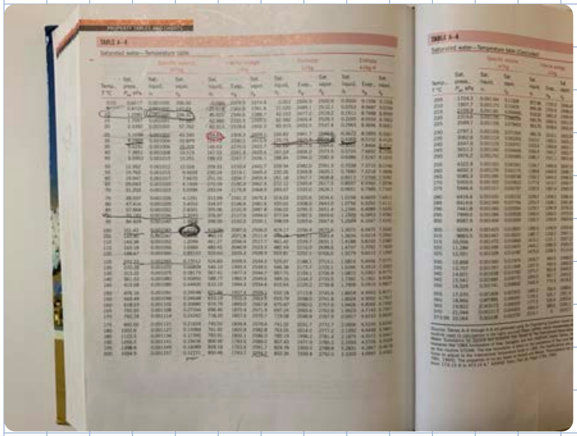
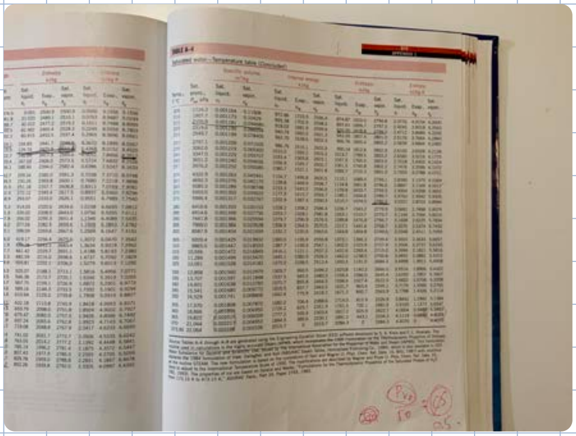
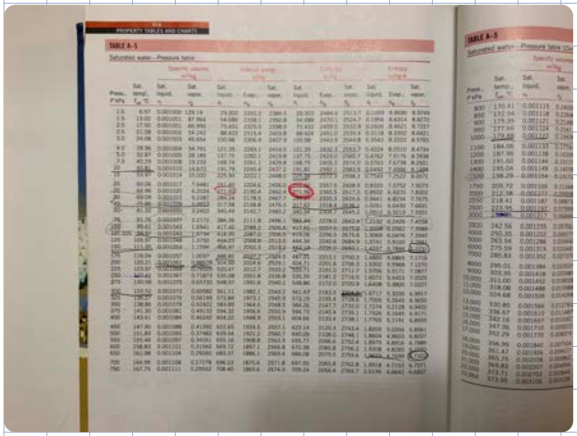
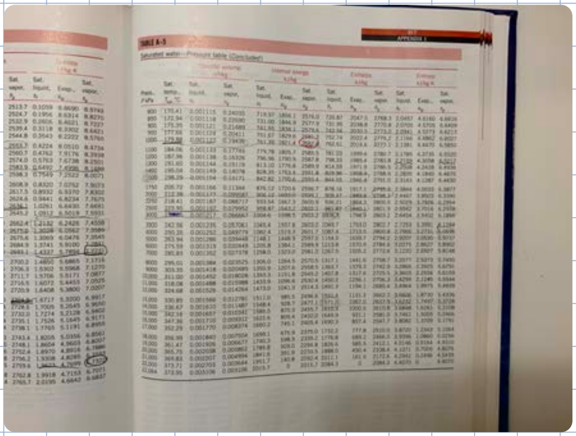
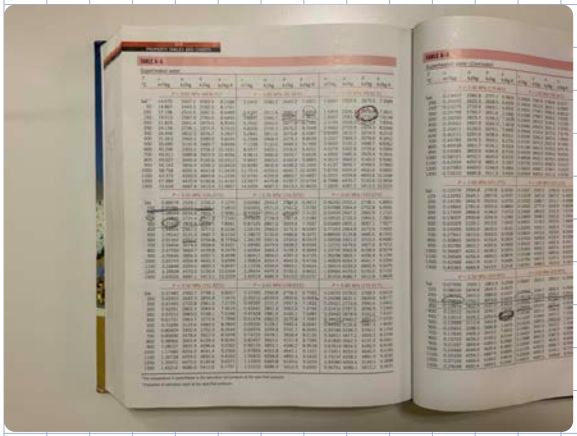
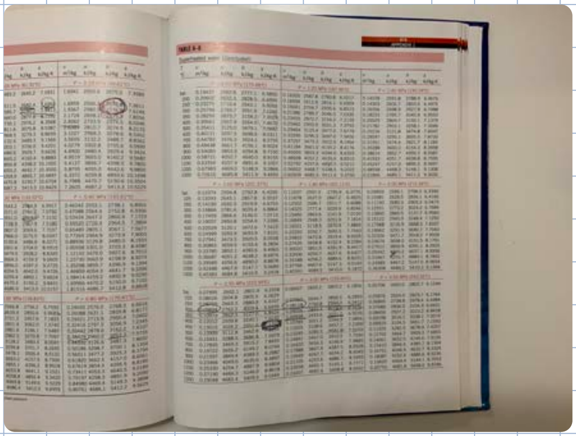


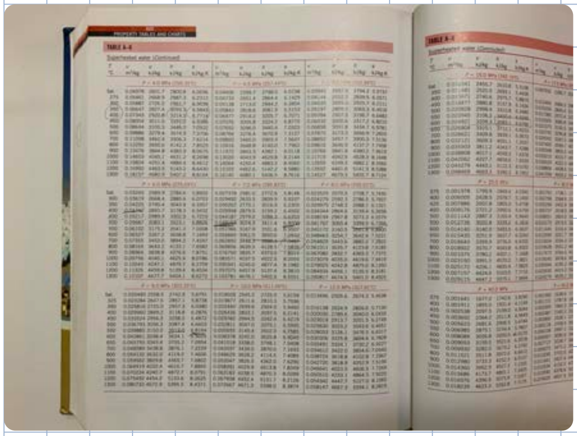


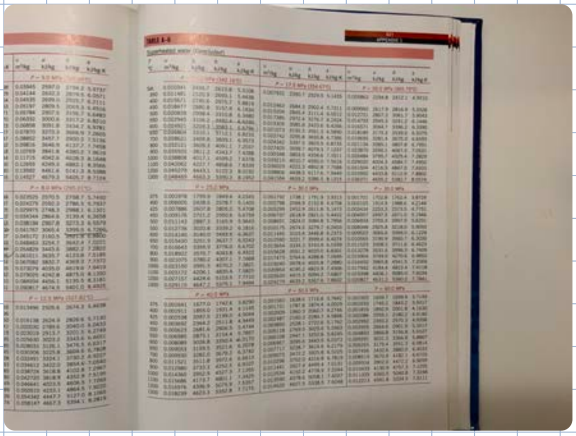












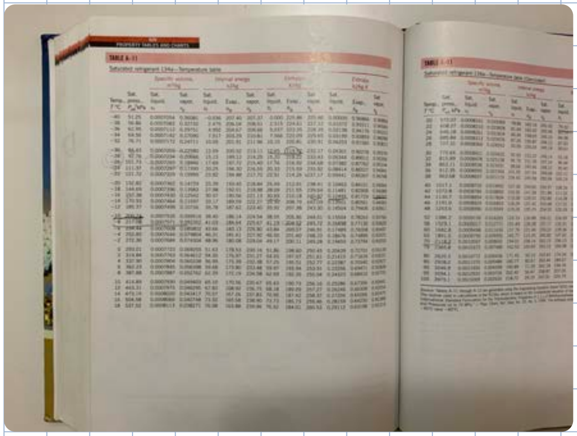


TABLE A-11

Saturated refrigerant-134a—Temperature table

TABLE A-11

Saturated refrigerant-134a—Temperature table (Continued)

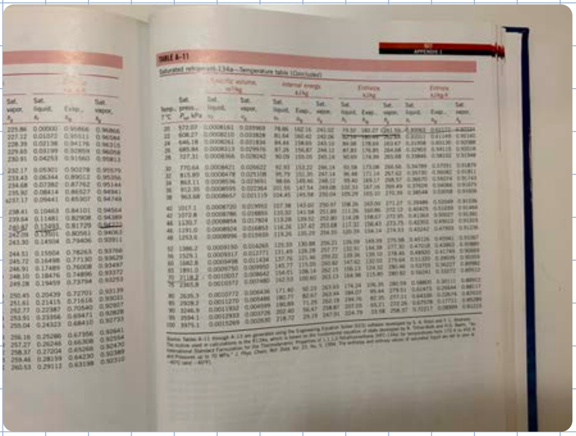


TABLE A-11

Saturated refrigerant-134a—Temperature table (Concluded)

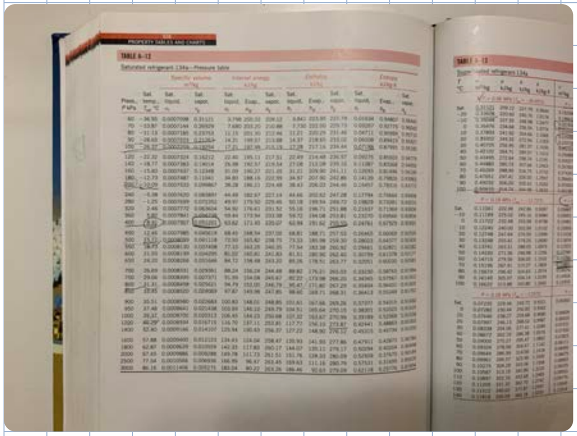


TABLE A-12

Saturated refrigerant-134a—Pressure table

TABLE A-13

Superheated refrigerant 134a

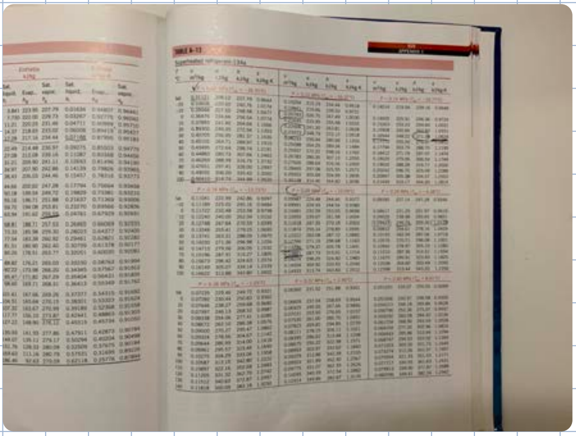


TABLE A-13

Superheated refrigerant 134a

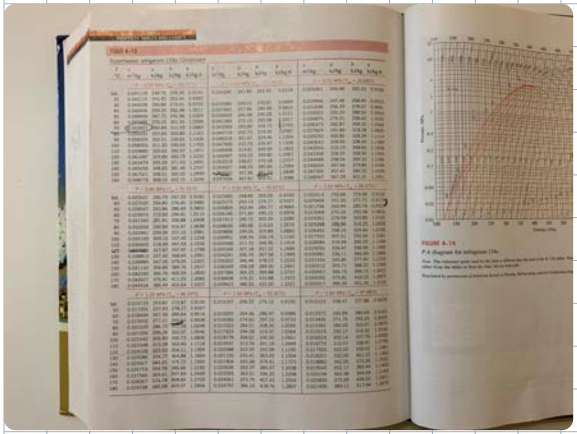


TABLE A-13

Superheated refrigerant 134a (Concluded)

FIGURE A-14

P-h diagram for refrigerant 134a.

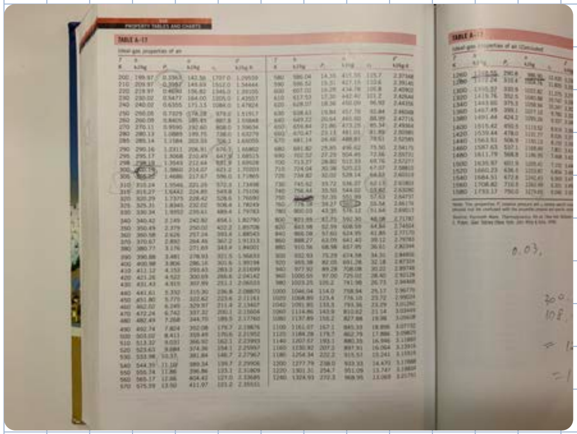


TABLE A-17

Ideal-gas properties of air

TABLE A-17

Ideal-gas properties of air (Continued)

0.03,

300.

108.

= 1

= 1

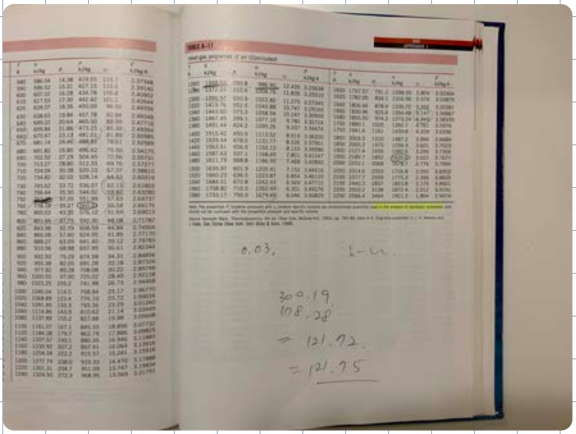


TABLE A-17

Ideal-gas properties of air (Concluded)

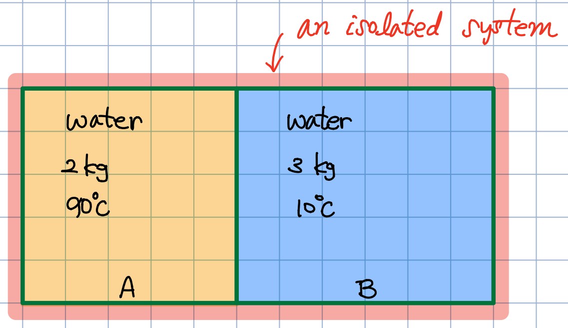
0.03,

h-u.

300.19
108.28

= 121.72.

= 121.75



ΔS_{system} : ?

(due to the mixing process)

$C_{water} = 4.18\ kJ/kg\cdot K$

Reversible ? Irreversible ?

$$\Delta S_{system} = \Delta S_A + \Delta S_B$$

$$\Delta E = Q - W = \Delta U + \cancel{\Delta KE} + \cancel{\Delta PE} \cdots$$

$$\boxed{\delta q} = du + pdv$$

$= Tds$

$$Tds = C_v dT + \boxed{pdv}$$

$dv = 0$

(∵ water is incompressible)

$$\Delta E = \cancel{Q} - \cancel{W} = \boxed{\Delta U} = 0$$

(∵ isolated system)

$$\{\cancel{C} m (T_f - T_i)\}_A + \{\cancel{C} m (T_f - T_i)\}_B = 0$$

$$(2)\cdot(T_f - 363) + (3)\cdot(T_f - 283) = 0$$

$$5T_f = (2)\cdot(363) + (3)\cdot(283)$$

$$\therefore T_f = 315\,K = 42^\circ C$$

$$\int_i^f ds = \int_i^f C_v \frac{dT}{T}$$

$$\Delta s = C_{water} \cdot \ln \frac{T_f}{T_i}$$

$$\Delta S_A = \left\{ m C_{water} \cdot \ln \frac{T_f}{T_i} \right\}_A$$

$$= (2kg)\cdot(4.18\ kJ/kg\cdot K)\cdot \ln \frac{315K}{363K}$$

$$= -1.1857\ kJ/K$$

$$\Delta S_B = \left\{ m C_{water} \cdot \ln \frac{T_f}{T_i} \right\}_B$$

$$= (3kg)\cdot(4.18\ kJ/kg\cdot K)\cdot \ln \frac{315K}{283K}$$

$$= 1.34\ kJ/K$$

$$\Delta S_{system} = \Delta S_A + \Delta S_B$$

$$= (-1.1857) + (1.34)$$

$$= 0.1543\ kJ/K$$

Ans.

$$\Delta S = \Sigma \cancel{\frac{Q_b}{T_b}} + \boxed{S_{gen}} = \Delta S_A + \Delta S_B$$

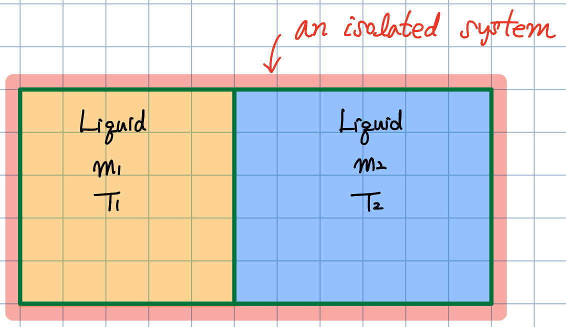
$S_{gen} = 0.1543\ kJ/K$

Ans.

↓

irreversible !

Ans.



Show $\Delta S = mC\ln\left\{\frac{T_1+T_2}{2(T_1\cdot T_2)^{1/2}}\right\}$

$m_1 = m_2$

$m_1 + m_2 = m$

C = constant

isolated system : $\Delta E = \cancel{Q} - \cancel{W} = \Delta U = 0$

$$\{\Delta U\}_1 + \{\Delta U\}_2 = 0$$

$$\{\cancel{C} m_1(T_f - T_1)\}_1 + \{\cancel{C} m_2(T_f - T_2)\}_2 = 0$$

$$m_1T_f - m_1T_1 + m_2T_f - m_2T_2 = 0$$

$$(m_1+m_2)T_f = m_1T_1 + m_2T_2$$

$$T_f = \frac{m_1T_1 + m_2T_2}{m_1+m_2} \quad \leftarrow \quad m_1 = m_2 = m$$

$$= \frac{\cancel{m}(T_1+T_2)}{2\cancel{m}} = \frac{T_1+T_2}{2}$$

$\delta q = du + p\cancel{dv} \quad \leftarrow \quad \delta q/T = ds \quad , \quad du = C_v dT$

$dv \approx 0$ incompressible

$$ds = CdT/T$$

$$\Delta S_1 = m_1 C \ln T_f/T_1$$

$$\Delta S_2 = m_2 C \ln T_f/T_2$$

$$\Delta S_{total} = \Delta S_1 + \Delta S_2 \quad \leftarrow \quad m_1 = m_2 = m/2$$

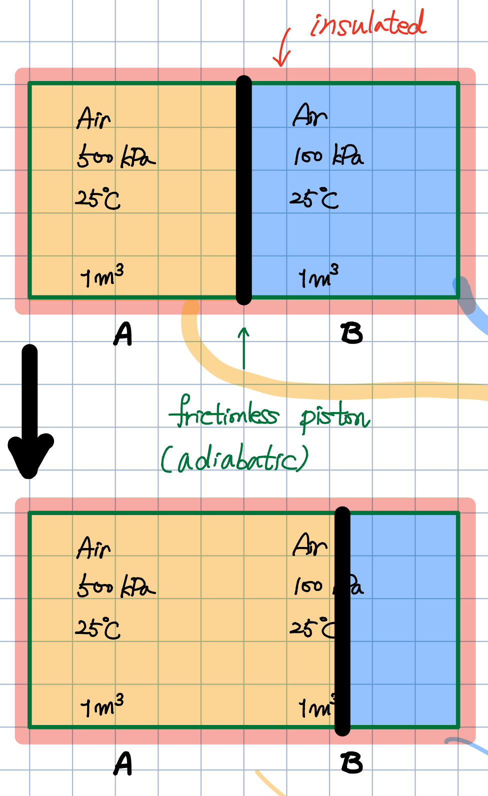
$$= \frac{m}{2}\cdot C\cdot\{\ln T_f/T_1 + \ln T_f/T_2\}$$

$$= mC/2 \cdot \ln\{T_f^2/T_1\cdot T_2\}$$

$$= mC\cdot\ln\left\{\frac{T_f}{(T_1\cdot T_2)^{1/2}}\right\} \quad \leftarrow \quad T_f = \frac{T_1+T_2}{2}$$

$$= m\cdot C\cdot\ln\left\{\frac{T_1+T_2}{2(T_1\cdot T_2)^{1/2}}\right\}$$

Ans.



Assume "ideal gas"

$k = C_p/C_v = 1.4$

adiabatic & reversible process → Determine P_f.

ideal gas → $Pv = RT$

$PV = mRT$

$\boxed{V = mRT/P}$ → $m_A = 5 \cdot m_B$

$(\because T = 25°C)$

Total volume = const

$$\frac{m_A \cancel{R} T_{1A}}{P_{1A}} + \frac{m_B \cancel{R} T_{1B}}{P_{1B}} = \frac{m_A \cancel{R} T_{2A}}{P_f} + \frac{m_B \cancel{R} T_{2B}}{P_f}$$

$$\frac{T_{2A}}{T_{1A}} = \left(\frac{V_{1A}}{V_{2A}}\right)^{k-1} = \left(\frac{P_{2A}}{P_{1A}}\right)^{k-1/k} \rightarrow T_{2A} = T_{1A} \cdot \left(\frac{P_{2A}}{P_{1A}}\right)^{k-1/k}$$

$$\frac{T_{2B}}{T_{1B}} = \left(\frac{P_{2B}}{P_{1B}}\right)^{k-1/k} \rightarrow T_{2B} = T_{1B} \cdot \left(\frac{P_{2B}}{P_{1B}}\right)^{k-1/k}$$

$$\frac{(5\cancel{m_B})\cancel{T_{1A}}}{P_{1A}} + \frac{\cancel{m_B} \cdot \cancel{T_{1B}}}{P_{1B}} = \frac{(5\cancel{m_B}) \cdot \cancel{T_{1A}} \cdot \left(\frac{P_f}{P_{1A}}\right)^{k-1/k}}{P_f} + \frac{\cancel{m_B} \cdot \cancel{T_{1B}} \cdot \left(\frac{P_f}{P_{1B}}\right)^{k-1/k}}{P_f}$$

$(\because T_{1A} = T_{1B} = 25°C)$

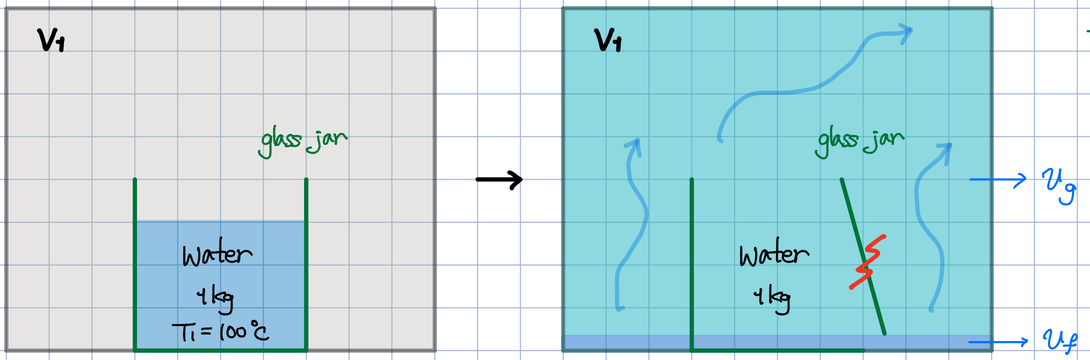
$$\underbrace{\frac{5}{500} + \frac{1}{100}}_{} = \frac{5 \cdot \left(\frac{P_f}{500}\right)^{k-1/k}}{P_f} + \frac{1 \cdot \left(P_f/100\right)^{k-1/k}}{P_f} \leftarrow k = 1.4$$

$$\boxed{10/500} = 5 \cdot \left(P_f/500\right)^{0.4/1.4} \cdot P_f^{-1} + \left(P_f/100\right)^{0.4/1.4} \cdot P_f^{-1}$$

$$0.02 = (0.847) \cdot P_f^{-1/1.4} + (0.268) \cdot P_f^{-1/1.4}$$

$$= (1.115) \cdot P_f^{-1/1.4} \longrightarrow P_f = \left(\frac{0.02}{1.115}\right)^{-1.4} = 278.5\,kPa$$

Ans.

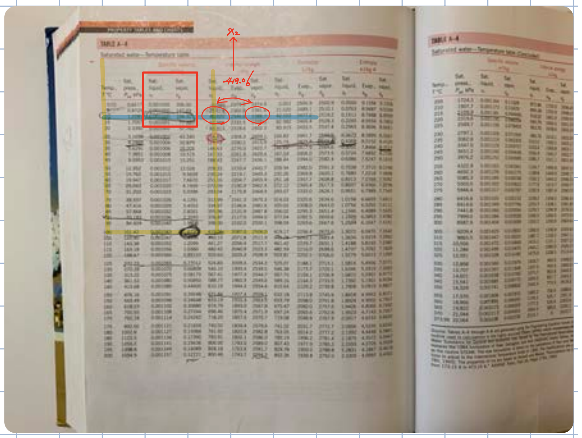


$T_f = 10°C \rightarrow V_1 = ?$

The glass jar is broken,
and the water expands into the tank.

$\Delta E = \cancel{Q} - \cancel{W} = \Delta U + \cancel{\Delta KE} + \cancel{\Delta PE} = 0$

$\boxed{U_1 = U_2}$



State1 : Sat. liq. $\longrightarrow$ $T_1 = 100°C$ $\longrightarrow$ $u_1 = 419.06$ kJ/kg.K
(assumption)

State2 : $T_2 = 10°C$, $u_2 = 419.06$ kJ/kg

$\downarrow$

$u_f = 42.020$ $\longrightarrow$ $u_2 = u_f + x_2 \cdot (u_g - u_f)$
$u_g = 2388.7$

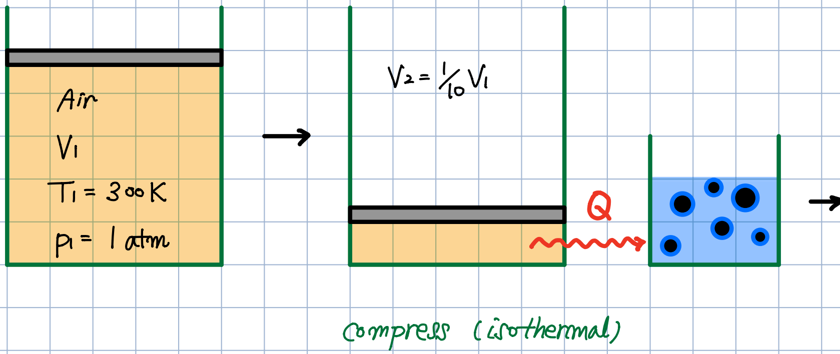
$$\therefore x_2 = \frac{u_2 - u_f}{u_g - u_f} = \frac{419.06 - 42.020}{2388.7 - 42.020} = 0.1607$$

$\downarrow$

$$v_2 = v_f + x_2 \cdot (v_g - v_f)$$
$$= (0.001) + (0.1607) \cdot (106.32 - 0.001)$$
$$= 17.08 \ m^3/kg$$

$\because m = 1kg$

$V_1 = V_2 = 17.08 \ m^3$ Ans.



ideal gas

$C_v = 0.718$ kJ/kg·K
$R = 0.287$ kJ/kg·K
$k = 1.4$

$m = 1\,kg$

a) Determine the heat transfer

A mixture of ice & liquid water (0°C, 1atm) is used to absorb the heat generated from the isothermal compression process. (Latent heat of fusion, $h_{if} = 333.7$ kJ/kg)

b) Determine $\underbrace{\text{the total amount of ice}}_{m_{melt}}$ that melts during this heat transfer process.

c) Determine ΔS_a (the air), ΔS_b (the ice & water)

a) Determine the heat transfer

$$\Delta E = Q - W = \cancel{\Delta U} + \cancel{\Delta KE} + \cancel{\Delta PE} = 0 \longrightarrow Q = W_b = \int_1^2 P\,dV \longleftarrow$$

ideal gas: $PV = mRT$

$P = mRT/V$

$\Delta T = 0 \longrightarrow \Delta U = 0$

$$= \int_1^2 \frac{mRT}{V}\,dV$$

$$= mRT \cdot \ln V_2/V_1 \longleftarrow V_2 = \frac{1}{10} V_1$$

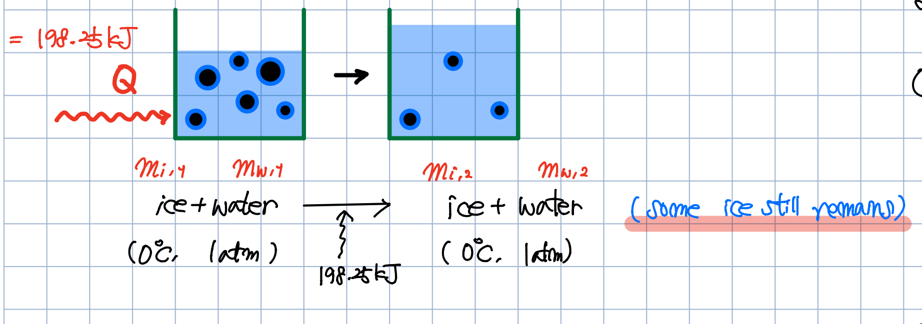
$\therefore V_2/V_1 = 1/10$

$$\therefore Q = (1\,kg)\cdot(0.287\,kJ/kg\cdot K)\cdot(300\,K)\cdot\ln(1/10)$$

$$= -198.25\ kJ$$

Ans. (a)

b) Determine $\underbrace{\text{the total amount of ice}}_{m_{melt}}$ that melts during this heat transfer process.



$$\delta q = dh - \cancel{v\,dp}$$

$$Q = \Delta H$$

$$= (\Delta H)_{ice} + \cancel{(\Delta H)_{water}}$$

We assume that provided heat was used to phase-chang from ice to water

$$Q = m_{melt} \cdot h_{if}$$

$$\therefore m_{melt} = \frac{Q}{h_{if}} = \frac{198.25\ kJ}{333.7\ kJ/kg} = 0.594\ kg$$

Ans.

c) Determine ΔS_a , ΔS_b

(the air) (the ice & water)

$$\Delta S_a = \left(\frac{Q}{T}\right)_b + \cancel{S_{gen}}$$ ← ∵ assume reversible

$$= \frac{-198.25\ \text{kJ}}{300\ \text{K}} = \underline{-0.6608\ \text{kJ/K}}$$

Ans. (C1)

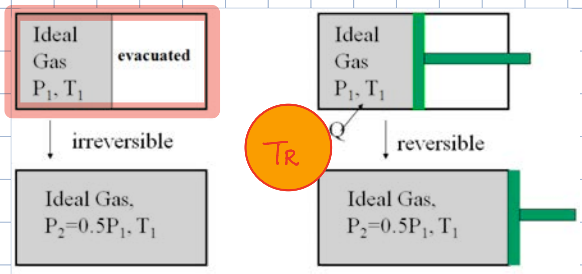
$$\Delta S_b = \frac{198.25\ \text{kJ}}{273\ \text{K}} = \underline{0.7262\ \text{kJ/K}}$$

Ans. (C2)

$$\Delta S_{total} = \Delta S_a + \Delta S_b = (-0.6608) + (0.7262)$$

$$= \underline{0.06539\ \text{kJ/K}}$$

Ans.



Initial and final states are the same for these two processes.

a) Sgen during the unconstrained expansion process

$\boxed{\text{Unconstrained expansion}} \rightarrow \boxed{\text{Reversible Expansion with heat addition}}$

The heat comes from the thermal reservoir ($T_R > T_1$)

= Requirement ?

b) What can be done between the thermal reservoir and the system in order to have a totally reversible process?

c) Determine the total amount of work.

Uncontrolled Expansion

2: $\Delta S_{system} = \frac{Q_b}{T_b} + S_{gen}$ $\longrightarrow$ assume adiabatic : $Q=0$ $\longrightarrow$ $\Delta S_{system} = S_{gen} = -R\ln P_2/P_1$

$= -R \cdot \ln \frac{0.5\cancel{P_1}}{\cancel{P_1}}$

$= -R\ln 1/2$

$= R\ln 2$

Ans. (a)

1: $Tds = dh - vdp$ $\leftarrow$ $pv = RT$

$= C_p dT - RT\,dp/p$

$\int_1^2 ds = \cancel{\int_1^2 C_p dT/T} - \int_1^2 R\,dp/p \rightarrow \Delta S = -R\ln P_2/P_1$

($\because T_1 = T_2$)

piston-cylinder

totally reversible process $\leftarrow$ $S_{gen} = 0$

$\because$ uncontrolled 이든 piston-cylinder 이든 각각의 state 값은 같다.

2: $\Delta S_{system} = \frac{Q_b}{T_b} + S_{gen}$

$= \Delta S_{surrounding} + S_{gen}$

$\therefore S_{gen} = \Delta S_{system} - \Delta S_{surrounding}$

$= \Delta S_{system} - Q_b/T_b$

$= R\ln 2 - \frac{Q}{T_R} = 0$

for a totally reversible process, there should be no entropy generation.

$\therefore Q = RT_R\ln 2$ Ans. (b)

$Q = RT_R\ln 2$

piston : $S_{gen} = R\ln 2 - \frac{Q}{T_R} = 0$

$= R\ln 2 - \frac{RT_1\ln 2}{T_R}$

$= R\ln 2 \left(1 - \frac{T_1}{T_R}\right)$

uncontrolled expansion: $S_{gen} = R\ln 2$

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

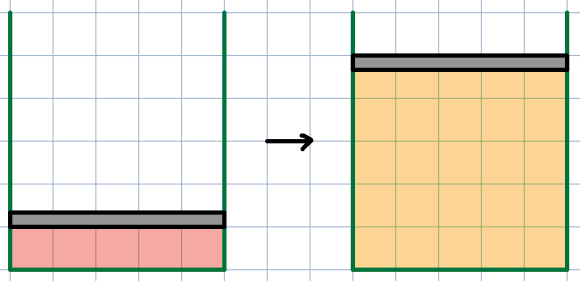
$W = Q - \Delta U$

$= Q - C_v(\cancel{T_2 - T_1})$ $\longrightarrow$ $W = \int_1^2 p\,dV = \int_1^2 RT/V\,dV = RT_1\ln V_2/V_1$ $\leftarrow$ $P_1V_1 = \cancel{m}RT_1$, $P_2V_2 = \cancel{m}RT_2$, $\therefore V_2 = 2V_1$

($m = 1kg$)

$= RT_1\ln 2$ Ans. (c)

in the reversible process entropy generation doesn't exist, which means total heat input on the system was converted onto the work done by the system totally.



$p_1 = 1000$ kPa
$T_1 = 1200$ K

$p_2 = 200$ kPa
$T_2 = 500$ K

Air, 1kg
$C_p = 1$ kJ/kg·K , $R = 0.287$ kJ/kg·K

a) ΔS

b) W

(a)

$\Delta S = S_2 - S_1 \leftarrow$ $\delta q = dh - vdp$

$Tds = C_p dT - RT\,dp/p$

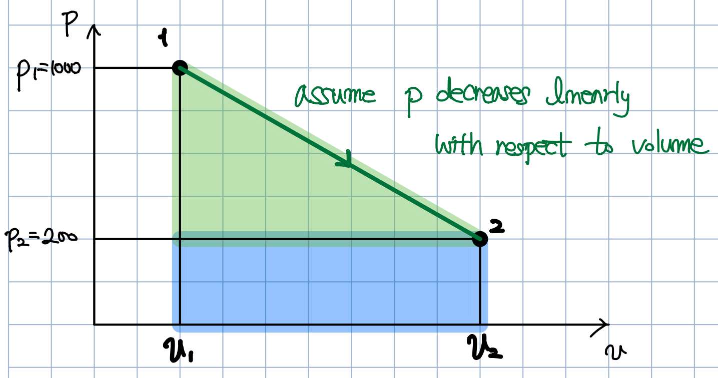
$ds = C_p\,dT/T - R\,dp/p$

$$= m\{C_p \ln T_2/T_1 - R \ln P_2/P_1\}$$

$$= (1\,\text{kg}) \cdot (1\,\text{kJ/kg·K}) \cdot \left\{\ln \frac{500\text{K}}{1200\text{K}} - (0.287) \cdot \ln \frac{200\,\text{kPa}}{1000\,\text{kPa}}\right\}$$

$$= \underline{-0.4136\ \text{kJ/K}}$$ **Ans. (a)**

(b)



assume p decreases linearly
with respect to volume

$$v_1 = RT_1/p_1 = \frac{(0.287\ \cancel{\text{kJ}}/\cancel{\text{kg·K}}) \cdot (1200\cancel{\text{K}})}{1000\ \text{kPa}} = 0.344\ \text{m}^3/\text{kg}$$

$$v_2 = RT_2/p_2 = \frac{(0.287) \cdot (500)}{(200)} = 0.7175\ \text{m}^3/\text{kg}$$

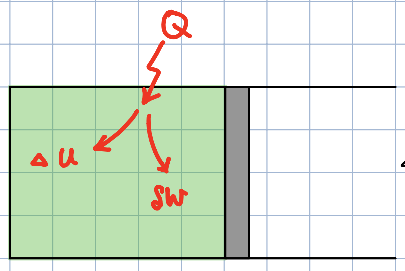
$$w = (v_2 - v_1) \cdot p_2 + (v_2 - v_1) \cdot \frac{p_1 - p_2}{2}$$

$$= (v_2 - v_1) \cdot \frac{p_1 + p_2}{2}$$

$$= (0.7175 - 0.344) \cdot \frac{1000 + 200}{2}$$

$$= 224.1\ \text{kJ/kg}$$

$$\underline{W = m \cdot w = 224.1\ \text{kJ}}$$ **Ans.(b)**



$\Delta E = Q - W = \Delta U + \cancel{\Delta KE} + \cancel{\Delta PE} + \cdots$

$Q = W + \Delta U$

$\delta q = du + pdv$

$\boxed{\delta q} = \cancel{du} + pdv$

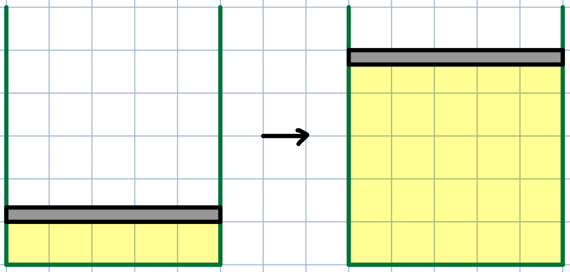
등온 ⟶
단열 ⟶
등압 ⟶
polytropic ⟶
⋮

A closed system , ideal gas , constant specific heat

expansion : $V_1 \to V_2$

$\frac{\Delta S_T}{\Delta S_p}$

Show that the ratio of the entropy change for an isothermal process to $= \frac{k-1}{k}$
the " " " " isobaric process



the ratio A to B = A:B = A/B

assume : reversible → $S_{gen} = 0$

$$\Delta S_{system} = \Delta S_{surr} + S_{gen} = \Sigma \frac{Q_b}{T_b} + \cancel{S_{gen}}$$

$$\boxed{\delta q = Tds}$$

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

$$Q = \Delta U + P\Delta V$$

$$\delta q = du + pdv \leftarrow \delta q = Tds$$

$$Tds = du + pdv \leftarrow pv = RT$$

$$= C_v dT + RT\, dv/v$$

$$\therefore ds = C_v dT/T + R\, dv/v$$

$$\int_1^2 ds = \Delta s = C_v \ln T_2/T_1 + R \ln v_2/v_1$$

$$\Delta s_T = R \ln v_2/v_1$$

$$Tds = dh - vdp \leftarrow pv = RT$$

$$= C_p dT - RT\, dp/p$$

$$\therefore \Delta s = C_p \ln T_2/T_1 - R \ln P_2/P_1$$

$$\Delta S_p = C_p \ln T_2/T_1$$

$$\Delta S_T/\Delta S_p = \frac{R \ln v_2/v_1}{C_p \ln T_2/T_1} = \frac{R \ln v_2/v_1}{C_p \ln v_2/v_1} = \frac{R}{C_p} = \frac{\cancel{R}}{k\cancel{R}/k-1} = k-1/k$$

Ans.

- ideal gas → $pv = RT$ ← R = const

$$pv/T = R = \text{const}$$

$$\downarrow$$

$$\cancel{P_1}V_1/T_1 = \cancel{P_2}V_2/T_2$$

if isobaric : $p_1 = p_2 \longrightarrow V_1/T_1 = V_2/T_2$

$$V_1/V_2 = T_1/T_2 = v_1/v_2$$

$$\delta q = du + pdv = dh - vdp$$

$$C_v dT + pdv = C_p dT - vdp$$

$$(C_p - C_v)\cancel{dT} = pdv + vdp$$

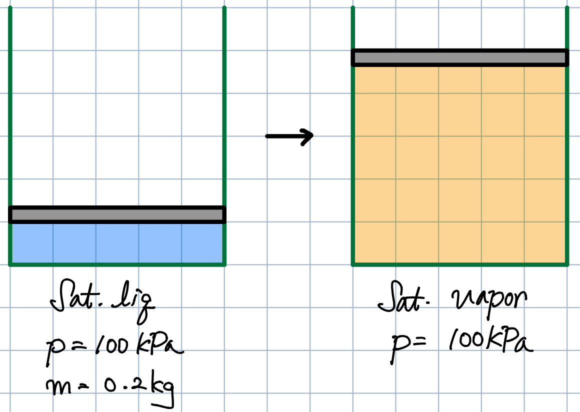
$$= d(pv) = d(RT) = R\cancel{dT}$$

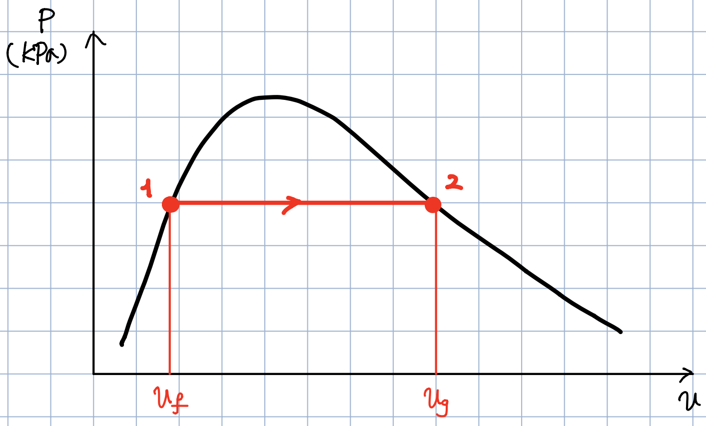
$$C_p - C_v = R$$

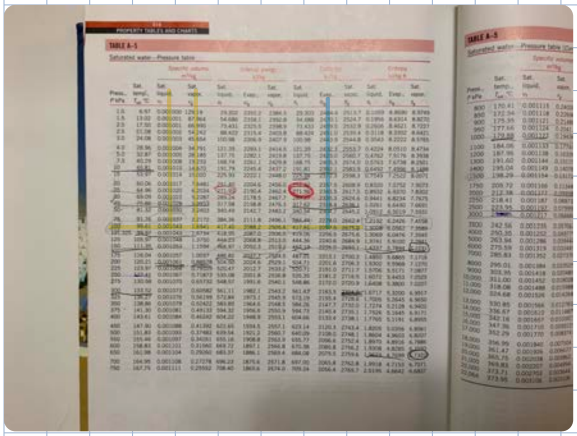
$$\boxed{C_p/C_v = k} \to C_p = kC_v$$

$$kC_v - C_v = C_v(k-1) = R$$

$$\therefore C_v = R/k-1 \quad , \quad C_p = kR/k-1$$







a) the Volume change

$v_{fg} = v_g - v_f$

$= (1.6941) - (0.001043)$

$= 1.6931 \ m^3/kg$

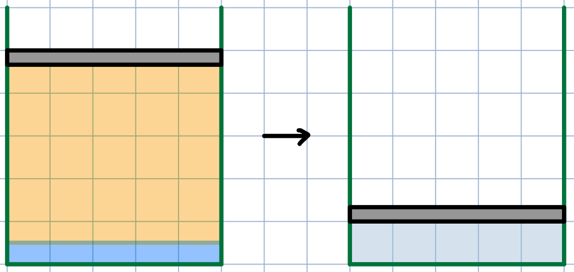
$\Delta V = m v_{fg} = (0.2kg) \cdot (1.6931 \ m^3/kg)$

$= 0.3386 m^3$

b) the amount of energy transferred to the water

Energy → the enthalpy of vaporization at that pressure

$E = m h_{fg} = (0.2kg) \cdot (2257.5 \ kJ/kg) = 451.5 \ kJ$



$T_1 = 25°C$

$p_1 = 100$ kPa

air + liq. water (1kg)

$V_1 = 1 m^3$

$T_2 = 180°C$

air + water vapor

$V_2 = 0.1 m^3$

Air, ideal gas

$c_v = 0.728$ kJ/kg·K

$R = 0.287$ kJ/kg·K

$c_p - c_v = R$

$c_p = c_v + R$

a) State 2 is ideal mixture → $p_2 = ?$

(Neglect any air dissolved in water)

b) $pv^n = \text{const}$ → $W = ?$

c) Determine the heat transfer from the surrounding

(a) State 2 = air + water vapor

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

$pv = RT$

$p = mRT/V$

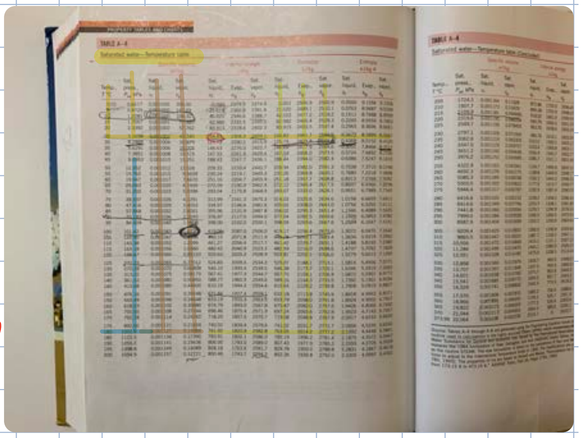
State 1 : Table A-4 : $T_1 = 25°C \rightarrow P_{sat} = 3.17$ kPa

air + liq. water $\rightarrow p_1 = p_{1,wv} + p_{1,air} = 100$ kPa

∴ $p_{1,air} = 96.83$ kPa

$p_1V_1 = mRT_1 \rightarrow m = p_1V_1/RT_1$ (∵ volume occupied by liquid is neglected)

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



State 2 : $p_2V_2 = mRT_2$

$$p_{2,air} = \frac{mRT_2}{V_2} = \frac{(1.13)\cdot(0.287)\cdot(453)}{(0.1)} = 1469.1 \text{ kPa} \longrightarrow p_2 = (1469.1 kPa) + (1002.8) = 2471.9 \text{ kPa}$$

Ans. (a)

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

(b) $pv^n = \text{const} \rightarrow W = ?$

$$W = \int_{V_1}^{V_2} p\,dV \leftarrow pV^n = C$$

⋮

$$= \frac{p_2V_2 - p_1V_1}{1-n}$$

$$= \frac{(2471.9)(0.1) - (100)(1)}{1-1.393}$$

$$= -374.53 \text{ kJ}$$

Ans(b)

$$p_1V_1^n = p_2V_2^n$$

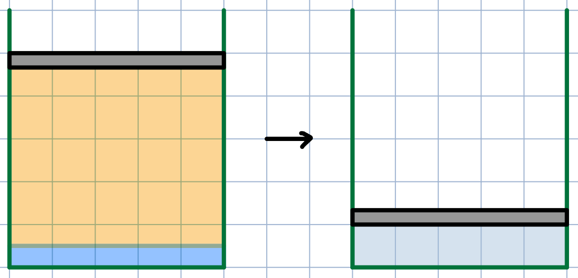
$$(100)\cdot(1)^n = (2471.9)(0.1)^n$$

$$(0.1)^n = 100/2471.9$$

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

∴ $n = 1.393$

(c) Determine the heat transfer from the surrounding



$T_1 = 25°C$

$p_1 = 100 kPa$

air + liq. water (1kg)

$V_1 = 1 m^3$

$T_2 = 180°C$

air + water vapor

$V_2 = 0.1 m^3$

Energy → the enthalpy of vaporization

$\Delta E = m h_{fg} = \Delta H = Q - W$

$Q = \Delta H + W$

$Q = \{\Delta H\}_{air} + \{\Delta H\}_{wv} + \{\Delta H\}_{wl} + W$

$m_{1,wl} = 1kg \longrightarrow V_2 = 0.1 m^3$

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

Table A-4 : $T_2 = 180°C \longrightarrow v_f = 0.001127$

$v_g = 0.19384$.

$v_2 = V_2/m$

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

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

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

$= (1.13 kg) \cdot (1.015 kJ/kg \cdot K) \cdot (180 - 25 K)$

$= 177.78 kJ$

$\{\Delta H\}_{wv} = m_{2,wv} \cdot h_{2,wv} - \cancel{m_{1,wv}} \cdot h_{1,wv} \longleftarrow T = 180°C \longrightarrow h_f = 763.05$

$h_{fg} = 2014.2$

$h_g = 2777.2$

$= (0.51589 kg) \cdot (1802.16)$

$= 929.73 kJ$

$x_2 = \frac{0.51589 kg}{1kg} = 0.51589 \longrightarrow h_{2,wv} = h_f + x_2 (h_{fg})$

$= 1802.16$

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

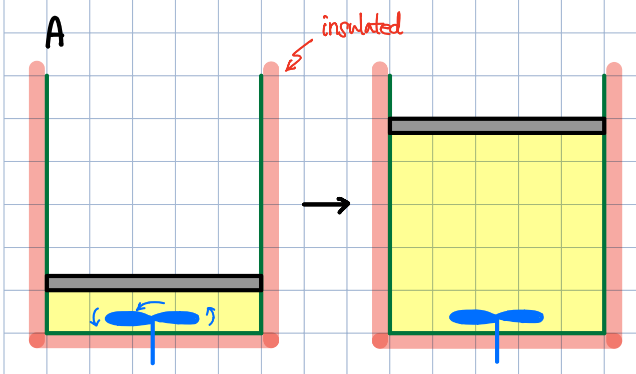
$= (0.484) \cdot (763.05) - (1) \cdot (104.83)$

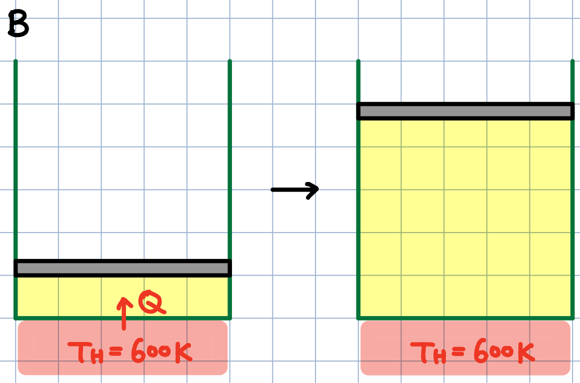
$= 264.48 kJ$

$Q = \{\Delta H\}_{air} + \{\Delta H\}_{wv} + \{\Delta H\}_{wl} + W$

$= (177.78) + (929.73) + (264.48) + (-374.53)$

$= 997.46 kJ$ Ans. (c)





$T_1 = 300K$ $T_2 = 500K$ $T_1 = 300K$ $T_2 = 500K$

$p_1 = 1$ bar $p_2 = 1$ bar $p_1 = 1$ bar $p_2 = 1$ bar

$S_{gen,A}$, $S_{gen,B}$? $(C_p = 1\ kJ/kg\cdot K)$

$\Delta S = \frac{Q_b}{T_b} + S_{gen}$ ← $\delta q = dh - \cancel{v dp}$

$T ds = C_p dT$

$ds = C_p dT/T$

$\Delta S = C_p \ln T_2/T_1$

A: $\Delta S = \cancel{\frac{Q_b}{T_b}} + S_{gen}$

$S_{gen,A} = C_p \ln T_2/T_1 = (1)\cdot \ln 500/300$

$= \underline{0.5108\ kJ/kg\cdot K}$

B: $\Delta S = \frac{Q_b}{T_b} + S_{gen}$

$S_{gen,B} = \Delta S - Q_b/T_b$ ← $\delta q = dh - \cancel{v dp}$

$= C_p dT$

$= C_p \ln T_2/T_1 - \frac{200}{600}$ $q_b = C_p(T_2 - T_1)$

$= (0.5108) - 1/3$ $= (1)\cdot(500-300)$

$= \underline{0.1775\ kJ/kg\cdot K}$ $= 200\ kJ/kg$

$\underline{S_{gen,A} > S_{gen,B}}$ Ans.

$S_{gen,A} = C_p \ln T_2/T_1$ $S_{gen,B} = C_p \ln T_2/T_1 - \frac{Q_b}{\boxed{T_b}}$

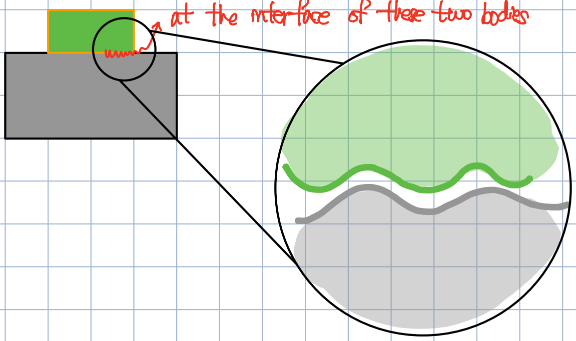
$\hookrightarrow T_b \to \infty$; $S_{gen,B} = S_{gen,A}$

2 → 3 : reversible isothermal expansion

Reversible Process : a process that can be reversed without leaving any trace on the surroundings

Irreversibilities

1. Friction



some work is needed to overcome the friction force

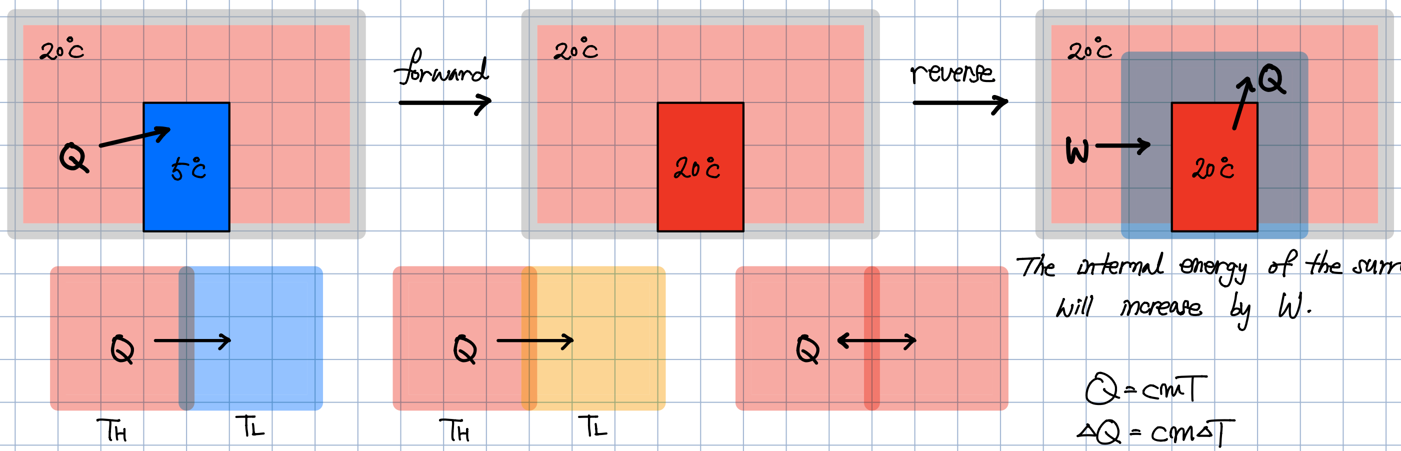
↓

This energy is converted to heat

↓

Temperature ↑

2. Heat Transfer



$\Delta T = T_H - T_L$ irreversible

$\Delta T \approx 0$ less and less irreversible

$\Delta T = 0$ reversible

The internal energy of the surroundings will increase by W.

$Q = cmT$

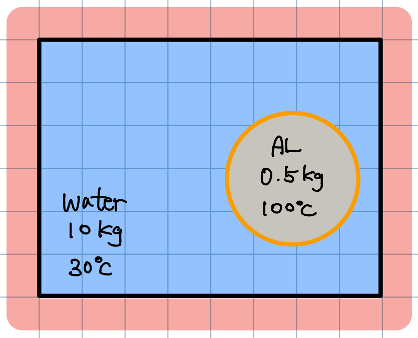
$\Delta Q = cm\Delta T$

↓

ΔT가 작으면 작을수록 ΔQ가 적다.

↓

아무리 reversible이 좋다고 해도 $\Delta T \approx 0$인 상태에서의 열교환 X



$C_{water} = 4.18\ kJ/kg\cdot K$
$C_{AL} = 0.941\ kJ/kg\cdot K$

The maximum potential work that is lost ? → AL 입장

$$\Delta E = Q - W = \cancel{\Delta U} + \cancel{\Delta KE} + \cancel{\Delta PE} = 0$$

$$Q \leftrightarrow W$$

$$\Delta S_{system} = \Delta S_{surr} + S_{gen}$$
$$= \frac{Q_b}{T_b} + S_{gen} = \Delta S_{water} + \Delta S_{AL}$$

$$\Delta S = \int_1^2 \frac{\delta q}{T} \leftarrow \delta q = C_{avg}\, dT$$

$$\left[\begin{array}{l} \delta q = du + \cancel{pdv} \\ \quad = C_v dT \\ \delta q = dh - \cancel{vdp} \\ \quad = C_p dT \end{array}\right.$$

$$\left[\begin{array}{l} \Delta S_w \\ \\ \Delta S_{AL} = C_{AL} \cdot M_{AL} \cdot \ln \frac{T_2}{T_1} \end{array}\right.$$

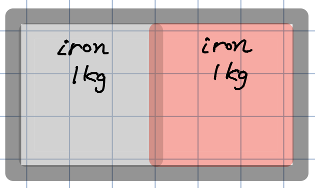
$\therefore\ S_{gen} = \Delta S_w + \Delta S_{AL} \approx$ ▨

$$Q_{AL} = C_{AL} \cdot M_{AL} \cdot \boxed{\Delta T}$$
$$= (0.941\ kJ/kgK)\cdot(0.5\ kg)\cdot(30.81 - 100\ K)$$
$$= \underline{-32.5\ kJ}$$

$$\Delta U = 0$$
$$\{Cm(T_2 - T_1)\}_{water} + \{Cm(T_2 - T_1)\}_{AL} = 0$$
$$\{(4.18\ kJ/kg\cdot K)\cdot(10\ kg)\cdot(T_2 - 30\ K)\} +$$
$$\{(0.941)\cdot(0.5)\cdot(T_2 - 100K)\} = 0$$
$$40.18(T_2 - 30) + 0.4705\cdot(T_2 - 100) = 0$$
$$40.65 T_2 = 1252.45$$
$$\therefore T_2 = 30.81\,℃$$

$$\therefore\ W_{AL} = |-32.5\,kJ| = \underline{32.5\,kJ}$$ Ans.

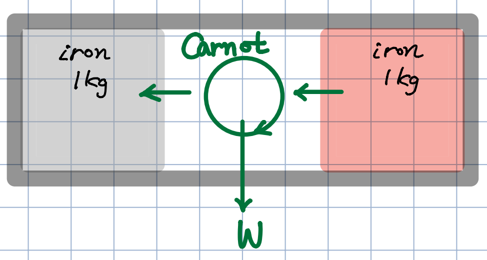
$C_p = C_v = 1\ kJ/kg \cdot K$



$T_1 = 0°C$ $T_2 = 100°C$

a) $T_f = ?$
b) $\Delta S = ?$

Two blocks → Carnot cycle



c) $T_f = ?$
d) $W = ?$
e) $\Delta S = ?$

(a, b) $\Delta E = \cancel{Q} - \cancel{W} = \Delta U + \Delta \cancel{KE} + \Delta \cancel{PE} = 0$

$\Delta U = \Delta U_{iron,1} + \Delta U_{iron,2}$ ← $\Delta U = C_{avg} \cdot \Delta T$

$= \cancel{m}C(T_f - T_1) + \cancel{m}C(T_f - T_2)$

$= 0$

$2T_f = T_1 + T_2$

$T_f = (T_1 + T_2)/2 = \underline{50°C}$ Ans. (a)

$= 323K$

$\delta q = du + pdv$

$\Delta S_{syst} = \cancel{\Delta S_{surr}} + S_{gen} = \Delta S_1 + \Delta S_2$ ← $Tds = C_v dT$

$ds = C_v dT/T$

$= mC \cdot \ln \frac{323K}{273K} + mC \cdot \ln \frac{323K}{373K}$ $\Delta S = C \cdot \ln T_2/T_1$

$= \underline{0.02425\ kJ/K}$ Ans. (b)

(c, d, e) $\boxed{\eta_c = 1 - q_{out}/q_{in}}$

$= 1 - \left| \frac{mC(T_f - T_1)}{mC(T_f - T_2)} \right|$ ← ∵ $T_f < T_2$

$= 1 - \frac{\cancel{mC}(T_f - T_1)}{\cancel{mC}(T_2 - T_f)} = \boxed{1 - \frac{T_L}{T_H}}$

$\boxed{\frac{T_f - T_1}{T_2 - T_f} = \frac{T_L}{T_H}}$

$\therefore \frac{\Delta T_L}{\Delta T_H} = \frac{T_L}{T_H}$ ★

$dT_L/dT_H = T_L/T_H$

$\int_{T_1}^{T_f} dT_L/T_L = \int_{T_f}^{T_2} dT_H/T_H$

$\ln T_L \Big]_{T_1}^{T_f} = \ln T_H \Big]_{T_f}^{T_2}$

$\ln T_f/T_1 = \ln T_2/T_f$

$T_f/T_1 = T_2/T_f$

$T_f^2 = T_1 \cdot T_2$

$\therefore T_f = (T_1 \cdot T_2)^{1/2}$

$= (273K \cdot 373K)^{1/2}$

$= \underline{319.1K}$ Ans. (c)

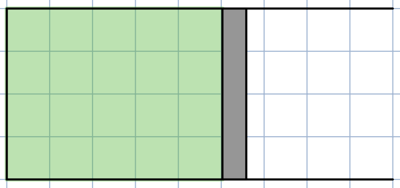
absolute !

$W = Q_{in} - Q_{out}$

$= mC(T_2 - T_f) - mC(T_f - T_1)$

$= (1kg) \cdot (1 kJ/kg \cdot K) \cdot (373K - 319.1K) - (1) \cdot (1) \cdot (319.1 - 273)$

$= \underline{7.8\ kJ}$ Ans. (d)



$\Delta Q = \Delta U + P\Delta V$

adiabatic $\cancel{\Delta Q} = \Delta U + P\Delta V$

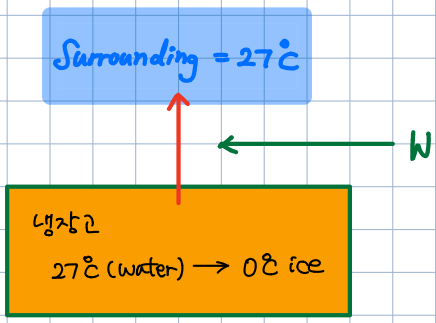
isothermal

isobaric $\Delta Q = \Delta U + P\Delta V$

const volume $\Delta Q = \Delta U + P\cancel{\Delta V}$

$\underline{\Delta S_{total} = 0}$ ∵ carnot cycle

Ans. (e)



$C_p = 1\,kJ/kg\cdot K$: Heat capacity of water is assumed constant.

The enthalpy of fusion at freezing point = $\Delta h = 333\ kJ/kg$

$\Delta S = 1.2204\ kJ/kg\cdot K$ at water 0°C → ice 0°C

The cost of 1kg of ice : \$2

Price of electricity = \$0.1/kW-hour

a) \$ to freeze water from 0°C to ice at 0°C

b) \$ to cool water from 27°C to 0°C

freeze : water(0°C) → ice(0°C)

$$\Delta S = \left(\frac{Q}{T}\right)_{int.rev} \leftarrow \text{reversible}$$

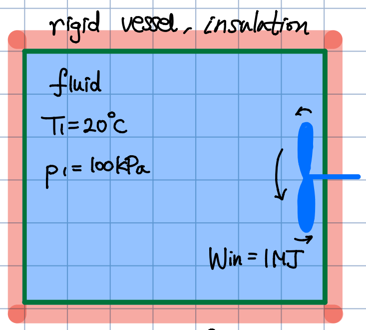
$$Q = T\Delta S = T\cdot m\Delta S$$
$$= (273K)\cdot(1kg)\cdot(1.2204\ kJ/kg\cdot K)$$
$$= \underline{333.17\ kJ}$$

$$cost = \left\{\$0.1/kW\text{-hour}\ \frac{1kW}{1kJ/s}\cdot\frac{1\ hour}{3600s}\right\}\cdot(333.17kJ) = \underline{\$\,9.25\times10^{-3}}\ \text{Ans.(a)}$$

Cool water(27°C) → water(0°C)

$$Q - \cancel{W} = \Delta U + \cancel{\Delta KE} + \cancel{\Delta PE}$$
$$Q = mC\Delta T$$
$$= (1kg)\cdot(1kJ/kg\cdot K)\cdot(27-0)K$$
$$\fallingdotseq \underline{27\ kJ}$$

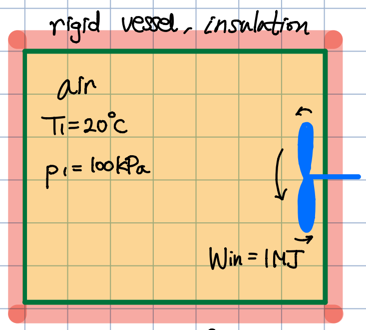
$$cost = \left\{\$0.1/kW\text{-hour}\ \frac{1kW}{1kJ/s}\cdot\frac{1\ hour}{3600s}\right\}\cdot(27kJ) = \underline{\$\,7.5\times10^{-4}}\ \text{Ans.(b)}$$



$V = 0.1m^3$

$v = 0.001 m^3/kg$

$C = 4.18 kJ/kgK$



$V = 0.1m^3$

$C_v = 0.72 kJ/kg \cdot K$

$R = 0.29 kJ/kg \cdot K$

$\Delta U = ?$

$\Delta S = ?$

A) Liquid water

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

$\Delta U = -W = -(-1MJ) = \underline{1MJ}$ Ans.

$Q = Cm\Delta T$

$\delta Q = Cm\,dT = TdS$

$\therefore dS = Cm\,dT/T$

$\Delta S = Cm \ln T_2/T_1$

$v = V/m \rightarrow m = V/v = \dfrac{0.1m^3}{0.001m^3/kg} = 100\,kg$

$\Delta U = -W = mC\Delta T$

$= mC(T_2 - T_1)$

$mCT_2 = -W + mcT_1$

$\therefore T_2 = -\dfrac{W}{mC} + T_1$

$= \dfrac{-(-1MJ)}{(100kg)\cdot(4.18kJ/kg \cdot K)} + 293K$

$= 295.4K$

$\Delta S = (4.18 kJ/kg \cdot K)\cdot(100kg)\cdot \ln {}^{295.4}/_{293} = \underline{3.41 kJ/K}$ Ans.

B) Air

$\underline{\Delta U = 1MJ}$ Ans.

$\delta q = du + p\cancel{dv}$

$Tds = C_v dT$

$ds = C_v dT/T$

$\Delta S = mC_v \ln T_2/T_1$

$pv = RT \rightarrow pV = mRT \rightarrow m = pV/RT$

$= \dfrac{(100kPa)\cdot(0.1m^3)}{(0.29kJ/kg \cdot K)\cdot(293K)}$

$= 0.1177 kg$

$\cancel{\delta q} = du + p\cancel{dv} = 0$?

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

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

$\cancel{Q} + W_{in} = \Delta U + \cancel{W_b} = \Delta U + P\cancel{\Delta V}$

$\Delta U = W_{in} = 1MJ$

$\int_1^2 mC_v dT = W$

$mC_v(T_2 - T_1) = W$

$T_2 = W/mC_v + T_1 = \dfrac{1000kJ}{(0.1177)\cdot(0.72)} + 293K$

$= 12{,}093K$

$\Delta S = mC_v \ln T_2/T_1$

$= (0.1177)\cdot(0.72)\cdot \ln \dfrac{12093}{293}$

$= \underline{0.3153\ kJ/K}$ Ans.