MULTIPLE CHOICE SECTION, PROBLEMS 1-5 [2 POINTS EACH]
Please select one answer for all questions.

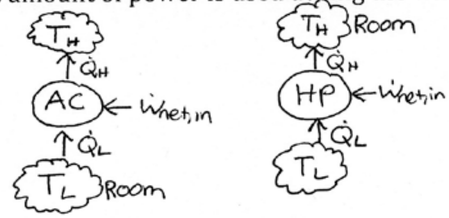
(1) A window air conditioner in a room is used for cooling during the summer and reversed during the winter for heating. Under the cooling mode, the coefficient of performance (COP) is 2, the air conditioner consumes 500 W. If this amount of power is used during the winter, what is the rate of heat supply to the room.

a) 1000 W
b) 1500 W
c) 2000 W
d) 2500 W

$COP = \frac{\dot{Q}_L}{\dot{W}_{net,in}}$

$2 = \frac{\dot{Q}_L}{500W}$

$\dot{Q}_L = 1{,}000W$



$\dot{Q}_L + \dot{W}_{net,in} = \dot{Q}_H$

$1{,}000W + 500W = \dot{Q}_H$

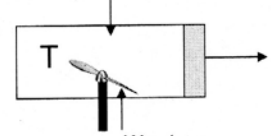
$\dot{Q}_H = 1{,}500W$

(2) A unit mass of an ideal gas at temperature T undergoes an **isothermal** expansion process from pressure P_1 to P_2 as sketched. During this process, the system receives heat in amount of *q* and an amount of work *w* which is dissipated into heat via friction. Assuming that the ideal gas has constant species heats, c_p and c_v ($R=c_p-c_v$), the entropy generation, s_{gen}, during this process is

See below

a) $s_{gen} = q/T$
b) $s_{gen} = q/T - w/T$
c) $s_{gen} = w/T$
d) $s_{gen} = q/T + w/T$

$q = q_{in}$



$W = w_{pw}$

(3) The entropy generation rate of a power plant is 5 kW/K. If a thermal reservoir at 400K is available to the power plant for use , the potential additional power that can be produced is

a) 500 kW
b) 1000 kW
c) 1500 kW
d) 2000 kW

$\dot{S} = \frac{\dot{Q}}{T}$

$5\frac{kW}{K} = \frac{\dot{Q}}{400K}$

$\dot{Q} = 2{,}000kW$
Lost that could have been used for work

1-5	
10	
10	
Total	

#2

1st Law

$E_{in} - E_{out} = \Delta E_{sys}$

$(q_{in} + w_{in}) - (\cancel{q_{out}} + w_{out}) = \Delta u + \cancel{\Delta ke} + \cancel{\Delta pe}$

$q_{in} + w_{pw} - w_{b,out} = c_v \cancel{\Delta T}^{\,0}$

isothermal process with ideal gas:

$w_{b,out} = RT\ln\frac{V_2}{V_1}$

$q_{in} = RT\ln\frac{V_2}{V_1} - w_{pw}$

2nd Law

$S_{in} - S_{out} + S_{gen} = \Delta S_{sys}$

$\left(\sum_{in}\frac{Q}{T} + \cancel{\sum_{in} ms}\right) - \left(\cancel{\sum_{out}\frac{Q}{T}} + \cancel{\sum_{out} ms}\right) + S_{gen} = \Delta S_{sys}$

$\frac{Q_{in}}{T} + S_{gen} = m\Delta s = m\left(c_v\ln\cancel{\frac{T_2}{T_1}} + R\ln\frac{V_2}{V_1}\right)$

$\frac{Q_{in}}{T} + S_{gen} = mR\ln\frac{V_2}{V_1}$

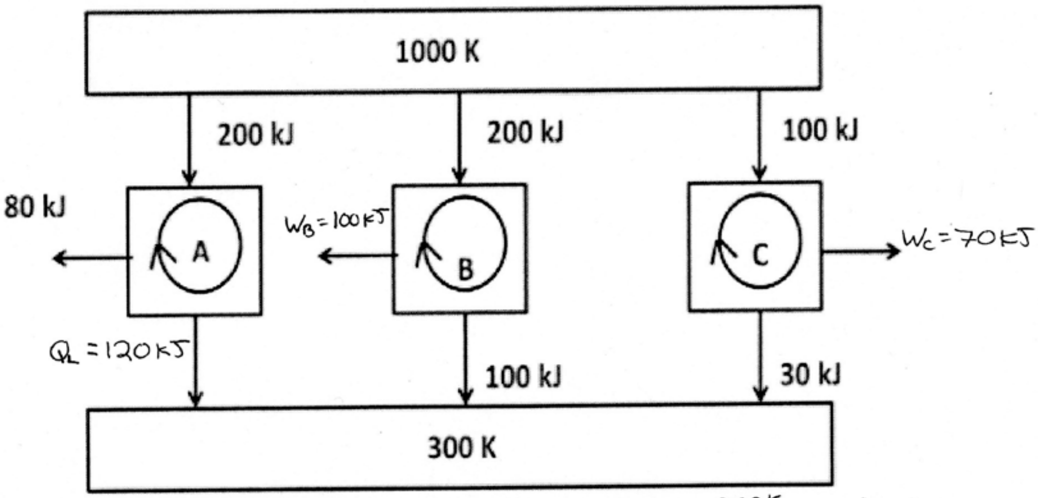
$\frac{mq_{in}}{T} + ms_{gen} = mR\ln\frac{V_2}{V_1}$

$s_{gen} = R\ln\frac{V_2}{V_1} - \frac{q_{in}}{T}$

$s_{gen} = R\ln\frac{V_2}{V_1} - \frac{RT\ln\frac{V_2}{V_1} - w_{pw}}{T}$

$s_{gen} = \frac{w_{pw}}{T}$

Please refer to the following diagram of three heat engines in parallel to answer the following multiple choice questions. **Please note that 80 kJ refers only to the work output of heat engine A.**



(4) Which heat engine is a Carnot heat engine?

$\eta_{carnot} = 1 - \frac{T_L}{T_H} = 1 - \frac{300\,K}{1000\,K} = 0.7 \leftarrow$

$\eta_A = \frac{W_A}{Q_{H,A}} = \frac{80\,kJ}{200\,kJ} = 0.4$

$\eta_B = \frac{100\,kJ}{200\,kJ} = 0.5$

$\eta_C = \frac{70\,kJ}{100\,kJ} = 0.7 \leftarrow$

a) Heat Engine A
b) Heat Engine B
c) Heat Engine C
d) None of the heat engines are Carnot heat engines.
e) More than one heat engine is a Carnot heat engine.

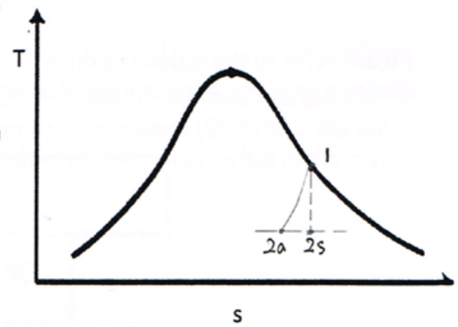
(5) What is the combined thermal efficiency of all three heat engines operating as a single cyclic device?

$\eta = \frac{W_{total}}{Q_{in,\,total}} = \frac{(80+100+70)\,kJ}{(200+200+100)\,kJ} = \frac{250\,kJ}{500\,kJ} = 0.5$

a) 26%
b) 50%
c) 62%
d) 70%

(6) [10 points] Two kilograms of saturated water vapor at 600 kPa are contained in a piston-cylinder device. The water expands adiabatically until the pressure is 100 kPa and is said to produce 700 kJ of work output.

- **(a)** [5 points] Determine the entropy change of the water in kJ/kgK.
- **(a)** [2 points] Is this process realistic? Why?
- **(b)** [3 points] Draw this process on the T-s diagram provided on right. Please label the initial state as **1**, the actual final state as **2**, and the final state for an isentropic process as **2s**.



Pressure (kPa)	Sat. Temp. (C)	v_f (m^3/kg)	v_g (m^3/kg)	u_f (kJ/kg)	u_g (kJ/kg)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/kgK)	s_g (kJ/kgK)
100	99.61	0.001043	1.6941	417.4	2505.6	417.51	2675.0	1.3028	7.3589
600	158.83	0.001101	0.3156	669.72	2566.8	670.38	2756.2	1.9308	6.7593

Given: State I: saturated water vapor, $m = 2$ kg

$P_1 = 600$ kPa, $x_1 = 1$.

State II: $P_2 = 100$ kPa.

Solution: (a) State I: $P_1 = 600$ kPa, $x_1 = 1$ $\Big\}$ $u_1 = 2566.8$ kJ/kg, $s_1 = 6.7593$ kJ/kg·K

First Law: $E_{in} - E_{out} = \Delta E_{system}$, $W_{out} = 700$ kJ

$$-W_{out} = m(u_2 - u_1)$$

$$u_2 = u_1 - \frac{W_{out}}{m} = 2566.8 - 350 \text{ kJ/kg} = 2216.8 \text{ kJ/kg}$$

State II: $P_2 = 100$ kPa, $u_2 = 2216.8$ kJ/kg $\Big\}$

$$x_2 = \frac{u_2 - u_f}{u_{fg}} = \frac{2216.8 - 417.4}{2088.2} = 0.8617$$

$$s_2 = s_f + x s_{fg} = 1.3028 + 0.8617 \times 6.0562 = 6.5215 \text{ kJ/kg·K}$$

Entropy change: $\Delta s = s_2 - s_1 = 6.5215 - 6.7593 = \boxed{-0.238 \text{ kJ/kg·K}}$

(b) The process is not realistic.

As it is an adiabatic process of a closed system:

$$S_2 - S_1 = \cancel{\int \frac{\delta Q}{T}}^{\,0} + S_{gen}.$$

Therefore $S_{gen} < 0$, which violates ~~the second law of thermodynamics.~~ ~~of~~ the increase of entropy principle.

7) [10 points] Air at 100 kPa and 20 °C is compressed to 700 kPa steadily and adiabatically at a rate of 2 kg/s. Assume constant specific heats (c_p = 1.013 kJ/kgK and c_v = 0.726 kJ/kgK).

(a) [6 points] Determine the power required to compress this air if the isentropic compression efficiency is 85%.

(b) [4 points] Determine the rate of entropy generation.

Given: Air, steady-flow, adiabatic process, $\dot{m} = 2$ kg/s

State I: $P_1 = 100$ kPa, $T_1 = 20°C = 293$K

State II: $P_2 = 700$ kPa.

Solution: (a) First law: $\dot{E}_{in} - \dot{E}_{out} = \Delta \dot{E}_{sys} = 0$ (steady flow)

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{m}h_1 + \dot{W}_{in} = \dot{m}h_2 \Rightarrow \dot{W}_{in} = \dot{m}(h_2 - h_1) \Rightarrow \dot{W}_{in} = \dot{m}c_p(T_2 - T_1)$$

Isentropic process: $k = C_p/C_v = 1.395$

$$T_{2s} = T_1\left(\frac{P_2}{P_1}\right)^{(k-1)/k} = 293\text{K}\cdot\left(\frac{700}{100}\right)^{0.395/1.395} = 508.3\text{K}$$

$$\dot{W}_{in,s} = \dot{m}c_p(T_{2s} - T_1) = 2 \times 1.013 \times (508.3 - 293)\text{kW} = 436.3\text{kW}$$

Isentropic efficiency: $\eta = 0.85$

$$\dot{W}_{in} = \frac{\dot{W}_{in,s}}{\eta} = \frac{436.3\text{kW}}{0.85} = \boxed{513.3\text{kW}}$$

(b) $\dot{W}_{in} = \dot{m}c_p(T_2 - T_1)$

$$T_2 = \frac{\dot{W}_{in}}{\dot{m}c_p} + T_1 = 546.3\text{K}$$

$$S_{out} - S_{in} = C_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}$$

$$= C_p \ln\frac{T_2}{T_1} - (C_p - C_v)\ln\frac{P_2}{P_1}$$

$$= 1.013 \times \ln\frac{546.3}{293} - (1.013 - 0.726)\ln\frac{700}{100} \text{ kJ/kgK}$$

$$= 0.073 \text{ kJ/kg·K}$$

As the process is adiabatic and steady-flow

$$\cancel{\Delta \dot{S}_{sys}}^{0} = \dot{m}(S_{in} - S_{out}) + \dot{S}_{gen} + \cancel{\sum \frac{\dot{Q}}{T}}^{0}$$

$$\dot{S}_{gen} = \dot{m}(S_{out} - S_{in}) = \boxed{0.146 \text{ kJ/K·s}}$$