$$W = \int_1^2 p\,dV$$

$$= p\int_1^2 dV$$

$$= p(V_2 - V_1) \leftarrow p = 300\,kPa$$

1) p_1 = 300 kPa , Sat. water vapor → Table> A-5 v_g = 0.60582 m^3/kg

$$\therefore V_1 = v_g \cdot m = 3.03\ m^3$$

2) T_2 = 200°C → Table> A-4

P_{sat} = 1554.9 kPa

p_2 = 300 kPa $p_2 < P_{sat}$ → Superheated !

Table> A-6

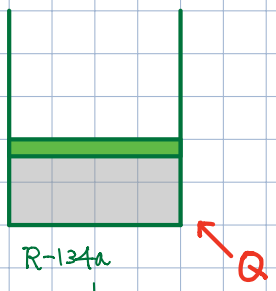
p_2 = 0.3MPa → v_2 = 0.71643

T_2 = 200°C $V_2 = v_2 m = 3.58215\ m^3$

$$\therefore W = p(V_2 - V_1) = (300kPa)\cdot(3.58215 - 3.03\ m^3)$$

$$= 165\ kJ$$

Ans.



frictionless piston-cylinder
50L , ref-134a (sat. liquid) → heated until T=70°C
p= 500 kPa

Calculate the work done during this process.

$W = p(V_2 - V_1)$

$V_1 = 50\,L \cdot \frac{1\,m^3}{1000\,L} = 0.05\,m^3$

$T_2 = 70°C \rightarrow$ Table A-11 $\quad p_{sat} = 2118.2\,kPa > p_2 = 500\,kPa$

Table A-13 $\quad p_2 = 500\,kPa,\ T_2 = 70°C \rightarrow v = 0.05243\,m^3/kg$

$p_1 = 500\,kPa$, sat. liquid → Table A-12 $\quad v_f = 0.0008059\,m^3/kg = v_1$

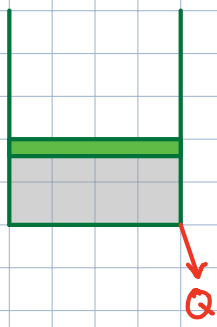
$v_1 = V_1/m \rightarrow m = V_1/v_1 = \frac{0.05\,m^3}{0.0008059\,m^3/kg}$

$= 62.04\,kg$

$W = mp(v_2 - v_1) = p(V_2 - V_1)$

$= (62.04\,kg)\cdot(500\,kPa)\cdot(0.05243 - 0.0008059)\,m^3/kg$

$= 1600\,kJ$ Ans.



Piston – cylinder (N_2)

$p_1 = 1\,MPa$, $T_1 = 427°C$ (isobaric process)

$\downarrow$

$T_2 = 27°C$

Q Determine the heat transfer (kJ/kg)

$$\Delta E_{sys} = Q - W = \Delta U + \Delta KE + \Delta PE$$

$$Q - (W_b) = \Delta U$$

$$Q = \Delta U + W_b$$
$$= \Delta H$$

$\delta q = du + pdV$ ← $u + pv = h$

$= dh - udp$

$\delta q = dh = C_p dT$

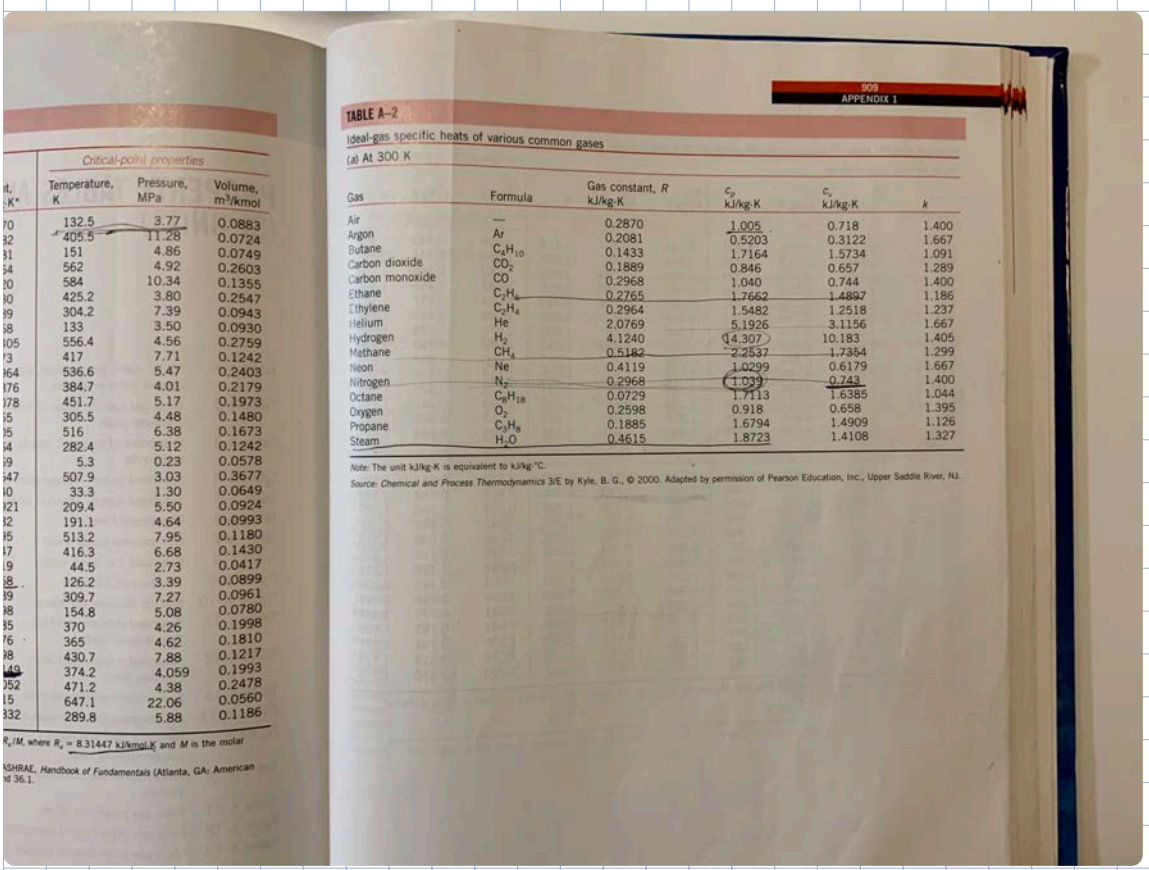
$q = \Delta h = C_p (T_2 - T_1)$

N_2 : Table > A-2 → $C_p = 1.039\ kJ/kg \cdot K$

$q = C_p (T_2 - T_1) = (1.039\ kJ/kg \cdot K) \cdot (27 - 427)\ K$

$= -415.6\ kJ/kg$

Ans.



Critical-point properties

Temperature, K	Pressure, MPa	Volume, m^3/kmol
132.5	3.77	0.0883
405.5	11.28	0.0724
151	4.86	0.0749
562	4.92	0.2603
584	10.34	0.1355
425.2	3.80	0.2547
304.2	7.39	0.0943
133	3.50	0.0930
556.4	4.56	0.2759
417	7.71	0.1242
536.6	5.47	0.2403
384.7	4.01	0.2179
451.7	5.17	0.1973
305.5	4.48	0.1480
516	6.38	0.1673
282.4	5.12	0.1242
5.3	0.23	0.0578
507.9	3.03	0.3677
33.3	1.30	0.0649
209.4	5.50	0.0924
191.1	4.64	0.0993
513.2	7.95	0.1180
416.3	6.68	0.1430
44.5	2.73	0.0417
126.2	3.39	0.0899
309.7	7.27	0.0961
154.8	5.08	0.0780
370	4.26	0.1998
365	4.62	0.1810
430.7	7.88	0.1217
374.2	4.059	0.1993
471.2	4.38	0.2478
647.1	22.06	0.0560
289.8	5.88	0.1186

R_u/M, where $R_u = 8.31447$ kJ/kmol·K and M is the molar

ASHRAE, *Handbook of Fundamentals* (Atlanta, GA: American
ed 36.1.

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APPENDIX 1

TABLE A–2

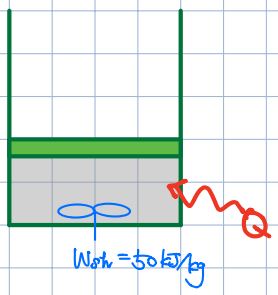
Ideal-gas specific heats of various common gases

(a) At 300 K

Gas	Formula	Gas constant, R kJ/kg·K	c_p kJ/kg·K	c_v kJ/kg·K	k
Air	—	0.2870	1.005	0.718	1.400
Argon	Ar	0.2081	0.5203	0.3122	1.667
Butane	C_4H_{10}	0.1433	1.7164	1.5734	1.091
Carbon dioxide	CO_2	0.1889	0.846	0.657	1.289
Carbon monoxide	CO	0.2968	1.040	0.744	1.400
Ethane	C_2H_6	0.2765	1.7662	1.4897	1.186
Ethylene	C_2H_4	0.2964	1.5482	1.2518	1.237
Helium	He	2.0769	5.1926	3.1156	1.667
Hydrogen	H_2	4.1240	14.307	10.183	1.405
Methane	CH_4	0.5182	2.2537	1.7354	1.299
Neon	Ne	0.4119	1.0299	0.6179	1.667
Nitrogen	N_2	0.2968	1.039	0.743	1.400
Octane	C_8H_{18}	0.0729	1.7113	1.6385	1.044
Oxygen	O_2	0.2598	0.918	0.658	1.395
Propane	C_3H_8	0.1885	1.6794	1.4909	1.126
Steam	H_2O	0.4615	1.8723	1.4108	1.327

Note: The unit kJ/kg·K is equivalent to kJ/kg·°C.

Source: *Chemical and Process Thermodynamics* 3/E by Kyle, B. G., © 2000. Adapted by permission of Pearson Education, Inc., Upper Saddle River, NJ.



Air, Piston-cylinder (variable-load)

$p_1 = 500\,kPa$, $T_1 = 27^\circ C$

$W_{sh} = 50\,kJ/kg$ → into air

heat is transferred to maintain a constant air temp. 등온과정.

(allowing the gas volume ×3)

Calculate the required amount of heat transfer (kJ/kg)

$$\Delta E = Q - W = \Delta U + \Delta PE + \Delta KE$$

$$Q - \{-W_{sh} + W_b\} = \Delta U$$

$$Q + W_{sh} - W_b = \Delta U$$

$$Q = -W_{sh} + W_b + \Delta U \quad \leftarrow W_b = \int_1^2 p\,dV$$

$$= -W_{sh} + \int_1^2 p\,dV + C_v(T_2 - T_1) \quad \leftarrow pv = RT,\ p = \frac{RT}{v}$$

$\because T_1 = T_2$

$$q = -w_{sh} + \int_1^2 p\,dv \quad \leftarrow pv = RT$$

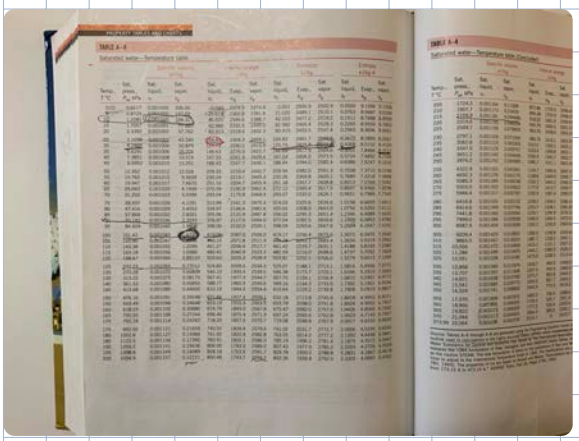
$$= (-50\,kJ/kg) + \int_1^2 \frac{RT}{v}\,dv$$

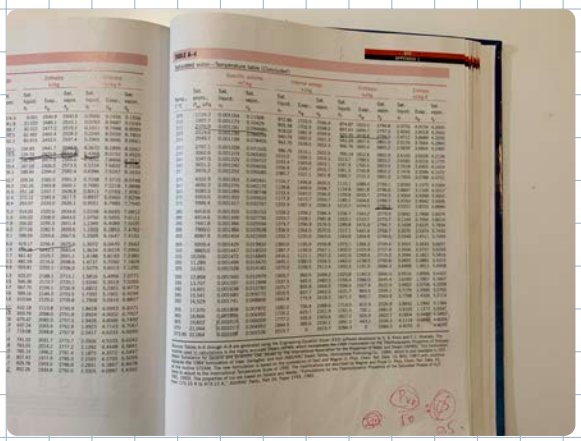
$$= (-50) + RT \ln v_2/v_1 \quad \leftarrow v_2 = 3 \times v_1$$

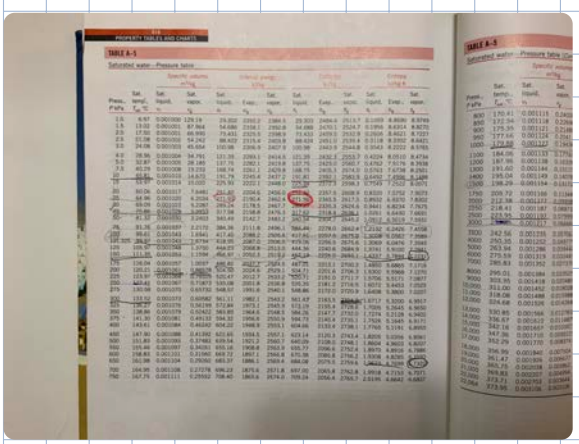
$$= (-50) + (0.287\,kJ/kg\cdot K)\cdot(300K)\cdot(\ln 3)$$

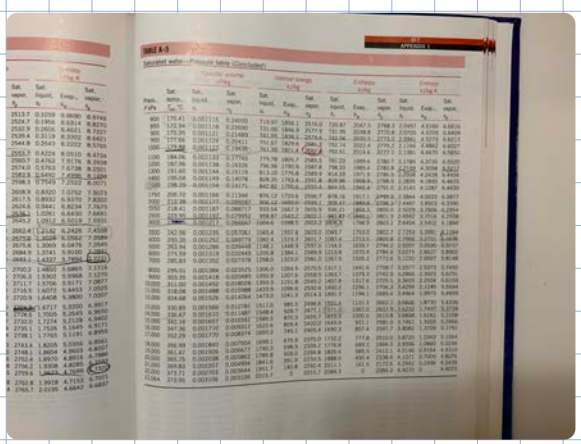
$$= 44.59\,kJ/kg$$

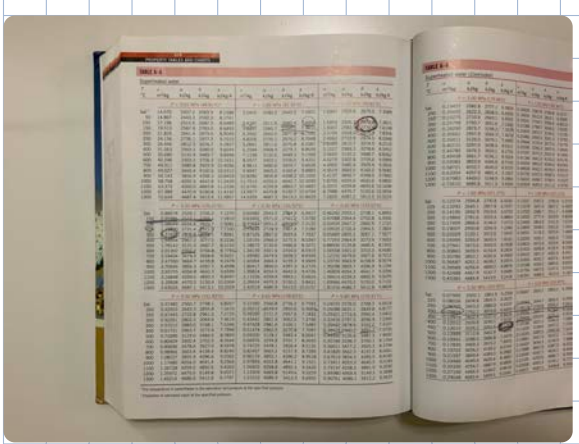
~~~~~~~~~~ Ans.
~~~~~~~~~~

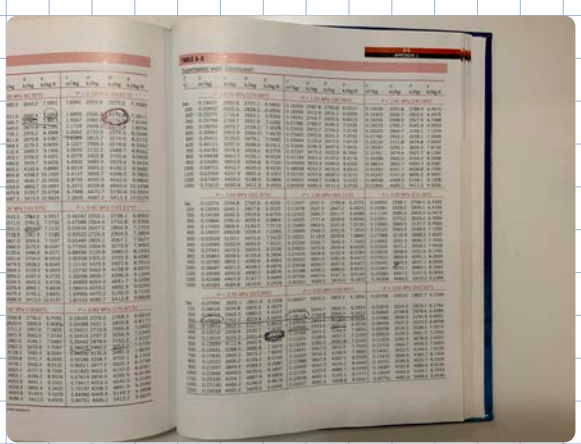


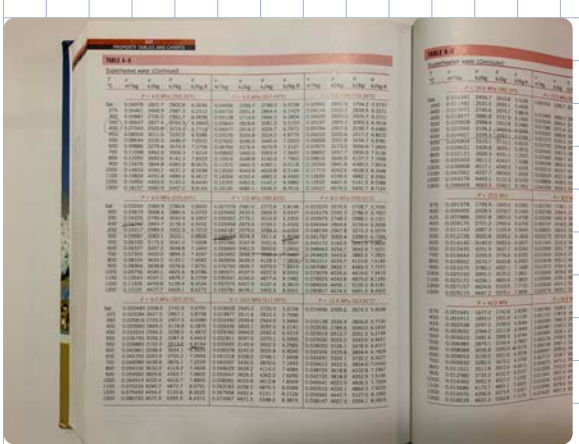


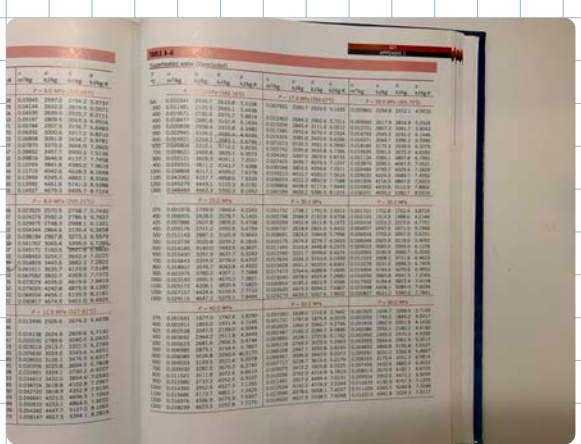


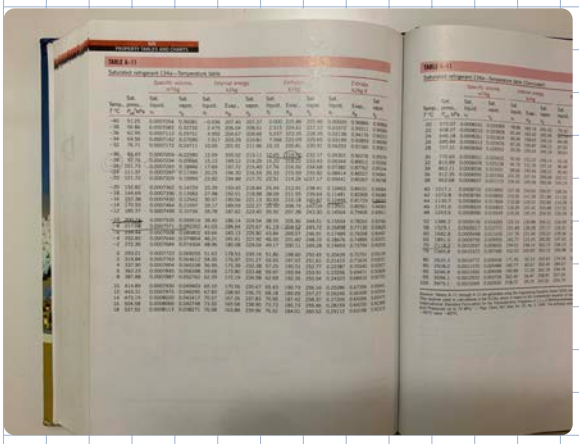


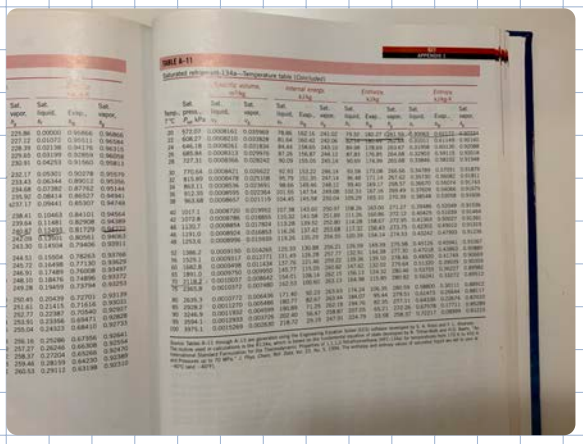


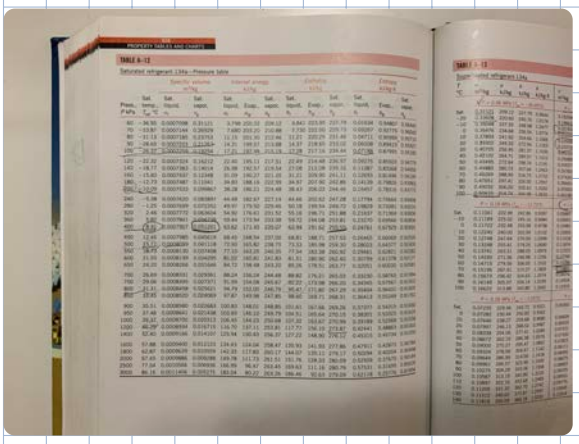


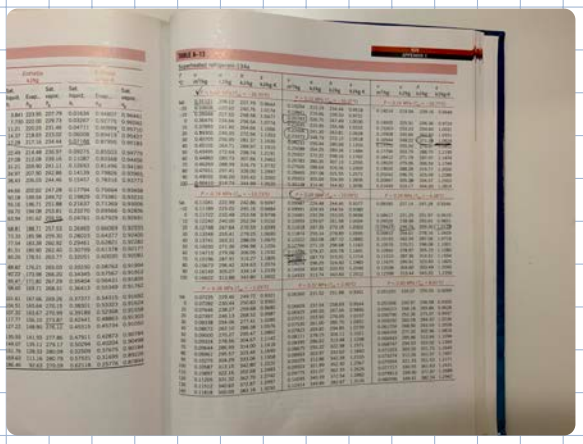


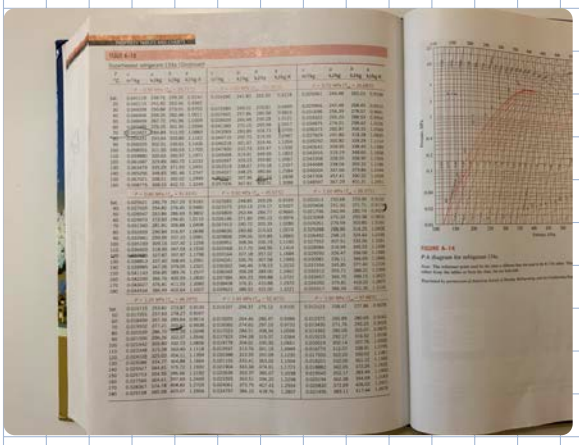


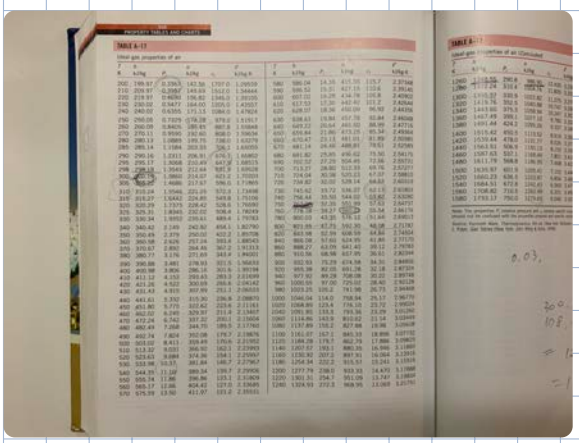


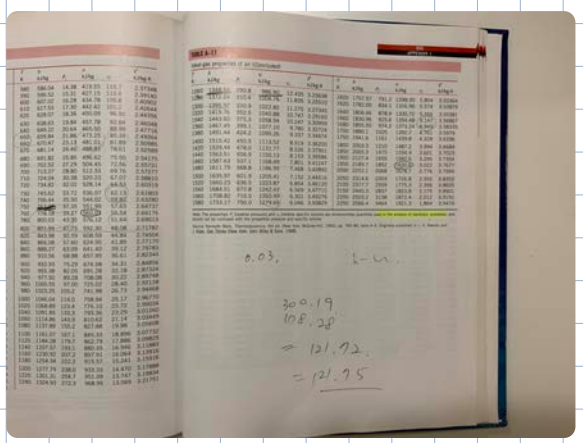












A piston-cylinder : air & liquid water → compression process (State 1 → State 2)

Stage 1 :	Stage 2 :
$T_1 = 25°C$	a mixture of water vapor and air
$p_1 = 100\ kPa$	$T_2 = 180°C$
the air contains no water vapor	$V_2 = 0.1\ m^3$
the cylinder volume = $1\ m^3$	
mass of liq. water = $1\ kg$	

The volume occupied by the liquid can be neglected
Air is assumed to be an ideal gas with $C_v = 0.728\ kJ/kg\cdot K$, $R = 0.287\ kJ/kg\cdot K$

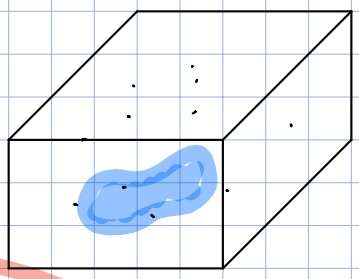
(a) Assuming : the water vapor and air is an ideal mixture.
Determine the pressure inside the cylinder at State 2 , p_2.
Neglect any air dissolved in the water

(b) During the compression : $pV^n = constant$
Determine the total amount of work during the compression

(c) Determine the heat transfer from the surrounding into the piston-cylinder process

(a) Assuming : the water vapor and air is an ideal mixture.
Determine the pressure inside the cylinder at State 2 , p_2.
Neglect any air dissolved in the water

$p_2 = p_{2,air} + p_{2,wv}$



- State 2 : $p_2V_2 = mRT_2$

$p_{2,air} = \dfrac{mRT_2}{V_2}$ ← $T_2 = 180°C$, $V_2 = 0.1\ m^3$, $m = ?$, $R = 0.287\ kJ/kg\cdot K$

- State 1 : Table A-4 $T_1 = 25°C$ → $p_{wt} = 3.17\ kPa$

$p_1 = p_{1,wl} + p_{1,air} = 100\ kPa$ ∴ $p_{1,air} = 96.83\ kPa$

$p_{1,wl} = 3.17\ kPa$

$p_1V_1 = mRT_1$ → $m_{air} = \dfrac{p_1V_1}{RT_1}$ (∵ volume occupied by liquid = neglected)

$= \dfrac{(96.83\ kPa)\cdot(1\ m^3)}{(0.287\ kJ/kg\cdot K)\cdot(298\ K)} = 1.13\ kg$

$\therefore p_{2,air} = \dfrac{(1.13\ kg)\cdot(0.287\ kJ/kg\cdot K)\cdot(453\ K)}{(0.1\ m^3)} = 1469.1\ kPa$

- State 2 : $T_2 = 180°C$ Table A-4 → $p_{2,wv} = 1002.8\ kPa$

∴ $p_2 = p_{2,air} + p_{2,wv}$
$= 2471.9\ kPa$ Ans.

(b) During the compression : $pV^n = \text{constant}$

Determine the total amount of work during the compression

$$W = \int_{V_1}^{V_2} p\,dV \longleftarrow pV^n = \text{const} = p_1V_1^n = p_2V_2^n \;,\quad p = \text{const}/V^n = p_1V_1^n/V^n$$

$$= \int_{V_1}^{V_2} \frac{\text{const}}{V^n}\,dV$$

$$= \text{const} \cdot \frac{1}{1-n} \cdot V^{1-n}\Big]_{V_1}^{V_2} \qquad 1 < n < k$$

$$= \frac{\text{const}}{1-n} \cdot (V_2^{1-n} - V_1^{1-n})$$

$$= \frac{p_2V_2^n \cdot V_2^{1-n} - p_1V_1^n \cdot V_1^{1-n}}{1-n} = \frac{p_2V_2 - p_1V_1}{1-n} = \frac{(2471.9)(0.1) - (100)(1)}{1-1.393} = -374.53\ \text{kJ}$$

Ans.

$n = ?$ $\quad p_1V_1^n = p_2V_2^n$

$(100)(1)^n = (2471.9)\cdot(0.1)^n$

$100/2471.9 = 0.1^n$

$n \log(0.1) = \log(100/2471.9) \longrightarrow n = 1.393$

(c) Determine the heat transfer from the surrounding into the piston-cylinder process

State 1	→	State 2
Liq. water air		Liq. water + water vapor air

$$\Delta E = Q - W = \Delta U + \Delta KE + \Delta PE$$

$$Q - (-W_{in} + W_b) = \Delta U$$

$$Q = \Delta U + W_b - W_{in}$$

$H = U + PV$

$\Delta H = \Delta U + \Delta(PV)$

$dH = dU + dP\,V + P\,dV$ ($P\,dV = \delta W_b$)

$$Q = \Delta H - W_{in} \longleftarrow$$

$$Q = \Delta H - W_{in}$$

$$= (\Delta H)_{air} + (\Delta H)_{wv} + (\Delta H)_{wl} - W_{in}$$

$$= \{mC_p(T_2 - T_1)\}_{air} + \{m_2h_2 - m_1h_1\}_{wv} + \{m_2h_2 - m_1h_1\}_{wl} - W_{in}$$

- $(\Delta H)_{air} = m_{air} C_p \cdot (T_2 - T_1)$ $\longleftarrow$ $C_p - C_v = R$, $C_p = C_v + R$

$= (1.13\ \text{kg})(1.015\ \text{kJ/kg.K}) \cdot (180 - 25)\ \text{K}$

$= 177.78\ \text{kJ}$

m_1, liq. water = 1 kg

if all liq. water turned into sat. vapor $v_2 = 0.1\ m^3/kg$

Table A-4 $T = 180°C \longrightarrow v_f = 0.001127 \sim v_g = 0.19384$

$$m_{2,wv} = V_2/v_g = \frac{0.1\ m^3}{0.19384\ m^3/kg} = 0.51589\ kg$$

$$m_{2,wl} = 1 - 0.51589 = 0.484\ kg$$

$\cdot (\Delta H)_{wv} = m_{2,wv} \cdot h_{2,wv} - m_{1,wv} \cdot h_{1,wv}$

no water vapor at stage 1

$= (0.5159\ kg) \cdot (1802.16) = 929.73\ kJ$

$T = 180°C$, Table A-4 $\longrightarrow$ $h_f = 763.05$, $h_{fg} = 2014.2$, $h_g = 2777.2$

$x_2 = \frac{0.5159}{1} \longrightarrow h_{2,wv} = 1802.16$

$(\Delta H)_{wl} = m_{2,wl} \cdot h_{2,wl} - m_{1,wl} \cdot h_{1,wl}$

* $m_{2,wl} = 0.484\ kg$ $\quad h_{2,wl} = h_f = 763.05$

$m_{1,wl} = 1\ kg$ $\quad h_{1,wl} = 104.83$ ← Table A-4, $T_1 = 25°C$

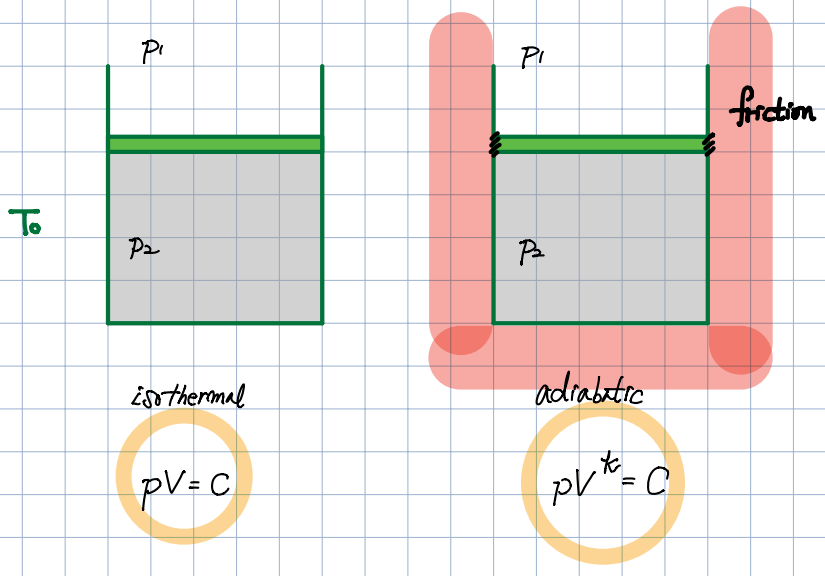
$= (0.484) \cdot (763.05) - (1)(104.83) = 264.48$

$\therefore Q = (177.78) + (929.73) + (264.48) - 374.53$

$= 997.46\ kJ$

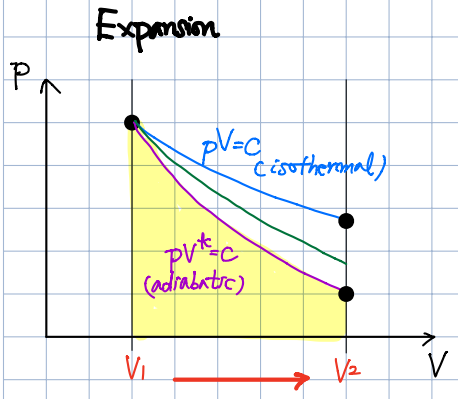
Ans.

Closed System (Piston-Cylinder) : isothermal vs adiabatic vs. polytropic

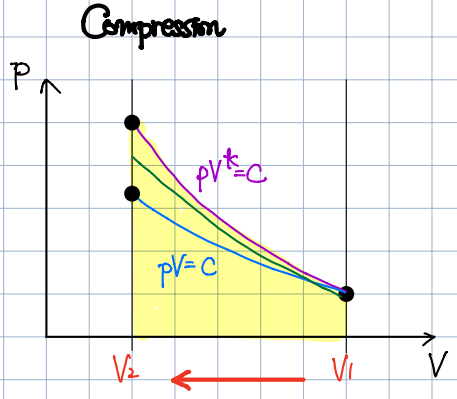


ideal gas : $pv = RT$

friction 이 W을 만들어내고,
그 W는 Q을 만들어내고,
그 Q가 ∫을 증가시킬 것이다.



등온과정이 일을 더 많이 한다.



단열과정이 일을 더 많이 소모한다.

isothermal : $pV^1 = C$

↕

polytropic : $pV^n = C$ $\quad 1 < n < k$

↕

adiabatic : $pV^k = C$
$pV^{1.7} = C$

$1\,m^3$ of diatomic ideal gas is first expanded from an initial state ($T_1 = 298K$, $p_1 = 15\,atm$) to a final state ($p_2 = 1\,atm$)

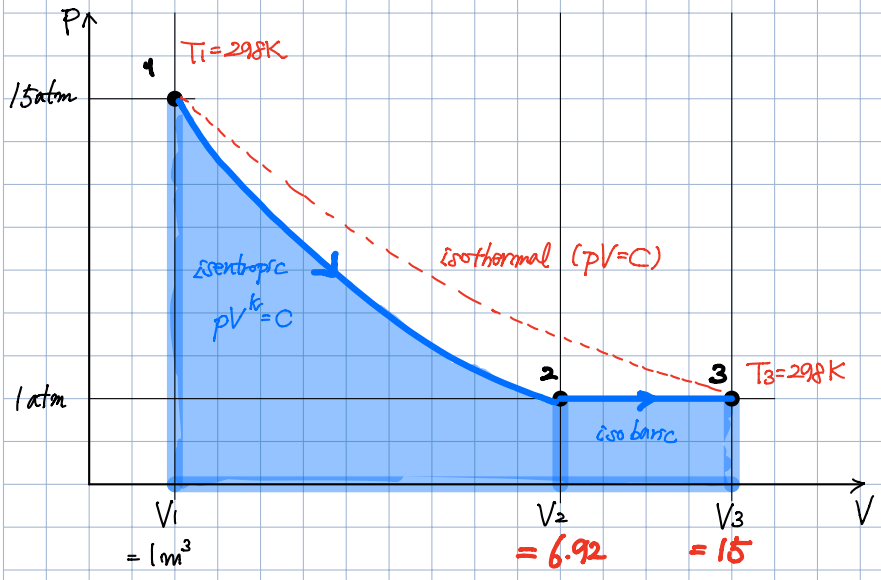
↳ $C_p = \frac{7}{2}R$, $C_v = \frac{5}{2}R$

During the expansion, thermally insulated.

After this expansion, the insulation is removed and the gas is allowed to cool or heat, (back to 298K)

while keeping the pressure constant at 1 atm.

What is the amount of work done on the gas in these two processes?



1 → 2 : isentropic & ideal gas $\quad p_1V_1^k = p_2V_2^k$ $\quad$ k: specific heat ratio $= C_p/C_v = \frac{7}{2}R/\frac{5}{2}R = 1.4$

$$\left(\frac{V_2}{V_1}\right)^k = \frac{p_1}{p_2}$$

$$\left(\frac{V_2}{V_1}\right) = \left(p_1/p_2\right)^{1/k}$$

$$\therefore V_2 = V_1 \cdot \left(p_1/p_2\right)^{1/k} = (1m^3) \cdot \left(\frac{15\,atm}{1\,atm}\right)^{1/1.4} = \underline{6.92m^3}$$

* $pV = mRT$

$$mR = \frac{pV}{T} = \frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2} = \frac{p_3V_3}{T_3}$$

$$T_2 = \frac{p_2V_2}{p_1V_1} \cdot T_1 = \frac{(1atm)(6.92m^3)}{(15atm)(1m^3)} \cdot (298K) = \underline{137.48K}$$

$$V_3 = \frac{p_2V_2}{T_2} \cdot T_3/p_3 = \frac{(atm) \cdot (6.92m^3)}{(137.48K)} \cdot \frac{(298K)}{(1atm)} = \underline{15\,m^3}$$

$1 \to 2$: $\quad {}_1W_2 = \int_1^2 p\,dV \quad \leftarrow pV^k = C$

$p = C \cdot V^{-k}$

$= \int_1^2 C \cdot V^{-k}\,dV$

$= \frac{C}{1-k} V^{1-k} \Big]_1^2$

$= \frac{C}{1-k} \cdot (V_2^{1-k} - V_1^{1-k}) \quad \leftarrow \quad pV_1^k = C$

$= \frac{(15\,\text{atm}) \cdot (1\,m^3)^{1.4} \; \frac{101.325\,kPa}{1\,atm}}{1-1.4} (6.92^{-0.4} - 1^{-0.4})$

$= 2047\,kJ$

$2 \to 3 \qquad {}_2W_3 = \int_2^3 p\,dV$

$= p(V_3 - V_2)$

$= (1\,atm) \cdot \left(\frac{101.325\,kPa}{1\,atm}\right) \cdot (15 - 6.92\,m^3)$

$= 818\,kJ$

${}_1W_3 = {}_1W_2 + {}_2W_3$

$= 2047 + 818 = 2865.7\,kJ$ Ans.

*** another way.**

$1 \to 2$: isentropic

1st Law : $\Delta E = Q - W = \Delta U + \Delta KE + \Delta PE \cdots$

${}_1W_2 = \Delta U = \int_1^2 nC_v\,dT$

$= n \cdot (5/2)R \cdot (T_2 - T_1) \quad \leftarrow \quad T_2 = 137.5K, \; T_1 = 298K$

$pv = RT$

$pV = mRT = n\bar{R}T$

$n\bar{R} = \frac{pV}{T}$

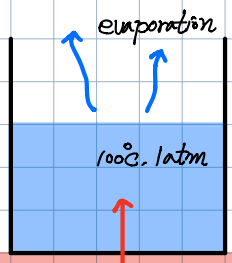
$= (5/2) \cdot \frac{p_1V_1}{T_1}(T_2 - T_1)$

$= (5/2) \cdot \frac{(15\,\text{atm}) \cdot (1\,m^3)}{298K}(137.5 - 298\,k)$

$= 2047\,kJ$

The heat of evaporation of water is 2261 J/g at 100°C, 1atm

$\rho_{water,\,vapor} = 0.597\ kg/m^3$ (100°C, 1atm)



(a) What percentage of that energy is used as work done by the vapor?

(b) What is the internal energy change for the evaporation of water?

(a)

$$W = \int_{initial}^{final} p\,dv \qquad (v_{final} = v_{vap},\ v_{initial} = v_{liq})$$

$$= \int_{v_{liq}}^{v_{vap}} p\,dv \quad \leftarrow \quad v = \text{Volume}/\text{mass}$$

$$= p \cdot \int_{v_{liq}}^{v_{vap}} dv \quad (\because \text{isobaric})$$

$$= p \cdot (v_{vap} - v_{liq}) = p \cdot v_{vap}$$

$v_{vap} \gg v_{liq}$

$$W = p \cdot v_{vap} = p \cdot V_{vap}/m_{vapor} = p \cdot 1/\rho_{water,vapor}$$

$$= (1\,atm) \cdot \frac{1}{0.597\ kg/m^3} \cdot \frac{101.325\ kPa}{1\,atm} \cdot \frac{1\ kN/m^2}{1\ kPa}$$

$$= 169.7\ kJ/kg = 169.7\ J/g$$

$$\frac{169.7\ J/g}{2261\ J/g} \times 100 = 7.5\%$$ Ans.

(b) isobaric ⟶ U와 H크기가 같다!

$$H = U + pV$$

- $\Delta H = \Delta U + \Delta(pV)$
  $= \Delta U + \Delta pV + p\Delta V$ ⟶ $\Delta h = \Delta u + p\Delta v$
  ($\because$ isobaric)

- $\Delta H = C_p \Delta T \quad \leftarrow \quad C_p = \left(\frac{dQ}{dT}\right)_p$
  $= (Q)_p$

$\Delta h = 2261\ J/g$

$W = \int p\,dv = p\Delta v = 169.7\ J/g$

$$\Delta u = \Delta h - p\Delta v$$
$$= (2261\ J/g) - (169.7)$$
$$= 2094\ J/g$$ Ans.

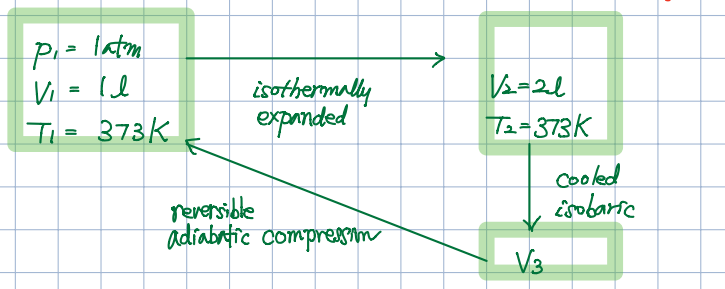
ΔU는 breaking bonds를 위해 사용됨!

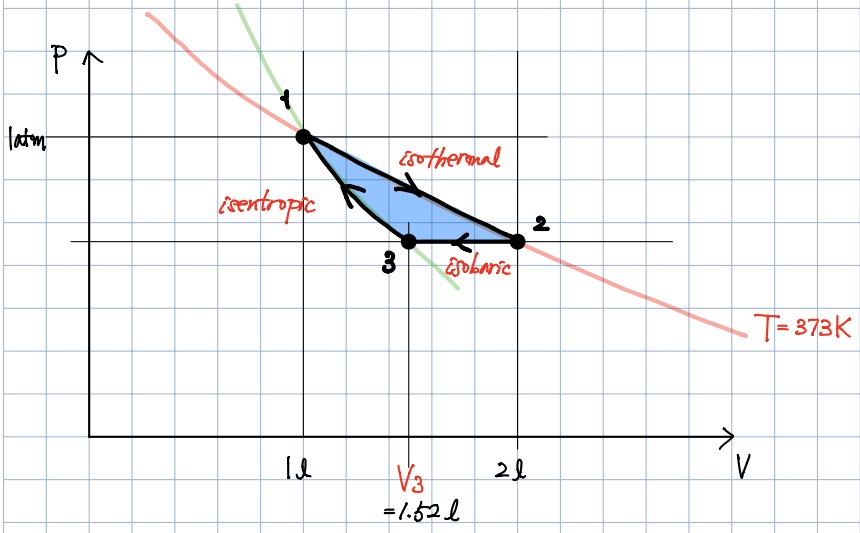
The heat (to transfer to water to evaporate it!) is used for increasing the internal energy of water (2094 J/g, breaking bond).

but also includes the work required for expansion of the vapor.

• monoatomic ideal gas → $k = C_p/C_v = 5/3$ for monoatomic ideal gas

All of the changes of the states are conducted reversely.
Calculate V_3 and the total work done on or by gas?





ideal gas : $pV = nRT$ ← $R = 8.314\ J/mol\cdot K$

$$n = \frac{pV}{RT} = \frac{(1atm)\cdot\left(\frac{101325Pa}{1atm}\right)\cdot(1l)\cdot\left(\frac{1m^3}{1000l}\right)}{(8.314\ J/mol\cdot K)\ (373K)} = 0.033\ mol$$

1 → 2 : isothermal

$$_1W_2 = \int_1^2 p\,dV \leftarrow pV = nRT,\quad p = \frac{nRT}{V}$$

$$= \int_1^2 \frac{nRT}{V}\,dV = nRT\cdot \ln\frac{V_2}{V_1}$$

$$= (0.033\,mol)\cdot(8.314\ J/mol\cdot K)\cdot(373K)\cdot\ln\left(\frac{2l}{1l}\right)$$

$$= 70.9\ J$$

2 → 3 : isobaric

$V_3 = ?$

3 → 1 : isentropic

ideal gas : $pV^k = Const$

$p_3V_3^k = p_1V_1^k$

$$V_3 = \left(\frac{p_1}{p_3}\right)^{1/k}\cdot V_1 \leftarrow \text{1→2 : isothermal, } p_1V_1 = p_2V_2 = const$$

$$= \left(\frac{1}{0.5}\right)^{1/(5/3)}\cdot(1l)$$

$$= 1.52\,l$$

$p_2 = p_1\cdot V_1/V_2 = (1atm)\cdot\frac{1}{2} = 0.5\,atm = p_2 = p_3$

2 → 3 : isobaric

$$_2W_3 = \int_2^3 p\,dV = p\cdot(V_3 - V_2) = (0.5atm)\cdot(1.52-2\,l)\cdot\frac{101325Pa}{1atm}\cdot\frac{1m^3}{1000l}$$

$$= -24.3\ J$$

3 → 1 : isentropic

$$_2W_1 = \int_3^1 p\,dV \quad \leftarrow \quad pV^k = \text{const} = p_1V_1^k = p_3V_3^k$$

$$p = \text{Const} \cdot V^{-k}$$

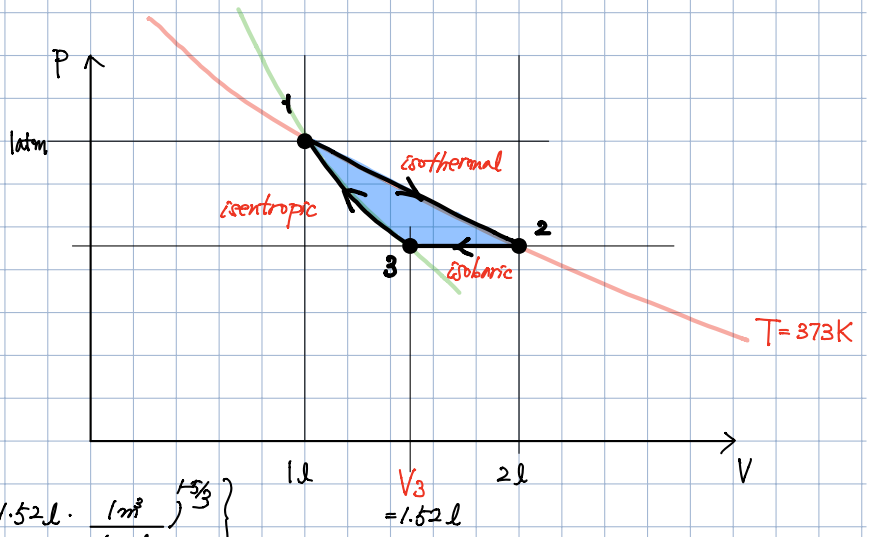
$$= \int_3^1 C \cdot V^{-k}\,dV$$

$$= (p_1V_1^k) \cdot \frac{1}{1-k} V^{1-k} \Big]_3^1$$

$$= (p_1V_1^k) \cdot \frac{1}{1-k} \cdot (V_1^{1-k} - V_3^{1-k})$$

$$= (1\text{atm}) \cdot (1\ell \cdot \frac{1m^3}{1000\ell})^{5/3} \cdot \frac{1}{1-5/3} \cdot \left\{ (1\ell \cdot \frac{1m^3}{1000\ell})^{1-5/3} - (1.52\ell \cdot \frac{1m^3}{1000\ell})^{1-5/3} \right\}$$

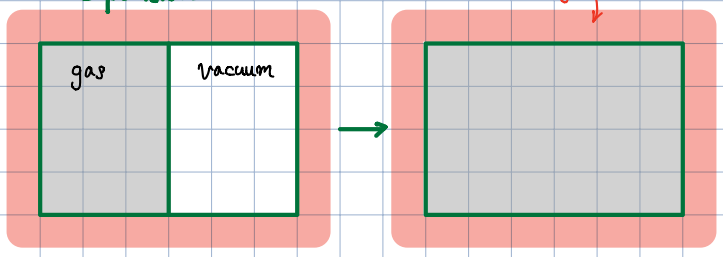
$$= -37\ \text{J}$$



$$W_{total} = (70.9) + (-24.3) + (-37) = 9.6\ \text{J}$$ Ans.

9.6J work done by gas **Ans.**

Free expansion



gas volume = V　　2V

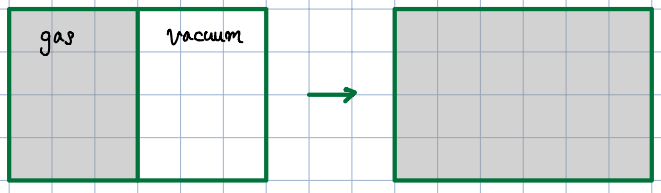
i) What is the work performed by gas?

ii) ΔU (the change in internal energy) (after it has equilibrated after the expansion)

iii) ideal gas → ΔT = ?

iv) not ideal gas (i.e. $U = U(T, V)$) → ΔT = ?

(assume the wall conducts heat.)



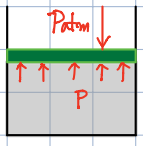
v) ideal gas → ΔU = ?

vi) not ideal gas (i.e. $U = U(T, V)$) → ΔU = ?

---

i) What is the work performed by gas?

$W = \int p dV$ cannot be applied, since the process is not reversible.



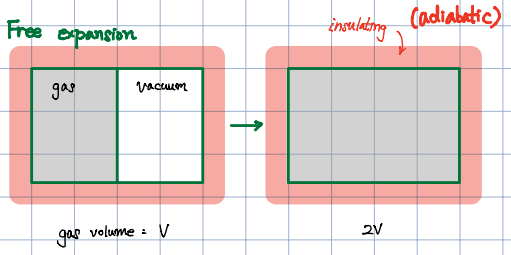
∴ The amount of work done by the gas is zero Ans.

↑ ∵ the gas does no work on the surroundings outside of the chamber.

quasi-equilibrium (준평형)

---

ii) ΔU (the change in internal energy) (after it has equilibrated after the expansion)



Thermodynamic's 1st Law: $\Delta U = Q - W$

∵ insulating　no work

∴ $\Delta U = 0$ Ans.

---

iii) ideal gas → ΔT = ?　　ideal gas: $U = f(T)$ only a function of temp → $dU = C_v dT$

$\frac{dU}{dT} = C_v$

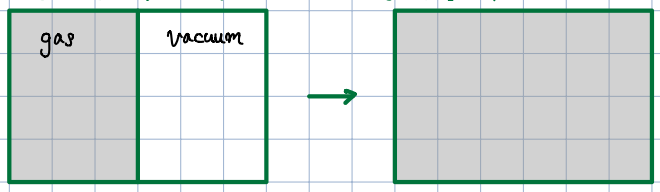
iv) not ideal gas (i.e. $U = U(T, V)$) → ΔT = ?

$\Delta T = 0 \rightarrow T_{initial} = T_{final}$ Ans.

$\Delta U = U(T_{final}, V_{final}) - U(T_{initial}, V_{initial}) = 0$

T will change after a free expansion in an insulated chamber, since V changes.

(assume the wall conducts heat.)



v) ideal gas → $\Delta U = ?$

vi) not ideal gas (i.e. $U = U(T,V)$) → $\Delta U = ?$

ideal gas : $U = f(T)$

$T_{initial} = T_{final} = T_{environment}$ $\Delta U = 0$ Ans.

not ideal gas : $U = f(T,V)$

$\Delta U \neq 0$ (∵ heat exchange) $\Delta U \neq 0$ Ans.

V가 바뀌므로 $U(T,V)$ 도 바뀐다.

	$U = f(T)$ ideal gas	$U = f(T,V)$ non-ideal gas
insulation	$\Delta U = Q - W = 0$ $\Delta U = 0 \rightarrow U(T) \rightarrow T_i = T_f$	$\Delta U = 0 = U(T_f, V_f) - U(T_i, V_i)$ $\Delta V \neq 0 \rightarrow \Delta T \neq 0,\ T_i \neq T_f$
conduct	equilibrium → $T_i = T_f = T_{env}$ $U(T) \rightarrow \Delta U = 0$	$U(T,V)$ $\Delta V \neq 0 \rightarrow \Delta U \neq 0$

· Ideal Gas

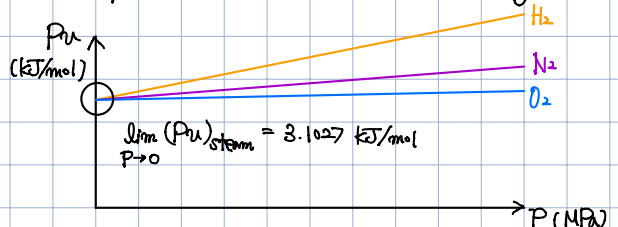
$PV = nRT$ ← R : the molar Gas constant

ideal gas ~ real gas at low pressure

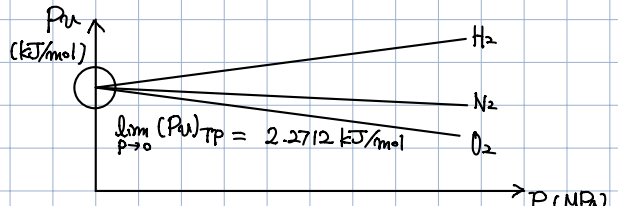
$P/P_{TP} = P \rightarrow 0 / P_{TP} \rightarrow 0 =$ value (independent of the nature of the gas)

~ P, V, n

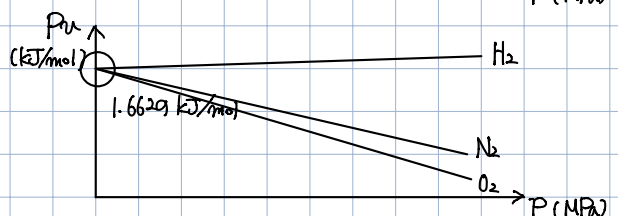
$v = V/n$



T : the boiling temp.



T : at triple point



$\lim_{p\to 0}(pv) = A$: function of temperature only
independent of gas

$pv = A(1 + Bp + Cp^2 + \cdots)$ ← power series (virial expansion)
(Real-gas)

$p/p_{tp} = p\to 0 / p_{tp}\to 0 =$ value
(independent of the nature of the gas)

$T = (273.16\,K)\lim_{p_{tp}\to 0}(p/p_{tp})$ (const V) ← T: the ideal-gas temperature

$= (273.16\,K)\lim \frac{pV/n}{p_{tp}V/n}$

$= (273.16)\lim \frac{pv}{(pv)_{tp}}$

$\lim(pv) = \frac{\lim(pv)_{tp}}{(273.16\,K)}\cdot T \longrightarrow pv = RT, \quad v = V/n$
$pV = nRT$

$= R$
(the molar gas constant)

$pv/RT = 1 + Bp + Cp^2 + Dp^3 + \cdots$ ← power series (virial expansion)
↖ Real gas!

---

ideal gas: $pV = nRT$

$\left(\frac{\partial U}{\partial p}\right)_T = 0$

$\left(\frac{\partial U}{\partial V}\right)_T = \left(\frac{\partial U}{\partial p}\right)_T \cdot \left(\frac{\partial p}{\partial V}\right)_T$ (→ 0; $= 0$; $\neq 0$)

$\left(\frac{\partial p}{\partial V}\right)_T = -nRT/V^2 = -p/V \neq 0$

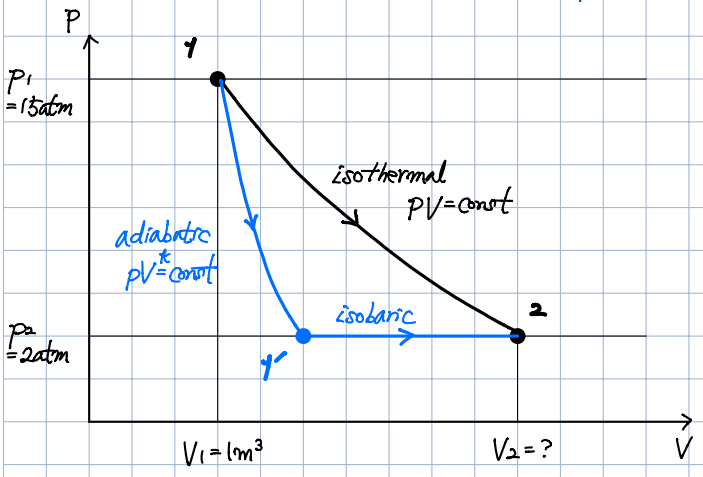
$\left(\frac{\partial U}{\partial V}\right)_T = 0 \longrightarrow U = f(T)$ ★★

$1\,m^3$, diatomic ideal gas :

$V_1 = 1\,m^3$ → $V_2 = ?$

$T_1 = 298\,K$ → $T_2 = 298\,K$ (isothermal)

$p_1 = 15\,atm$ → $p_2 = 2\,atm$



a) $V_2 = ?$

b) the amount of work done by the gas ? (isothermal)

c) the amount of the work ?
(thermally insulated during the expansion : 15 atm → 2 atm)
(then cool or warm back to 298 K (isobaric, 2 atm))

a) $V_2 = ?$

ideal gas : $p_1V_1 = p_2V_2 = nRT$ ← isothermal
$= \text{const}$

$$V_2 = \frac{p_1}{p_2}V_1 = \frac{15\ atm}{2\ atm} \cdot (1\,m^3) = 7.5\,m^3$$ Ans.

b) the amount of work done by the gas ? (isothermal)

$W = \int_1^2 p\,dV$ ← $pV = \text{Const}$

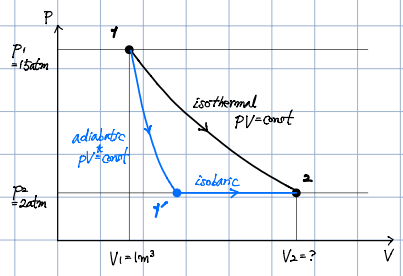
$p = \text{Const}/V$

$= \int_1^2 \text{Const}/V\,dV$

$= \text{Const} \cdot \ln V_2/V_1$ ← $\text{Const} = p_1V_1$

$$= (15\ atm)\cdot(1\,m^3)\cdot\frac{101.325\ kPa}{1\ atm}\cdot\ln\frac{7.5\,m^3}{1\,m^3} = 3062.4\ kJ$$ Ans.

c) the amount of the work ?
(thermally insulated during the expansion : 15 atm → 2 atm)
(then cool or warm back to 298 K (isobaric, 2 atm))



1 → 1' : isentropic → $p_1V_1^k = p_{1'}V_{1'}^k$

$\left(\frac{V_{1'}}{V_1}\right)^k = \frac{p_1}{p_{1'}}$

$V_{1'} = V_1 \cdot \left(\frac{p_1}{p_{1'}}\right)^{1/k}$ ← k = 1.4

$= (1m^3) \cdot \left(\frac{15atm}{2atm}\right)^{1/1.4}$

$= 4.22 m^3$

$W_{total} = 2328.3$ kJ Ans.

$_1W_{1'} = \int_1^{1'} p\,dV$ ← pV^k = const , $p = C \cdot V^{-k}$

$= \int_1^{1'} C \cdot V^{-k}\,dV$

$= (p_1V_1^k) \cdot \frac{1}{1-k} \cdot (V_{1'}^{1-k} - V_1^{1-k})$

$= \left\{15atm \cdot \frac{101.325kPa}{1atm} \cdot 1m^{3\,1.4}\right\} \cdot \frac{1}{1-1.4} \cdot (4.22^{-0.4} - 1^{-0.4}) = 1663.6$ kJ Ans.

1' → 2 : isobaric $\quad {}_{1'}W_2 = \int_{1'}^{2} p\,dV = p \cdot (V_2 - V_{1'}) = (2atm) \cdot \frac{101.325kPa}{1atm} \cdot (7.5 - 4.22m^3)$

$= 664.7$ kJ Ans.

another way ! $\quad U = f(T)$

1 → 2 : isothermal (ideal gas)

1st Law : $\Delta U = Q - W$ $\quad \therefore W = Q$

$\Delta U = 0$ (∵ isothermal, ideal gas)

1 → 1' : isentropic → $_1Q_{1'} = 0$

1' → 2 : isobaric → $_{1'}Q_2 = nC_p\Delta T = nC_p(T_2 - T_{1'})$

n ?
C_p ?
$T_{1'}$?

1. $p_1V_1 = nRT_1$

$n = \frac{p_1V_1}{RT_1} = \frac{15atm \cdot \frac{101325Pa}{1atm} \cdot 1m^3}{(8.314J/mol\cdot K) \cdot (298K)}$

$= 613.5$ mol Ans.

2. $C_p = \frac{7}{2}R$ ← diatomic ideal gas

3. $p_{1'} = 2atm$, $V_{1'} = 4.22m^3$ → $T_{1'} = \frac{p_{1'}V_{1'}}{nR}$

$= \frac{(2atm) \cdot \frac{101325Pa}{1atm} \cdot (4.22m^3)}{(613.5mol) \cdot (8.314J/mol\cdot K)}$

$= 167.6K$

$\therefore {}_{1'}Q_2 = nC_p(T_2 - T_{1'})$

$= (613.5mol) \cdot (\frac{7}{2}) \cdot (8.314J/molK) \cdot (298 - 167.6K)$

$= 2327.9$ kJ Ans.

The energy of a system : $U = Ap^2V$ (1 mol) ← A: a positive constant $[p]^{-1}$

Find the equation of the reversible adiabats in the p-V plane.

1st Law : $dU = \delta Q - \delta W$

reversible → $\delta W = pdV$

adiabatic → $\delta Q = 0$

$U = Ap^2V \rightarrow dU = \delta Q - \delta W \rightarrow$ New eqn!

$dU = pdV \leftarrow U = Ap^2V = U(p,V)$

$$dU = \left(\frac{\partial U}{\partial p}\right)_V dV + \left(\frac{\partial U}{\partial V}\right)_p dV$$

$\left(\frac{\partial U}{\partial p}\right)_V = 2ApV$, $\left(\frac{\partial U}{\partial V}\right)_p = Ap^2$

$dU = (2ApV)dp + (Ap^2)dV = pdV$

$(2ApV)dp = (-Ap^2 + p)dV$

$= p(-Ap+1)dV$

$(2AV)dp = (1-Ap)dV$

$\left(\frac{1}{1-Ap}\right)dp = \left(\frac{1}{2AV}\right)dV$

$\therefore (1-Ap)\cdot V^{\frac{1}{2}} = \text{Const}$ Ans.

$-\frac{1}{A}\cdot \ln(1-Ap) = \frac{1}{2A}\cdot \ln V + C_1$

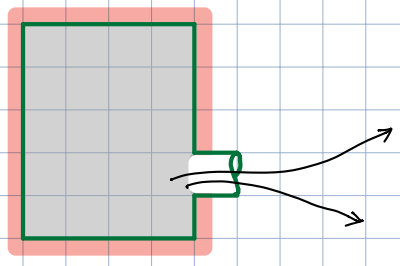
$-1\cdot \ln(1-Ap) = \frac{1}{2}\ln V + AC_1$

$-\ln(1-Ap) - \frac{1}{2}\ln V = AC_1$

$\ln(1-Ap) + \frac{1}{2}\ln V = -AC_1 = C_2$

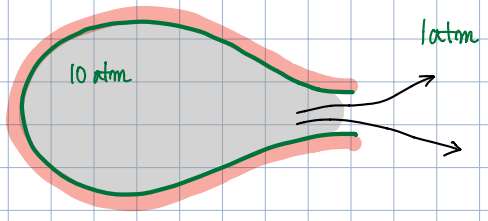
$\ln\{(1-Ap)\cdot V^{\frac{1}{2}}\} = C_2$

a) An insulated tank, gas, 10 atm
T_a : the temp. of the last air coming out of tank



$p_1 = 10\,atm \longrightarrow p_2 = 1\,atm$

b) A balloon, gas, 10 atm
T_b : the temp. of the air in the balloon, when it is deflated.



$T_a > T_b$? $T_b > T_a$? $T_a = T_b$?

1st Law : $dU = \delta Q - \delta W$

풍선이 줄어서, 시스템이 일을 해줍니다.

(a) $dU = \delta Q - \delta W$
insulated, no work

(b) $dU = \delta Q - \delta W$
insulated, δW : extra work

$\Delta U_a < \Delta U_b$
$\Delta T_a < \Delta T_b$
$\therefore T_a < T_b$ Ans.

- in case (b) extra work is done on the gas so that its internal energy will remain higher than in (a).