PROBLEMS 1-5 [2 POINTS EACH]. Please select one answer for each question.

(1) A refrigerator produces a 2-kW **cooling** effect while rejecting 3 kW of heat. What is the Coefficient of Performance (COP) ?

(A) 1.5
(B) 0.67
(C) 2
(D) 2.5

$\dot{Q}_H$ 3 kW, ← 1 kW, $\dot{Q}_L = 2$ kW, T_L; $COP = \frac{\dot{Q}_L}{\dot{W}} = 2$

(2) Consider a Carnot refrigeration cycle and a Carnot heat pump cycle operating between the same energy reservoirs. If the COP of the heat pump cycle is 3, the COP of the refrigeration cycle is

(A) 3.
(B) 2.
(C) 1.
(D) none of the above

$COP_{HP} = \frac{Q_H}{W_{net}} = \frac{Q_L + W_{net}}{W_{net}} = \frac{Q_L}{W_{net}} + 1$

$COP_R = Q_L / W_{net}$

$COP_R = COP_{HP} - 1$

(3) The efficiency of a reversible heat engine increases greatest when:

(A) the temperature of the high temperature reservoir is increased
(B) the temperature of the low temperature reservoir is increased
(C) the difference in temperatures becomes smaller
(D) none of the above

$\eta = 1 - \frac{T_L}{T_H}$

(4) A substance undergoes an **irreversible** process from State 1 to Stat 2 while losing **300 J** of heat through a boundary at 300K. The entropy change of the substance is Δs= s2-s1 and which statement is true

(A) Δs = +1 J/K.
(B) Δs = -1 J/K.
(C) Δs > -1 J/K.
(D) none of the above

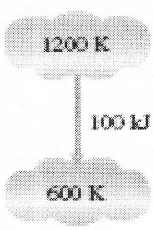
$\Delta s = \frac{Q}{T} + S_{gen} > \frac{Q}{T} = -\frac{300}{300} = -1\ J/K$

(5) Heat is transferred directly from an energy-source reservoir to an energy-sink as sketched below. The loss of potential work is.

(A) 25 kJ
(B) 50 kJ
(C) 75 kJ
(D) 100 kJ

1200 K → Carnot cyc → 600 K

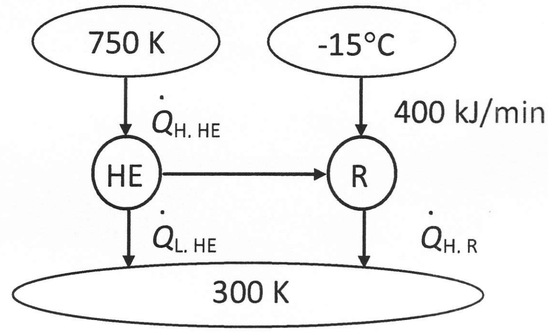
$W_{net} = 100\ kJ \cdot (1 - \frac{T_L}{T_H}) = 100\ kJ\ (1 - \frac{600}{1200}) = 50\ kJ$



Please do not write in this table.

1-4	
5	
6	
Total	

(6) [10 points total] A Carnot heat engine drives a Carnot refrigerator that removes heat from a cold medium at a specified rate as sketched on the right. The ambient environment at 300K is used as an energy reservoir.



Determine

A The rate of heat rejection to the ambient environment from the refrigerator, $Q_{H,R}$.

B The power input to the refrigerator.

C The rate of heat supply to the heat engine, $Q_{H,\ HE}$.

A) For Refrigerator $\dot{Q}_{LR} = 400\ kJ/min$

$$\frac{\dot{Q}_{H,R}}{\dot{Q}_{L,R}} = \frac{300K}{(273.15-15)K} \Rightarrow \dot{Q}_{HR} = \frac{300}{258.15} \times 400\frac{kJ}{min} = 464.85\frac{kJ}{min}$$

B) $\dot{W}_{net,\ R} = \dot{Q}_{HR} - \dot{Q}_{LR} = 64.85\frac{kJ}{min}$

c) For the heat Engine $\eta_{HE} = 1 - \frac{300}{750} = 0.6 = \frac{\dot{W}_{net}}{\dot{Q}_{H,HE}}$

$$\dot{Q}_{H,HE} = \frac{\dot{W}_{net}}{\eta_{HE}} = \frac{64.85\ kJ/min}{0.6} = 108.08\frac{kJ}{min}$$

(7) **[10 points total]** Consider the steady flow heat exchange system sketched below. The mass flow rate of air is 1kg/s and the power of the fan is 10kJ/s. The air is assumed to be ideal gas with constant specific heat c_p=1 kJ/kg-K and the system is assumed adiabatic.

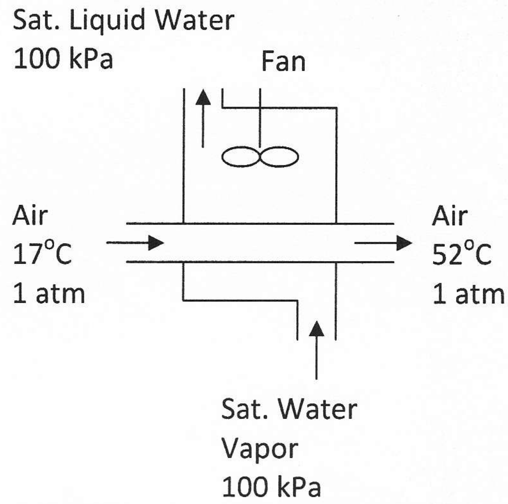
Determine a) the mass flow rate of water (kg/s)

b) the entropy generation rate of the system (kJ/K-s)

Saturation state at Psat=100kPa; vf=0.0010 (liquid) vg=1.694 (vapor) m^3/kg

Enthalpy: saturated liquid: h_f=417.51 kJ/kg; saturated vapor h_g=2257.5 kJ/kg

Entropy: saturated liquid: s_f=1.3028 kJ/kg-K; saturated vapor s_g= 7.3589 kJ/kg-K



a) 1st Law for stead flow

$$\dot{m}_w h_g + \dot{m}_a h_a(17°C) + \dot{W}_{in} = \dot{m}_w h_f + \dot{m}_a h_a(52°C)$$

$$\dot{m}_w (h_g - h_f) = \dot{m}_a C_p (52-17) - \dot{W}_{in}$$

$$\dot{m}_w = \frac{\dot{m}_a C_p (52-17) - \dot{W}_{in}}{h_g - h_f}$$

$$= \frac{1\,\frac{kg}{s}\;1\,\frac{kJ}{kg\text{-}K}\;35K - 10\,kJ/s}{2257.5\,\frac{kJ}{kg} - 417.51\,\frac{kJ}{kg}} = 0.01360\ kg/s$$

b) $$\dot{S}_{gen} = \Sigma \dot{m}_e s_e - \Sigma \dot{m}_i s_i - \Sigma \frac{\dot{Q}}{T} \to 0$$

$$= \dot{m}_w s_f + \dot{m}_a s_a(52°C) - \dot{m}_w s_g - \dot{m}_a s_a(17°C)$$

$$= \dot{m}_w (s_f - s_g) + \dot{m}_a (s_a(52°C) - s_a(17°C))$$

$$= 0.01360\,\frac{kg}{s}\,(1.3028 - 7.3589)\,\frac{kJ}{kg\text{-}K} + 1\,\frac{kg}{s}\,C_p \ln\frac{273+52}{273+17}$$

$$= -0.08236\,\frac{kJ}{K\text{-}s} + \underbrace{1\,\frac{kg}{s}\;1\;\ln\frac{325}{290}}_{0.1139} = 0.0316\,\frac{kJ}{K\text{-}s}$$