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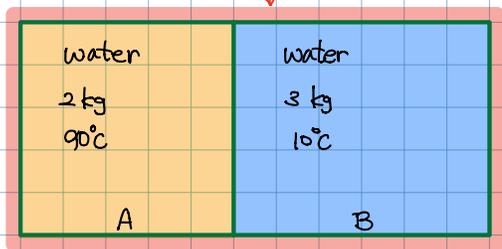
TABLE 8-11
Estimated enthalpy of saturated steam
Temperature table (continued)

Temp. °C	Temp. °F	Pressure bar	Pressure psia	Specific volume m³/kg	Specific volume ft³/lb	Enthalpy kJ/kg	Enthalpy Btu/lb	Entropy kJ/kg·K	Entropy Btu/lb·R
100	212	1.013	14.7	1.673	26.81	419.0	180.2	7.354	3.418
110	230	1.433	20.8	1.483	23.74	452.1	194.4	7.424	3.452
120	248	1.985	28.5	1.372	21.61	480.1	205.9	7.477	3.480
130	266	2.609	37.7	1.245	19.84	504.4	215.6	7.521	3.504
140	284	3.256	47.2	1.107	18.37	525.9	223.9	7.558	3.525
150	302	3.921	56.9	0.961	17.19	545.1	231.1	7.589	3.544
160	320	4.603	66.8	0.811	16.25	562.1	237.4	7.615	3.561
170	328	5.301	76.9	0.674	15.48	577.1	243.0	7.638	3.576
180	338	6.014	87.2	0.550	14.84	590.4	248.0	7.658	3.589
190	348	6.741	97.7	0.443	14.30	602.2	252.5	7.675	3.600
200	358	7.481	108.4	0.351	13.84	612.8	256.6	7.690	3.610
210	368	8.233	119.3	0.272	13.44	622.4	260.4	7.703	3.619
220	378	9.000	130.4	0.204	13.09	631.1	264.0	7.715	3.627
230	388	9.780	141.7	0.146	12.79	639.0	267.4	7.726	3.634
240	398	10.58	153.2	0.100	12.53	646.2	270.7	7.736	3.640
250	408	11.40	164.9	0.072	12.31	652.8	273.9	7.745	3.645
260	418	12.24	176.8	0.053	12.12	658.9	277.0	7.753	3.649
270	428	13.10	188.9	0.040	11.95	664.6	279.9	7.761	3.653
280	438	13.98	201.2	0.030	11.80	669.9	282.7	7.768	3.656
290	448	14.88	213.7	0.022	11.67	674.8	285.4	7.774	3.659
300	458	15.80	226.4	0.016	11.55	679.4	288.0	7.780	3.661
310	468	16.74	239.3	0.012	11.44	683.7	290.5	7.785	3.663
320	478	17.70	252.4	0.009	11.34	687.7	292.9	7.790	3.665
330	488	18.68	265.7	0.007	11.25	691.4	295.2	7.794	3.666
340	498	19.68	279.2	0.005	11.17	694.8	297.4	7.798	3.667
350	508	20.70	292.9	0.004	11.10	698.0	299.5	7.801	3.668
360	518	21.74	306.8	0.003	11.03	701.0	301.5	7.804	3.669
370	528	22.80	320.9	0.002	10.97	703.8	303.4	7.807	3.670
380	538	23.88	335.2	0.002	10.91	706.4	305.2	7.809	3.671
390	548	24.98	349.7	0.001	10.86	708.8	306.9	7.811	3.672
400	558	26.10	364.4	0.001	10.81	711.1	308.5	7.813	3.673
410	568	27.24	379.3	0.001	10.76	713.2	310.0	7.814	3.674
420	578	28.40	394.4	0.001	10.72	715.2	311.4	7.815	3.674
430	588	29.58	409.7	0.001	10.68	717.0	312.7	7.816	3.675
440	598	30.78	425.2	0.001	10.64	718.7	314.0	7.817	3.675
450	608	32.00	440.9	0.001	10.60	720.3	315.2	7.818	3.676
460	618	33.24	456.8	0.001	10.57	721.8	316.4	7.818	3.676
470	628	34.50	472.9	0.001	10.53	723.2	317.5	7.819	3.676
480	638	35.78	489.2	0.001	10.50	724.5	318.6	7.819	3.676
490	648	37.08	505.7	0.001	10.47	725.7	319.6	7.819	3.676
500	658	38.40	522.4	0.001	10.44	726.8	320.6	7.819	3.676
510	668	39.74	539.3	0.001	10.41	727.8	321.5	7.819	3.676
520	678	41.10	556.4	0.001	10.38	728.7	322.4	7.819	3.676
530	688	42.48	573.7	0.001	10.35	729.5	323.2	7.819	3.676
540	698	43.88	591.2	0.001	10.32	730.3	324.0	7.819	3.676
550	708	45.30	608.9	0.001	10.29	731.0	324.7	7.819	3.676
560	718	46.74	626.8	0.001	10.26	731.6	325.4	7.819	3.676
570	728	48.20	644.9	0.001	10.23	732.2	326.0	7.819	3.676
580	738	49.68	663.2	0.001	10.20	732.7	326.6	7.819	3.676
590	748	51.18	681.7	0.001	10.17	733.2	327.1	7.819	3.676
600	758	52.70	700.4	0.001	10.14	733.6	327.6	7.819	3.676
610	768	54.24	719.3	0.001	10.11	734.0	328.0	7.819	3.676
620	778	55.80	738.4	0.001	10.08	734.3	328.4	7.819	3.676
630	788	57.38	757.7	0.001	10.05	734.6	328.7	7.819	3.676
640	798	58.98	777.2	0.001	10.02	734.8	329.0	7.819	3.676
650	808	60.60	796.9	0.001	10.00	735.0	329.2	7.819	3.676
660	818	62.24	816.8	0.001	9.97	735.1	329.4	7.819	3.676
670	828	63.90	836.9	0.001	9.94	735.2	329.5	7.819	3.676
680	838	65.58	857.2	0.001	9.91	735.2	329.6	7.819	3.676
690	848	67.28	877.7	0.001	9.88	735.2	329.6	7.819	3.676
700	858	69.00	898.4	0.001	9.85	735.1	329.6	7.819	3.676
710	868	70.74	919.3	0.001	9.82	735.0	329.5	7.819	3.676
720	878	72.50	940.4	0.001	9.79	734.9	329.4	7.819	3.676
730	888	74.28	961.7	0.001	9.76	734.7	329.3	7.819	3.676
740	898	76.08	983.2	0.001	9.73	734.5	329.2	7.819	3.676
750	908	77.90	1004.9	0.001	9.70	734.3	329.1	7.819	3.676
760	918	79.74	1026.8	0.001	9.67	734.1	329.0	7.819	3.676
770	928	81.60	1048.9	0.001	9.64	733.8	328.9	7.819	3.676
780	938	83.48	1071.2	0.001	9.61	733.5	328.8	7.819	3.676
790	948	85.38	1093.7	0.001	9.58	733.2	328.7	7.819	3.676
800	958	87.30	1116.4	0.001	9.55	732.9	328.6	7.819	3.676
810	968	89.24	1139.3	0.001	9.52	732.6	328.5	7.819	3.676
820	978	91.20	1162.4	0.001	9.49	732.2	328.4	7.819	3.676
830	988	93.18	1185.7	0.001	9.46	731.8	328.3	7.819	3.676
840	998	95.18	1209.2	0.001	9.43	731.4	328.2	7.819	3.676
850	1008	97.20	1232.9	0.001	9.40	730.9	328.1	7.819	3.676
860	1018	99.24	1256.8	0.001	9.37	730.4	328.0	7.819	3.676
870	1028	101.30	1280.9	0.001	9.34	729.9	327.9	7.819	3.676
880	1038	103.38	1305.2	0.001	9.31	729.3	327.8	7.819	3.676
890	1048	105.48	1329.7	0.001	9.28	728.7	327.7	7.819	3.676
900	1058	107.60	1354.4	0.001	9.25	728.1	327.6	7.819	3.676
910	1068	109.74	1379.3	0.001	9.22	727.4	327.5	7.819	3.676
920	1078	111.90	1404.4	0.001	9.19	726.7	327.4	7.819	3.676
930	1088	114.08	1429.7	0.001	9.16	726.0	327.3	7.819	3.676
940	1098	116.28	1455.2	0.001	9.13	725.2	327.2	7.819	3.676
950	1108	118.50	1480.9	0.001	9.10	724.4	327.1	7.819	3.676
960	1118	120.74	1506.8	0.001	9.07	723.6	327.0	7.819	3.676
970	1128	123.00	1532.9	0.001	9.04	722.7	326.9	7.819	3.676
980	1138	125.28	1559.2	0.001	9.01	721.8	326.8	7.819	3.676
990	1148	127.58	1585.7	0.001	8.98	720.8	326.7	7.819	3.676
1000	1158	129.90	1612.4	0.001	8.95	719.8	326.6	7.819	3.676

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Temperature table (continued)

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380	538	23.88	335.2	0.002	10.91	706.4	305.2	7.809	3.671
390	548	24.98	349.7	0					

an isolated system



$\Delta S_{\text{system}} = ?$
(due to the mixing process)

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

Reversible? Irreversible?

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

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

$$\delta q = du + p \, dv$$

$$= T \, ds$$

$$T \, ds = C_{\text{ud}} T + p \, dv$$

$$du = 0$$

(\because water is incompressible)

$$\int_i^f ds = \int_i^f C_{\text{ud}} \frac{dT}{T}$$

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

$$\Delta S_A = \left\{ m C_{\text{water}} \cdot \ln \frac{T_f}{T_{i,A}} \right\}$$

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

$$= -1.1857 \text{ kJ/K}$$

$$\Delta S_B = \left\{ m C_{\text{water}} \cdot \ln \frac{T_f}{T_{i,B}} \right\}$$

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

$$= 1.34 \text{ kJ/K}$$

$$\Delta E = Q - W = \Delta U = 0 \quad (\because \text{isolated system})$$

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

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

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

$$\therefore T_f = 315 \text{ K} = 42^\circ\text{C}$$

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

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

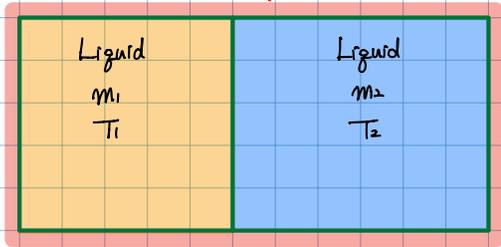
$$= 0.1543 \text{ kJ/K} \quad \text{Ans.}$$

$$\Delta S = \sum \frac{Q_b}{T_b} + S_{\text{gen}} = \Delta S_A + \Delta S_B$$

$$S_{\text{gen}} = 0.1543 \text{ kJ/K} \quad \text{Ans.}$$

irreversible!
Ans.

an isolated system



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

$$m_1 = m_2$$

$$m_1 + m_2 = m$$

$$C = \text{constant}$$

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

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

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

$$m_1 T_f - m_1 T_1 + m_2 T_f - m_2 T_2 = 0$$

$$(m_1 + m_2) T_f = m_1 T_1 + m_2 T_2$$

$$T_f = \frac{m_1 T_1 + m_2 T_2}{m_1 + m_2} \quad \leftarrow m_1 = m_2 = m$$

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

$$dS = du + pdv \quad \leftarrow dS_{T,P} = dv, \quad du = CvdT$$

$du \approx 0$ incompressible

$$dv = CvdT$$

$$\Delta S_1 = m_1 C \ln \frac{T_f}{T_1}$$

$$\Delta S_2 = m_2 C \ln \frac{T_f}{T_2}$$

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

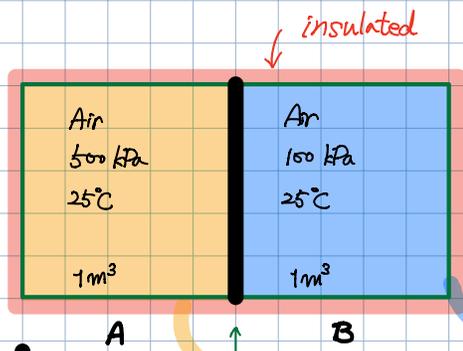
$$= \frac{m}{2} \cdot C \cdot \{ \ln \frac{T_f}{T_1} + \ln \frac{T_f}{T_2} \}$$

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

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

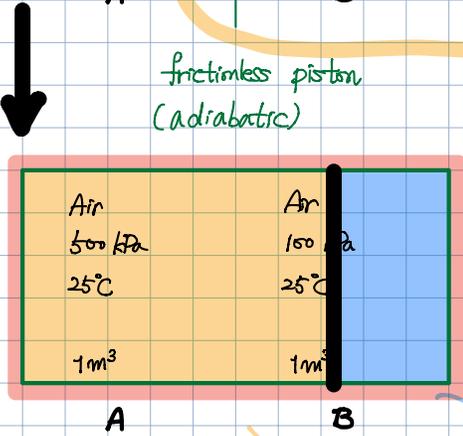
$$= m \cdot C \cdot \ln \left\{ \frac{T_1 + T_2}{2(T_1 T_2)^{1/2}} \right\}$$

Ans.



Assume "ideal gas"
 $\gamma = C_p/C_v = 1.4$

adiabatic & reversible process \rightarrow Determine P_f .



ideal gas $\rightarrow P_u = RT$

$$PV = mRT$$

$$V = \frac{mRT}{P}$$

$$\rightarrow \frac{m_A = 5 \cdot m_B}{(\because T = 25^\circ C)}$$

total volume = const

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

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

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

$$\frac{(5m_B) T_A}{P_{1A}} + \frac{m_B T_B}{P_{1B}} = \frac{(5m_B) T_A \cdot \left(\frac{P_f}{P_{1A}}\right)^{\frac{\gamma}{\gamma-1}}}{P_f} + \frac{m_B T_B \cdot \left(\frac{P_f}{P_{1B}}\right)^{\frac{\gamma}{\gamma-1}}}{P_f} \quad (\because T_A = T_B = 25^\circ C)$$

$$\frac{5}{500} + \frac{1}{100} = \frac{5 \cdot \left(\frac{P_f}{500}\right)^{\frac{1.4}{1.4-1}}}{P_f} + \frac{1 \cdot \left(\frac{P_f}{100}\right)^{\frac{1.4}{1.4-1}}}{P_f} \quad \leftarrow \gamma = 1.4$$

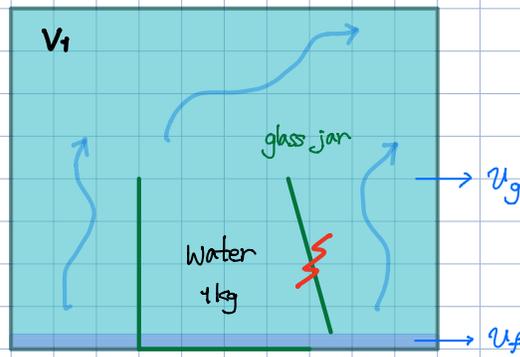
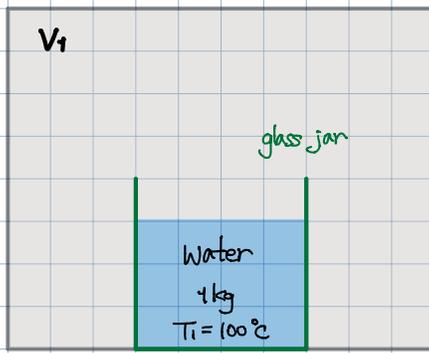
$$\frac{10}{500} = 5 \cdot \left(\frac{P_f}{500}\right)^{0.4} \cdot P_f^{-1} + \left(\frac{P_f}{100}\right)^{0.4} \cdot P_f^{-1}$$

$$0.02 = (0.847) \cdot P_f^{-0.4} + (0.268) \cdot P_f^{-0.4}$$

$$= (1.115) \cdot P_f^{-0.4}$$

$$P_f = \left(\frac{0.02}{1.115}\right)^{-1.4} = 278.5 \text{ kPa}$$

Ans.



$$T_2 = 10^\circ\text{C} \rightarrow V_1 = ?$$

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

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

$$U_1 = U_2$$

State 1 : Sat. liq. $\rightarrow T_1 = 100^\circ\text{C} \rightarrow u_1 = 419.06 \text{ kJ/kg}$
(assumption)

State 2 : $T_2 = 10^\circ\text{C}$, $u_2 = 419.06 \text{ kJ/kg}$

$$u_f = 42.020$$

$$u_g = 2388.7$$

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

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

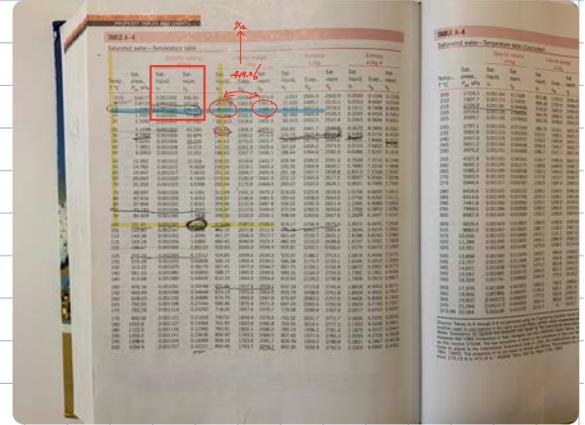
$$v_2 = v_f + x_2 \cdot (v_g - v_f)$$

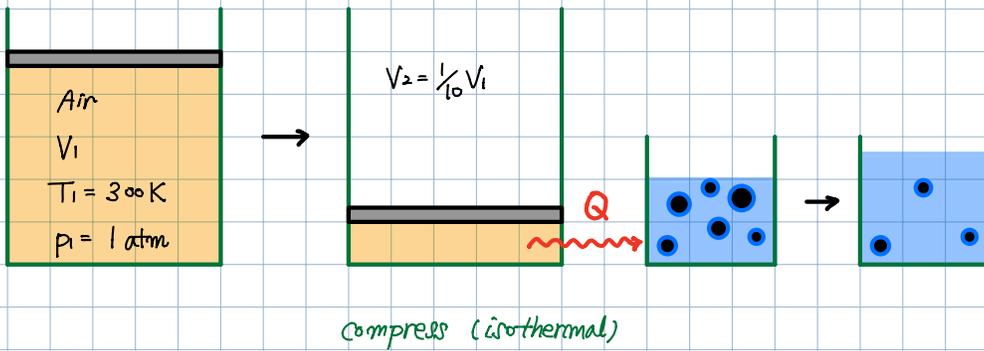
$$= (0.001) + (0.1607) \cdot (106.32 - 0.001)$$

$$= 17.08 \text{ m}^3/\text{kg}$$

$$V_1 = V_2 = 17.08 \text{ m}^3$$

Ans.





ideal gas

$$C_v = 0.718 \text{ kJ/kg}\cdot\text{K}$$

$$R = 0.287 \text{ kJ/kg}\cdot\text{K}$$

$$k = 1.4$$

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

compress (isothermal)

a) Determine the heat transfer

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

b) Determine the total amount of ice that melts during this heat transfer process.

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

a) Determine the heat transfer

$$\Delta E = Q - W = \Delta U + \Delta KE + \Delta PE = 0 \rightarrow Q = W_b = \int_1^2 P dV \leftarrow \text{ideal gas} \cdot PV = mRT$$

$$P = \frac{mRT}{V}$$

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

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

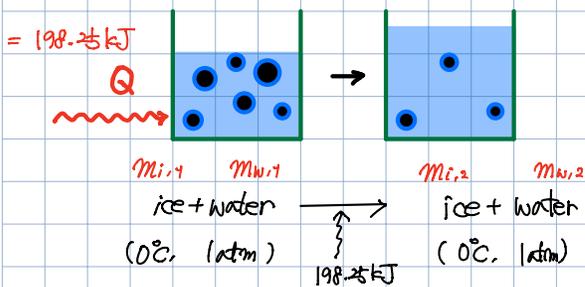
$$\therefore \frac{V_2}{V_1} = \frac{1}{10}$$

$$\therefore Q = (1 \text{ kg}) \cdot (0.287 \text{ kJ/kg}\cdot\text{K}) \cdot (300 \text{ K}) \cdot \ln\left(\frac{1}{10}\right)$$

$$= -198.25 \text{ kJ}$$

Ans. (a)

b) Determine the total amount of ice that melts during this heat transfer process.



$$d'q = dh - v dp$$

$$Q = \Delta H$$

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

(some ice still remains)

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

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

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

Ans.

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

$$\Delta S_a = \left(\frac{Q}{T}\right)_b + S_{gen} \leftarrow \because \text{assume reversible}$$

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

Ans. (c1)

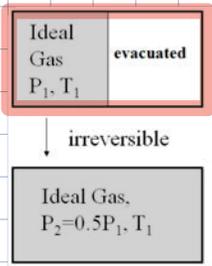
$$\Delta S_b = \frac{198.25 \text{ kJ}}{273 \text{ K}} = 0.7262 \text{ kJ/K}$$

Ans. (c2)

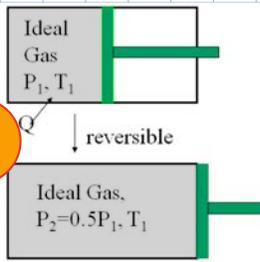
$$\Delta S_{total} = \Delta S_a + \Delta S_b = (-0.6608) + (0.7262)$$

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

Ans.



T_R



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

a) S_{gen} during the uncontrolled expansion process

Uncontrolled expansion

Reversible expansion with heat addition

The heat comes from the thermal reservoir ($T_R > T_i$)
= 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: $\Delta S_{system} = \frac{Q_b}{T_b} + S_{gen}$

assume adiabatic: $Q=0 \rightarrow \Delta S_{system} = S_{gen} = -R \ln \frac{P_2}{P_1}$

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

$= -R \ln \frac{1}{2}$

$= R \ln 2$ **Ans. (a)**

1: $T ds = dh - u dp \leftarrow pu = RT$
 $= C_p dT - RT dp/p$

$\int_1^2 ds = \int_1^2 C_p dT - \int_1^2 R dp/p \rightarrow \Delta S = -R \ln \frac{P_2}{P_1}$
($\because T_1 = T_2$)

Piston-cylinder

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

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

$\therefore S_{gen} = \Delta S_{system} - \Delta S_{surrounding}$
 $= \Delta S_{system} - \frac{Q_b}{T_b}$
 $= R \ln 2 - \frac{Q}{T_R} = 0$

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

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

$W = Q - \Delta U$
 $= Q - C_v(T_2 - T_1)$

($m=1\text{kg}$)

$W = \int_1^2 p dV = \int_1^2 \frac{RT}{V} dV = RT \ln \frac{V_2}{V_1}$
 $= RT \ln 2$ **Ans. (c)**

$PV_1 = mRT_1$
 $P_1 V_1 = mRT_1$
 $\therefore V_2 = 2V_1$

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

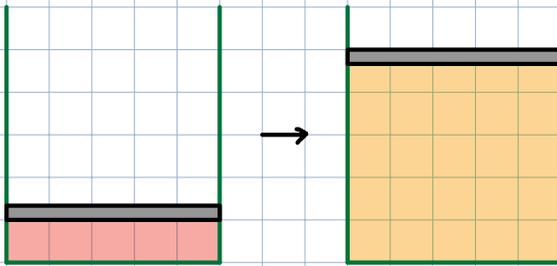
\because uncontrolled \neq piston-cylinder \neq 각각 상태 값은 같지 않.

piston:

$S_{gen} = R \ln 2 - \frac{Q}{T_R} = 0$
 $= R \ln 2 - \frac{RT_R \ln 2}{T_R}$
 $= R \ln 2 \left(1 - \frac{T_i}{T_R}\right)$

uncontrolled expansion:

$S_{gen} = R \ln 2$



$$p_1 = 1000 \text{ kPa}$$

$$T_1 = 1200 \text{ K}$$

$$p_2 = 200 \text{ kPa}$$

$$T_2 = 500 \text{ K}$$

Air, 1 kg

$$C_p = 1 \text{ kJ/kg}\cdot\text{K}, R = 0.287 \text{ kJ/kg}\cdot\text{K}$$

a) ΔS

b) W

(a)

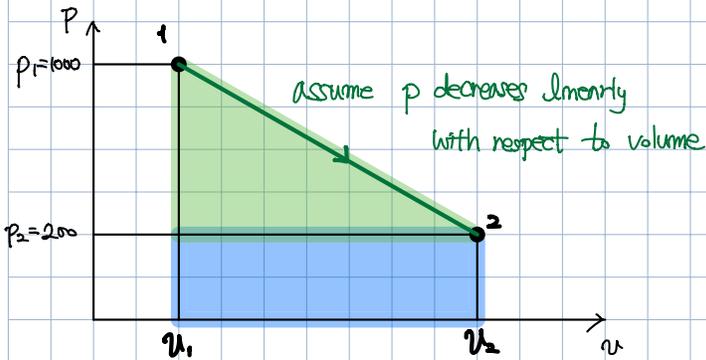
$$\Delta S = S_2 - S_1 \quad \leftarrow \quad \begin{aligned} \delta s &= dh - v dp \\ T ds &= C_p dT - R T \frac{dp}{p} \\ ds &= C_p \frac{dT}{T} - R \frac{dp}{p} \end{aligned}$$

$$= m \left\{ C_p \ln \frac{T_2}{T_1} - R \ln \frac{p_2}{p_1} \right\}$$

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

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

(b)



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

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

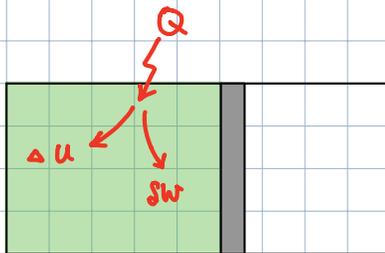
$$W = (v_2 - v_1) \cdot p_2 + (v_2 - v_1) \cdot \frac{p_1 - p_2}{2}$$

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

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

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

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



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

$$Q = W + \Delta U$$

$$\delta s = du + p dv$$

- 등온 \longrightarrow
- 등압 \longrightarrow
- 등容 \longrightarrow
- polytropic \longrightarrow
- ⋮

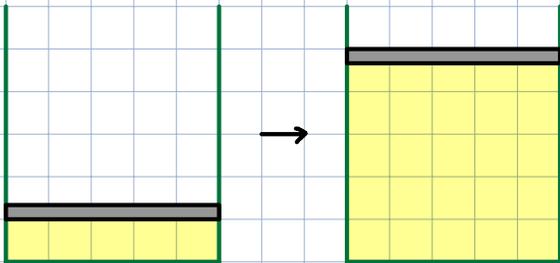
$$\delta s = du + p dv$$

A closed system, ideal gas, constant specific heat

Expansion: $V_1 \rightarrow V_2$



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



the ratio A to B = $A \cdot B = \frac{A}{B}$

assume = reversible $\rightarrow \Delta S_{gen} = 0$

$$\Delta S_{system} = \Delta S_{sum} + S_{gen} = \sum \frac{Q_k}{T_k} + S_{gen}$$

$$dS = T ds$$

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

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

$$dS = du + p dv \leftarrow dS = T ds$$

$$T ds = du + p dv \leftarrow pu = RT$$

$$= C_v dT + R T \frac{dv}{v}$$

$$\therefore dv = C_v \frac{dT}{T} + R \frac{dv}{v}$$

$$\int_1^2 ds = \Delta S = C_v \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1}$$

$$\Delta S_T = R \ln \frac{v_2}{v_1}$$

$$T ds = dh - v dp \leftarrow pu = RT$$

$$= C_p dT - R T \frac{dp}{p}$$

$$\therefore \Delta S = C_p \ln \frac{T_2}{T_1} - R \ln \frac{p_2}{p_1}$$

$$\Delta S_P = C_p \ln \frac{T_2}{T_1}$$

$$\frac{\Delta S_T}{\Delta S_P} = \frac{R \ln \frac{v_2}{v_1}}{C_p \ln \frac{T_2}{T_1}} = \frac{R \ln \frac{v_2}{v_1}}{C_p \ln \frac{v_2}{v_1}} = \frac{R}{C_p}$$

• ideal gas $\rightarrow pu = RT \leftarrow R = \text{const}$

$$\frac{pu}{T} = R = \text{const}$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

if isobaric = $p_1 = p_2 \rightarrow \frac{V_1}{T_1} = \frac{V_2}{T_2}$

$$\frac{V_1}{V_2} = \frac{T_1}{T_2} = \frac{v_1}{v_2}$$

$$dS = du + p dv = dh - v dp$$

$$C_v dT + p dv = C_p dT - v dp$$

$$(C_p - C_v) dT = p dv + v dp$$

$$= d(pv) = d(RT) = R dT$$

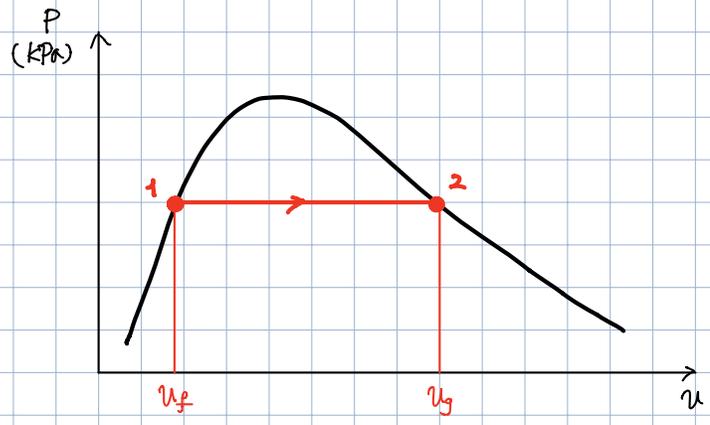
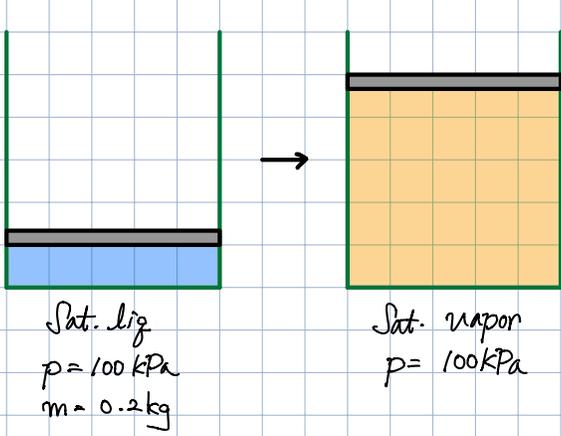
$$C_p - C_v = R$$

$$\frac{C_p}{C_v} = k \rightarrow C_p = k C_v$$

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

$$\therefore C_v = \frac{R}{k-1} \rightarrow C_p = \frac{kR}{k-1}$$

Ans.



a) the Volume change

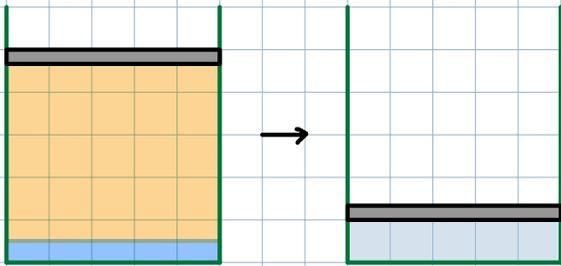
$$\begin{aligned}
 v_{fg} &= v_g - v_f \\
 &= (1.6941) - (0.001043) \\
 &= 1.6931 \text{ m}^3/\text{kg}
 \end{aligned}$$

$$\begin{aligned}
 \Delta V &= m v_{fg} = (0.2 \text{ kg}) \cdot (1.6931 \text{ m}^3/\text{kg}) \\
 &= 0.3386 \text{ m}^3
 \end{aligned}$$

b) the amount of energy transferred to the water

Energy \rightarrow the enthalpy of vaporization at that pressure

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



$T_1 = 25^\circ\text{C}$
 $p_1 = 100 \text{ kPa}$
 air + liq. water (1 kg)
 $V_1 = 1 \text{ m}^3$

$T_2 = 180^\circ\text{C}$
 air + water vapor
 $V_2 = 0.1 \text{ m}^3$

Air, ideal gas

$$C_{v,air} = 0.728 \text{ kJ/kg}\cdot\text{K}$$

$$R = 0.287 \text{ kJ/kg}\cdot\text{K}$$

$$C_p - C_v = R$$

$$C_p = C_v + R$$

a) State 2 is ideal mixture $\rightarrow p_2 = ?$

(Neglect any air dissolved in water)

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

c) Determine the heat transfer from the surrounding

(a) State 2 = air + water vapor

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

$$pV = nRT$$

$$p = nRT/V$$

State 1: Table A-4: $T_1 = 25^\circ\text{C} \rightarrow p_{\text{sat}} = 3.17 \text{ kPa}$

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

$$\therefore p_{1,air} = 96.83 \text{ kPa}$$

$$p_1 V_1 = n R T_1 \rightarrow n = \frac{p_1 V_1}{R T_1} \quad (\because \text{volume occupied by liquid is neglected})$$

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

State 2:

$$p_2 V_2 = n R T_2$$

$$p_{2,air} = \frac{n R T_2}{V_2}$$

$$= \frac{(1.13) \cdot (0.287) \cdot (453)}{(0.1)} = 1469.1 \text{ kPa}$$

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

$$p_2 = (1469.1 \text{ kPa}) + (1002.8)$$

$$= 2471.9 \text{ kPa}$$

Ans. (a)

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

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

$$= \frac{p_2 V_2 - p_1 V_1}{1-n}$$

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

$$= -874.53 \text{ kJ}$$

Ans (b)

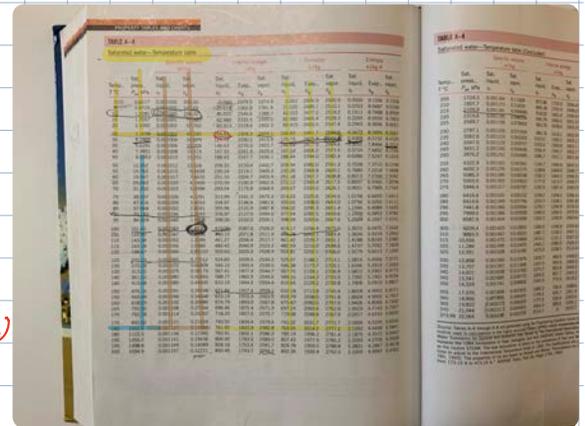
$$p_1 V_1^n = p_2 V_2^n$$

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

$$(0.1)^n = \frac{100}{2471.9}$$

$$n \cdot \log(0.1) = \log\left(\frac{100}{2471.9}\right)$$

$$\therefore n = 1.393$$



(c) Determine the heat transfer from the surrounding

Energy \rightarrow the enthalpy of vaporization

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

$$Q = \Delta H + W$$

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

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

if all liq. water turned into sat. vapor, $V_2 = 0.1 \text{ m}^3/\text{kg}$

$$\text{Table A-4: } T_2 = 180^\circ\text{C} \longrightarrow \begin{aligned} v_f &= 0.001127 \\ v_g &= 0.19384 \end{aligned}$$

$$\begin{aligned} v_2 &= \frac{V_2}{m} \\ v_g &= \frac{V_2}{m_{2,\text{wv}}} \longrightarrow m_{2,\text{wv}} = \frac{V_2}{v_g} = \frac{0.1 \text{ m}^3}{0.19384 \text{ m}^3/\text{kg}} = 0.51589 \text{ kg} \\ m_{2,\text{wl}} &= 1 - 0.51589 = 0.484 \text{ kg} \end{aligned}$$

$$\begin{aligned} \{\Delta H\}_{\text{air}} &= m_{\text{air}} \cdot C_p (T_2 - T_1) \leftarrow C_p = C_v + R \\ &= (1.13 \text{ kg}) \cdot (1.015 \text{ kJ/kg}\cdot\text{K}) \cdot (180 - 25 \text{ K}) \\ &= 177.78 \text{ kJ} \end{aligned}$$

$$\begin{aligned} \{\Delta H\}_{\text{wv}} &= m_{2,\text{wv}} \cdot h_{2,\text{wv}} - m_{1,\text{wv}} \cdot h_{1,\text{wv}} \leftarrow T = 180^\circ\text{C} \longrightarrow \begin{aligned} h_f &= 763.05 \\ h_g &= 2014.2 \\ h_g &= 2771.2 \end{aligned} \\ &= (0.51589 \text{ kg}) \cdot (1802.16) \\ &= 929.73 \text{ kJ} \end{aligned}$$

$$\begin{aligned} \{\Delta H\}_{\text{wl}} &= m_{2,\text{wl}} \cdot h_{2,\text{wl}} - m_{1,\text{wl}} \cdot h_{1,\text{wl}} \\ &= (0.484) \cdot (763.05) - (1) \cdot (104.83) \\ &= 264.48 \text{ kJ} \end{aligned}$$

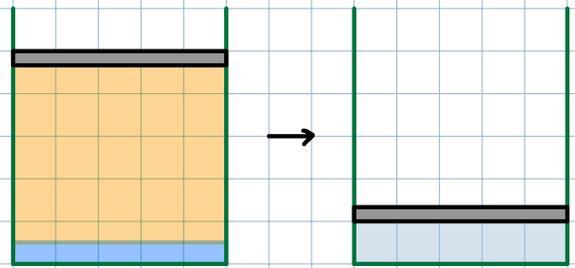
$$x_2 = \frac{0.51589 \text{ kg}}{1 \text{ kg}} = 0.51589 \longrightarrow h_{2,\text{wv}} = h_f + x_2 (h_{fg}) = 1802.16$$

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

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

$$= 997.46 \text{ kJ}$$

Ans. (c)



$$T_1 = 25^\circ\text{C}$$

$$p_1 = 100 \text{ kPa}$$

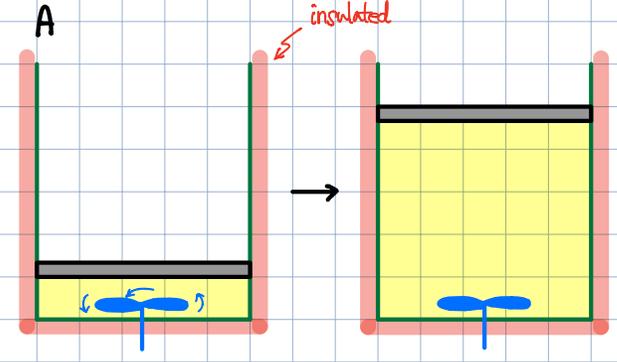
air + liq. water (1 kg)

$$V_1 = 1 \text{ m}^3$$

$$T_2 = 180^\circ\text{C}$$

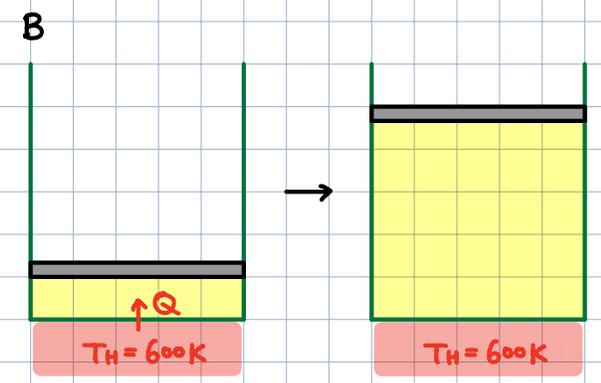
air + water vapor

$$V_2 = 0.1 \text{ m}^3$$



$T_1 = 300\text{K}$
 $p_1 = 1\text{ bar}$

$T_2 = 500\text{K}$
 $p_2 = 1\text{ bar}$



$T_1 = 300\text{K}$
 $p_1 = 1\text{ bar}$

$T_2 = 500\text{K}$
 $p_2 = 1\text{ bar}$

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

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

$ds = dh - vdp$
 $Tds = Cp dT$
 $ds = Cp dT/T$
 $\Delta S = Cp \ln T_2/T_1$

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

$S_{gen,A} = Cp \ln T_2/T_1 = (1) \cdot \ln 500/300 = 0.5108\text{ kJ/kg}\cdot\text{K}$

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

$S_{gen,B} = \Delta S - \frac{Q_b}{T_b}$
 $= Cp \ln T_2/T_1 - \frac{200}{600}$
 $= (0.5108) - 1/3$
 $= 0.1775\text{ kJ/kg}\cdot\text{K}$

$ds = dh - vdp$
 $= Cp dT$
 $q_b = Cp(T_2 - T_1)$
 $= (1) \cdot (500 - 300)$
 $= 200\text{ kJ/kg}$

$S_{gen,A} > S_{gen,B}$

Ans.

$S_{gen,A} = Cp \ln T_2/T_1$

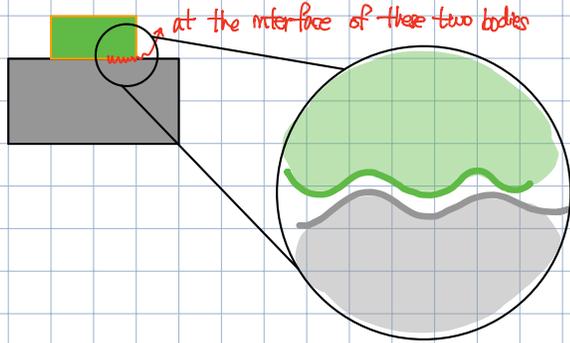
$S_{gen,B} = Cp \ln T_2/T_1 - \frac{Q_b}{T_b}$

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

2 → 3 = reversible isothermal expansion

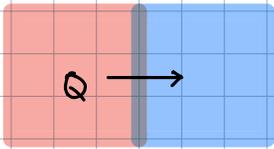
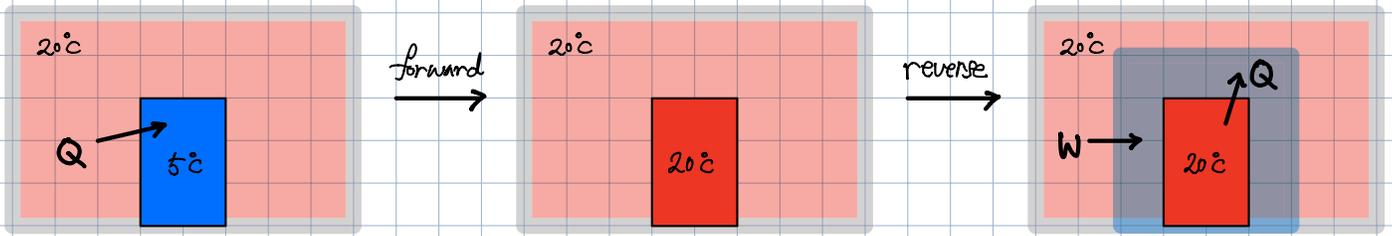
Reversible Process: a process that can be reversed without leaving any trace on the surroundings
Inreversibilities

1. Friction

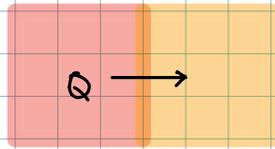


some work is needed to overcome the friction force
 ↓
 This energy is converted to heat
 ↓
 Temperature ↑

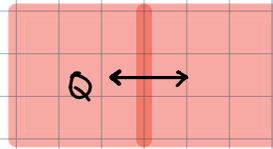
2. Heat Transfer



$\Delta T = T_H - T_L$
 irreversible



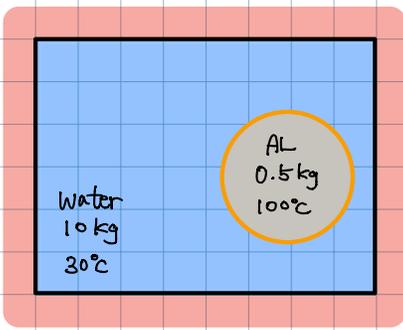
$\Delta T \approx 0$
 less and less irreversible



$\Delta T = 0$
 reversible

The internal energy of the surroundings will increase by W.

$Q = cm\Delta T$
 $\Delta Q = cm\Delta T$
 ↓
 ΔT 가 작으면 ΔQ 가 작아진다.
 ↓
 offset reversible의 결과로 $\Delta T \approx 0$ 인 상태에서의 열교환 X



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

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

The maximum potential work that is lost?

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

$$Q \leftrightarrow W$$

$$Q_{\text{AL}} = C_{\text{AL}} \cdot M_{\text{AL}} \cdot \Delta T$$

$$= (0.941 \text{ kJ/kg}\cdot\text{K}) \cdot (0.5 \text{ kg}) \cdot (30.81 - 100 \text{ K})$$

$$= \underline{-32.5 \text{ kJ}}$$

$$\Delta U = 0$$

$$\{Cm(T_2 - T_1)\}_{\text{water}} + \{Cm(T_2 - T_1)\}_{\text{AL}} = 0$$

$$\{4.18 \text{ kJ/kg}\cdot\text{K} \cdot (10 \text{ kg}) \cdot (T_2 - 30 \text{ K})\} +$$

$$\{(0.941) \cdot (0.5) \cdot (T_2 - 100 \text{ K})\} = 0$$

$$40.18(T_2 - 30) + 0.4705 \cdot (T_2 - 100) = 0$$

$$40.65 T_2 = 1252.45$$

$$\therefore T_2 = \underline{30.81^\circ\text{C}}$$

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

$$\Delta S_{\text{system}} = \Delta S_{\text{sur}} + S_{\text{gen}}$$

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

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

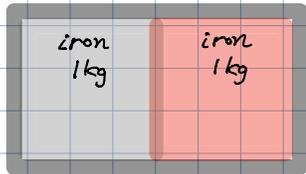
$$\left[\begin{aligned} \delta Q &= du + p\delta v \\ &= C_{\text{nd}} dT \\ \delta Q &= dh - v\delta p \\ &= C_{\text{pd}} dT \end{aligned} \right.$$

$$\Delta S_{\text{w}}$$

$$\Delta S_{\text{AL}} = C_{\text{AL}} \cdot M_{\text{AL}} \cdot \ln \frac{T_2}{T_1}$$

$$\therefore S_{\text{gen}} = \Delta S_{\text{w}} + \Delta S_{\text{AL}} = \textcircled{0}$$

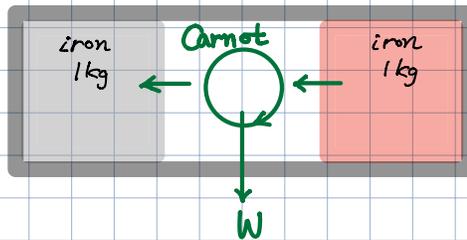
$$C_p = C_u = 1 \text{ kJ/kg}\cdot\text{K}$$



$$T_1 = 0^\circ\text{C} \quad T_2 = 100^\circ\text{C}$$

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

Two blocks \rightarrow Carnot cycle



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

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

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

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

$$= 0$$

$$2T_f = T_1 + T_2$$

$$T_f = (T_1 + T_2) / 2 = 50^\circ\text{C}$$

Ans. (a)

$$= 323\text{K}$$

(c, d, e) $\eta_c = 1 - \frac{Q_{\text{out}}}{Q_{\text{in}}}$

$$= 1 - \frac{mC(T_f - T_1)}{mC(T_f - T_2)} \leftarrow \because T_f < T_2$$

$$= 1 - \frac{T_f - T_1}{T_f - T_2} = 1 - \frac{T_L}{T_H}$$

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

$$\therefore \frac{\Delta T_L}{\Delta T_H} = \frac{T_L}{T_H} \quad \star$$

$$\Delta S_{\text{system}} = \Delta S_{\text{surround}} + \Delta S_{\text{gen}} = \Delta S_1 + \Delta S_2$$

$$= mC \cdot \ln \frac{323\text{K}}{273\text{K}} + mC \cdot \ln \frac{323\text{K}}{373\text{K}}$$

$$= 0.02425 \text{ kJ/K}$$

Ans. (b)

$$dS = du + pdu$$

$$Tds = C_{\text{nd}}dT$$

$$ds = C_{\text{nd}} \frac{dT}{T}$$

$$\Delta S = C \cdot \ln \frac{T_2}{T_1}$$

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

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

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

$$= 7.8 \text{ kJ}$$

Ans. (d)

$$\frac{dT_L}{dT_H} = \frac{T_L}{T_H}$$

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

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

$$\ln \frac{T_f}{T_1} = \ln \frac{T_2}{T_f}$$

$$\frac{T_f}{T_1} = \frac{T_2}{T_f}$$

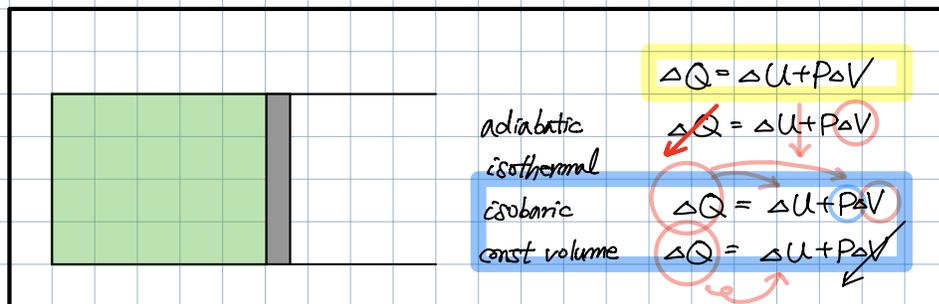
$$T_f^2 = T_1 \cdot T_2$$

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

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

$$= 319.1\text{K}$$

Ans. (c)



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

$$\Delta S_{\text{total}} = 0 \quad \because \text{Carnot cycle}$$

Ans. (e)

Surrounding = 27°C

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

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

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

냉장고

27°C (water) → 0°C ice

← W

The cost of 1 kg 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)

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

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

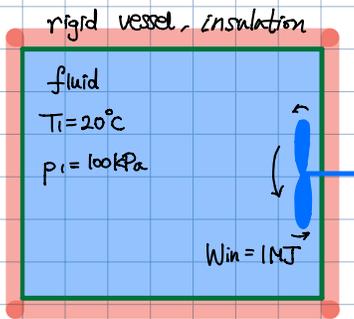
$$\text{cost} = \left\{ \$0.1 / \text{kW}\cdot\text{hour} \cdot \frac{1 \text{ kW}}{1 \text{ kJ/s}} \cdot \frac{1 \text{ hour}}{3600 \text{ s}} \right\} \cdot (333.17 \text{ kJ}) = \underline{\$9.25 \times 10^{-3}} \text{ Ans. (a)}$$

cool water (27°C) → water (0°C)

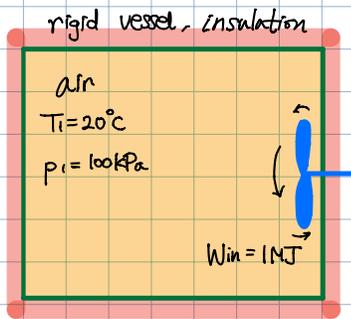
$$Q - W = \Delta U + \Delta KE + \Delta PE$$

$$\begin{aligned} Q &= m C \Delta T \\ &= (1 \text{ kg}) \cdot (1 \text{ kJ/kg}\cdot\text{K}) \cdot (27 - 0) \text{ K} \\ &= \underline{27 \text{ kJ}} \end{aligned}$$

$$\text{cost} = \left\{ \$0.1 / \text{kW}\cdot\text{hour} \cdot \frac{1 \text{ kW}}{1 \text{ kJ/s}} \cdot \frac{1 \text{ hour}}{3600 \text{ s}} \right\} \cdot (27 \text{ kJ}) = \underline{\$7.5 \times 10^{-4}} \text{ Ans. (b)}$$



$V = 0.1\text{m}^3$
 $\rho = 0.001\text{m}^3/\text{kg}$
 $C = 4.18\text{kJ}/\text{kg}\cdot\text{K}$



$V = 0.1\text{m}^3$
 $C_u = 0.72\text{kJ}/\text{kg}\cdot\text{K}$
 $R = 0.29\text{kJ}/\text{kg}\cdot\text{K}$

$\Delta U = ?$

$\Delta S = ?$

A) Liquid water

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

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

$Q = Cm\Delta T$
 $\delta Q = Cm dT = T dnS$

$\therefore dnS = Cm dT/T$

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

$\rho = V/m \rightarrow m = V/\rho = \frac{0.1\text{m}^3}{0.001\text{m}^3/\text{kg}} = 100\text{kg}$

$\Delta U = -W = mC\Delta T = mC(T_2 - T_1)$

$mCT_2 = -W + mCT_1$

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

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

$= 295.4\text{K}$

$\Delta S = (4.18\text{kJ}/\text{kg}\cdot\text{K}) \cdot (100\text{kg}) \cdot \ln \frac{295.4}{293} = 3.41\text{kJ}/\text{K}$ **Ans.**

B) Air

$\Delta U = 1\text{MJ}$ **Ans.**

$\delta q = du + p\delta u$
 $T ds = C_u dT$
 $ds = C_u dT/T$

$\Delta S = mC_u \ln(T_2/T_1)$

$p u = RT \rightarrow pV = mRT \rightarrow m = \frac{pV}{RT}$
 $= \frac{(100\text{kPa}) \cdot (0.1\text{m}^3)}{(0.29\text{kJ}/\text{kg}\cdot\text{K}) \cdot (293\text{K})}$
 $= 0.1177\text{kg}$

$\delta q = du + p\delta u = 0?$

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

$Q + W_m - W_b = \Delta U$
 $Q + W_m = \Delta U + W_b = \Delta U + p\delta V$

$\Delta U = W_m = 1\text{MJ}$

$\int_1^2 mC_u dT = W$
 $mC_u(T_2 - T_1) = W$
 $T_2 = \frac{W}{mC_u} + T_1 = \frac{1000\text{kJ}}{(0.1177) \cdot (0.72)} + 293\text{K}$
 $= 12,093\text{K}$

$\Delta S = mC_u \ln(T_2/T_1)$
 $= (0.1177) \cdot (0.72) \cdot \ln \frac{12093}{293}$
 $= 0.3153\text{kJ}/\text{K}$ **Ans.**