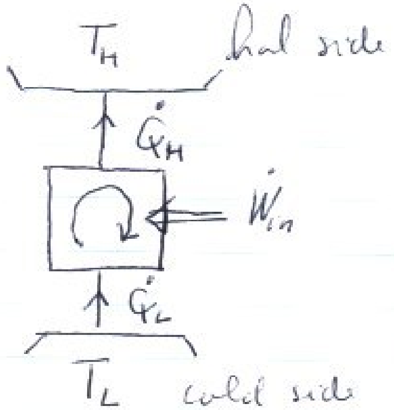
S 7.1, 7.2 Black box

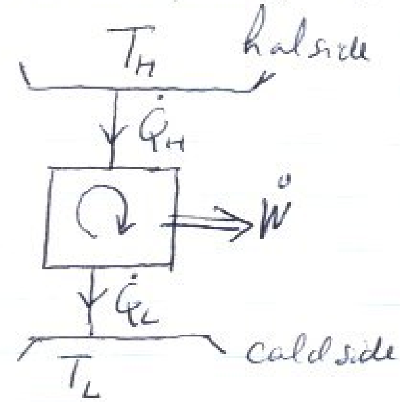
~~Generic~~ refrigerator, freezer, AC, ...

Generic heat pump producing heat

Generic heat engine (car engine, steam power plant, ...)



<like fridge>



T_H : high temperature side temperature

T_L : low " " "

Note : we are dropping our convention that heat in is positive for Q_H, Q_L; the sign of Q_H and Q_L will depend on the device as well

Conservation of energy : $\dot{Q} = \dot{W}$ (since no substance is flowing in or out) : <u>net</u> heat in = <u>net</u> work out

<u>net</u> heat out = <u>net</u> work in

<u>First law</u>

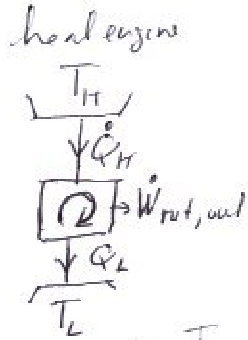
For refrigerator or heat pump devices:

$$\boxed{\dot{Q}_H - \dot{Q}_L = \dot{W}_{in}}$$ First law HP, R

For heat engines $$\boxed{\dot{Q}_H - \dot{Q}_L = \dot{W}}$$ First law HE

Efficiency

$$\text{efficiency} = \frac{\text{what you get}}{\text{what you "pay" for it}}$$

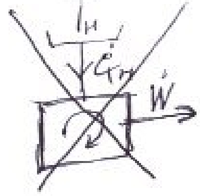


Heat engine thermal efficiency

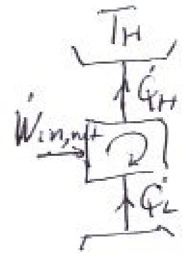
$$\eta_{th} \equiv \frac{\dot{W}_{net,out}}{\dot{Q}_H} = \frac{\dot{Q}_H - \dot{Q}_L}{\dot{Q}_H} \quad \text{HE}$$

Kelvin-Planck statement of the second law:

$\dot{Q}_L$ must be positive for a heat engine



$\rightarrow \eta_{th} < 1$



Refrigerator efficiency

$$COP_R = \frac{\dot{Q}_L}{\dot{W}_{net,in}} = \frac{\dot{Q}_L}{\dot{Q}_H - \dot{Q}_L}$$

$$COP_{HP} = COP_R + 1$$

Heat pump efficiency

$$COP_{HP} = \frac{\dot{Q}_H}{\dot{W}_{net,in}} = \frac{\dot{Q}_H}{\dot{Q}_H - \dot{Q}_L}$$

Can be greater than 1:
Resistance heater, radiator heater $COP \approx 1$

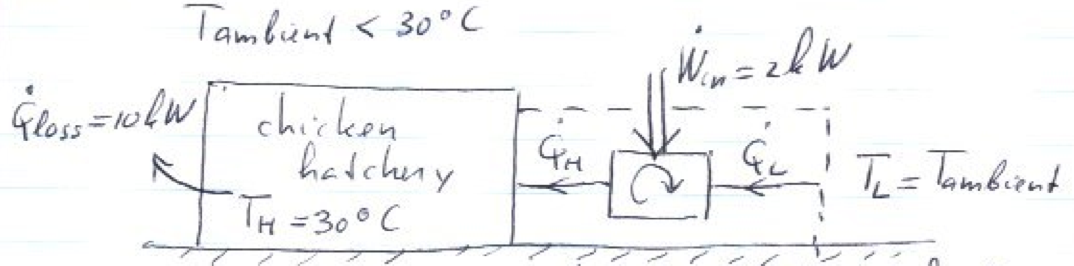
Clausius statement of the second law:

$\dot{W}_{net,in}$ must be positive for a heat pump / refrigerator

Kelvin ~~Planck~~ & Clausius statements are equivalent:

1) If Clausius could be violated you could send ~~[illegible]~~ $\dot{Q}_L$ from HE back to T_H
2) If K.P. could be violated, it acts as a free refrigerator

P 7.22



Asked: C.O.P. of heat pump

To maintain temperature,

$$\dot{Q}_H = \dot{Q}_{loss} = 10\ kW$$

Needed C.O.P.$_r$: $\beta' = \frac{\dot{Q}_H}{\dot{W}_{in}} = \frac{10\ kW}{2\ kW} = 5$

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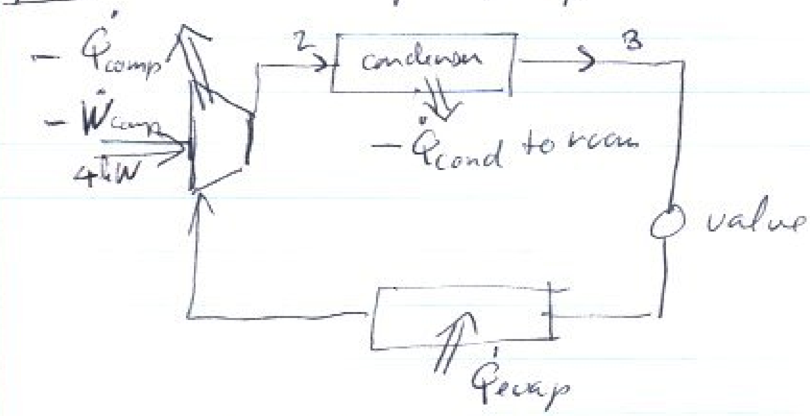
~~R7~~

7.2 R-12 heat pump p. 6.106



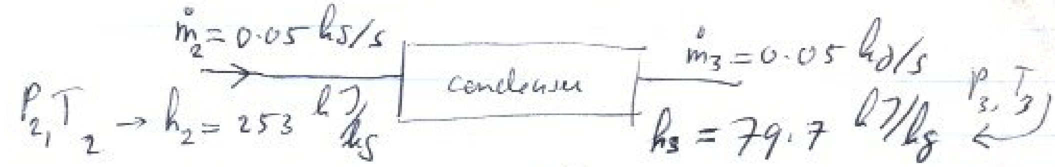
Asked: C.O.P.

Question: What is C.O.P.?

Works to heat room $\rightarrow \beta' = \dfrac{\dot{Q}_H}{\dot{W}_{net,in}}$ ($\dot{Q}_H \leftarrow -\dot{Q}_{cond}$; $\dot{W}_{net,in} \leftarrow -\dot{W}_{comp}$)

$-\dot{W}_{comp}$ is given at 4 kW

To get $-\dot{Q}_{cond}$, use Chapter 6



$$\dot{Q}_{cond} + \dot{m}_2 h_2 = \dot{W}^{\nearrow 0} + \dot{m}_3 h_3$$

$$\dot{Q}_{cond} = 0.05 \text{ kg/s } (79.7 - 253) \text{ kJ/kg}$$

$$= -8.665 \text{ kW}$$

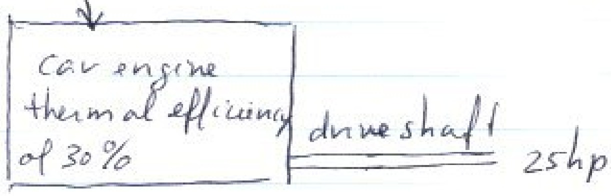
$$\beta' = \frac{8.665 \text{ kW}}{4 \text{ kW}} = \underline{\underline{2.166}}$$

(This assumes $-\dot{Q}_{comp}$ does not go into the room)

03/16/06 end →

7.29

$\dot{m}_{fuel}$ heating value $HV = 40{,}000$ kJ/kg



Asked: rate of fuel consumption (ROFC)
combined power rejected through the radiator and exhaust

Question: What is ROFC? $\dot{m}_{fuel}$

Question: What is "thermal efficiency of 30%"?

$$\eta_{TH} = \frac{\dot{W}_{out}}{\dot{Q}_H} = 0.30$$

Question: What does HV mean?

$$\dot{Q}_H = \dot{m}_{fuel}\, H.V. \Longrightarrow 0.30 = \frac{\dot{W}_{out}}{\dot{m}_{fuel}\, HV}$$

Question: What is $\dot{W}_{out}$?

$$\dot{W}_{out} = 25\,hp\ 0.7355\,\frac{kW}{hp}$$

(Table A1: $1\,hp = 0.7355$ kW ; $1 = \frac{0.7355\,kW}{1\,hp}$)

electrical horse: $1\,ehp = 0.746\,kW$
$1\,bhp = 0.74570\,kW$

Can now compute $\dot{m}_{fuel}$

$$0.30 = \frac{25\,hp\ 0.7355\,\frac{kW}{hp}}{\dot{m}_{fuel}\ 40{,}000\,\frac{kJ}{kg}} \Longrightarrow \dot{m}_{fuel} = \underline{\underline{0.00153\ kg/s}}$$

Question: What is CPRTTRAE?

$\dot{Q}_L$ (very debatable: → energy also goes into intake, → ~~alternator~~, → ~~power steering~~, → etc.)

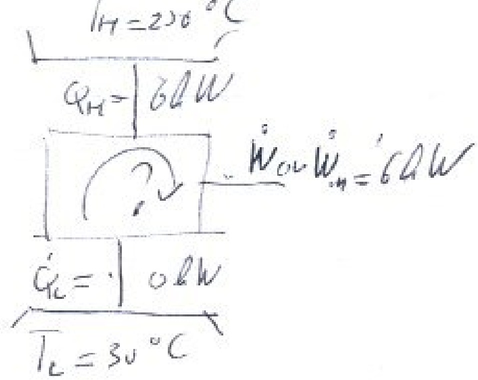
Anyway: energy $\dot{Q}_L$ not converted into drive shaft work:

$$\dot{Q}_L = \dot{m}_{fuel}\,HV - \dot{W} = 0.00153\ 40{,}000\,\frac{kg}{s}\frac{kJ}{kg} - 25\,hp\ 0.7355\,\frac{kW}{hp}$$
$$= 42.8\ \underline{kW}$$

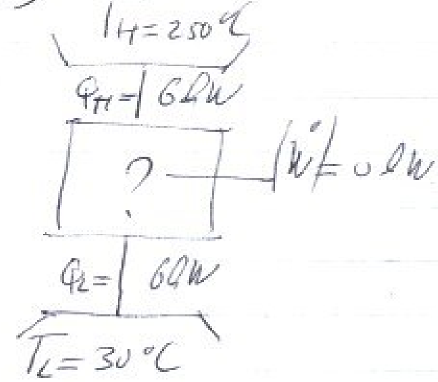
XIV 4C

7.35

a)



b)



About a): 1st law is certainly satisfied
If it is a heat engine, K.P. is violated: $\dot{Q}_L = 0$
If it is a heat pump, O.K. $\beta' = 1 = COP_{HP}$
A.C. O.K. $\beta = 0 = COP_R$

About b): 1st law is certainly satisfied.
If it is a heat ~~engine~~ pump or A.C., violates Clausius since work is needed to run it.

3/21/06 end