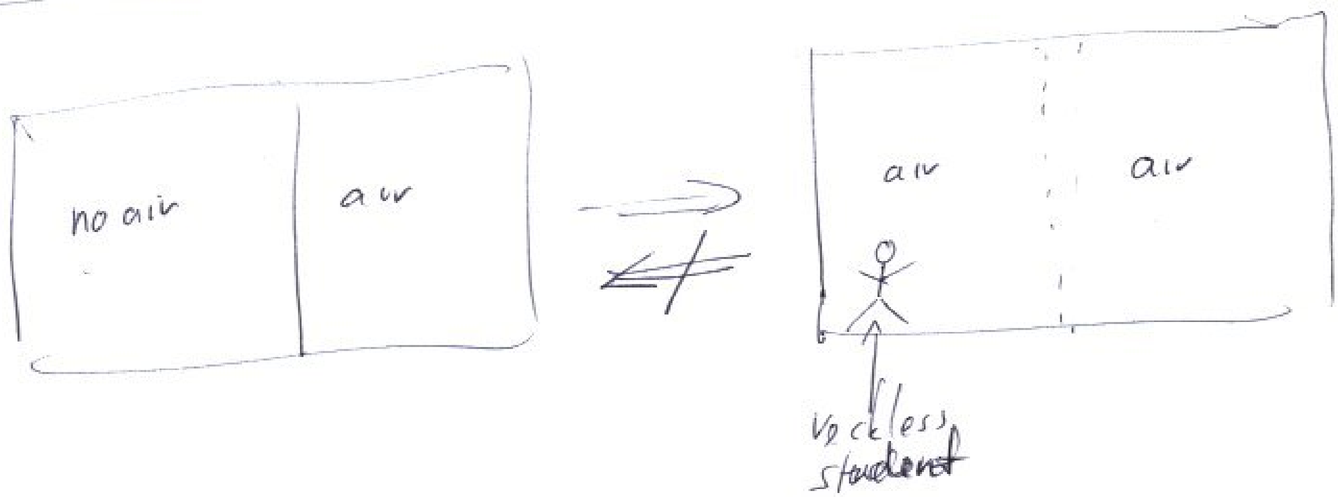
Humpty-Dumpty sat on a wall
Humpty-Dumpty had a great fall
All the king's horses and all the king's men
Couldn't put Humpty together again

The laws of nature are symmetric in time *
Nature is not



Tools: do irreversible reversible comparison,
then go directly to Carnot

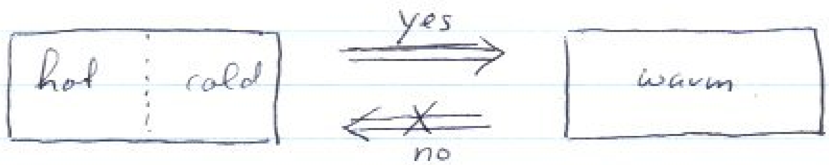
Tools: do irreversible reversible comparison,
then directly to Carnot

§7.3, 7.4 Reversible processes

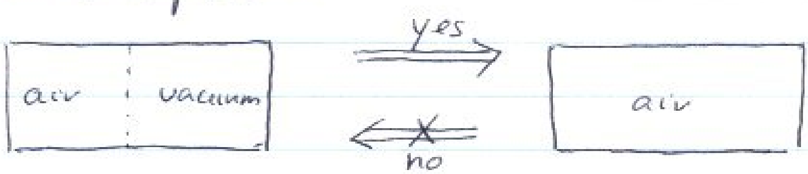
Reversible processes can be run in exactly the same way backward.

Examples of irreversible processes:

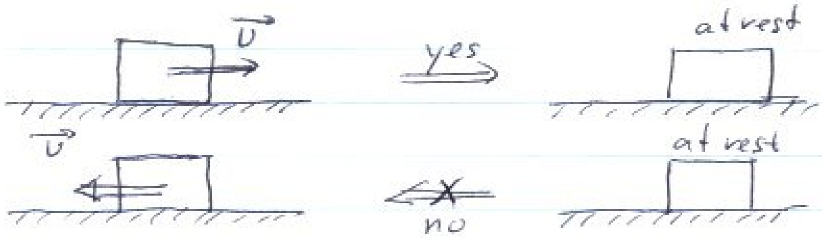
Heat conduction with a ~~fini~~ non small temperature difference:



Irreversible expansion:



Mechanical friction



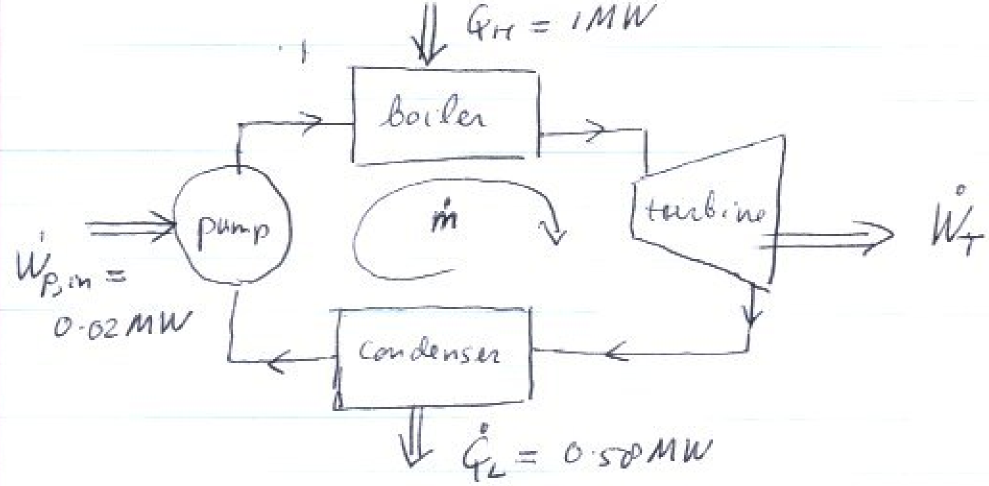
Reversible processes are an ideal that cannot be reached, just approximated by doing everything very gently and carefully.

03/14/06 end

XIV 6a

SKIP? does illustrate steam power plant
Out so does carnot cycle

P7.26 a) Steam power plant



Asked: η_{TH}.

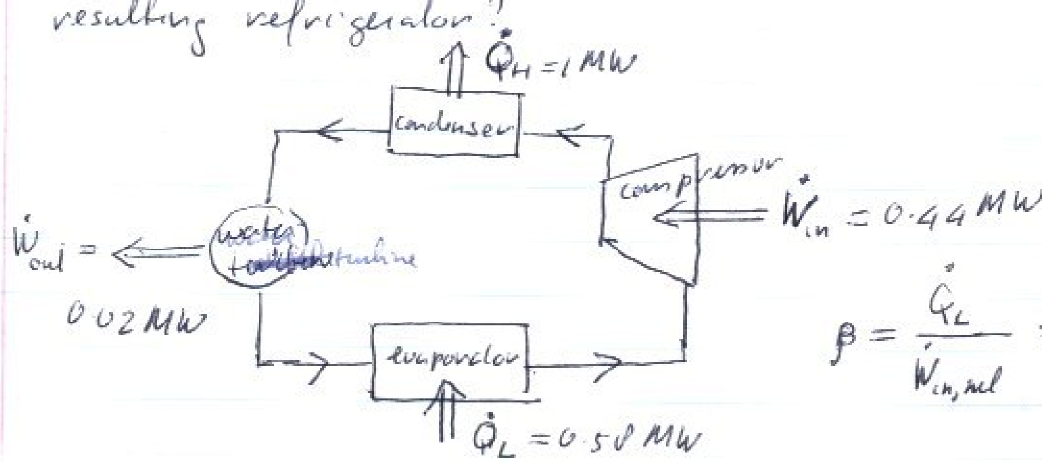
Note that a steam power plant, like fridges, etc, operates as a cycle: the working substance ~~water~~ returns to its original state after going around a full circle.

Solution: 1st law $\dot{Q}_{in} = \dot{W}_{out}$

$$\dot{Q}_H - \dot{Q}_L = \dot{W}_T - \dot{W}_{p,in} = 1MW - 0.58MW \qquad \dot{W}_T = 0.44\,MW$$

$$\eta_{TH} = \frac{\dot{W}_{net\,out}}{\dot{Q}_H} = \frac{\dot{W}_T - \dot{W}_{p,in}}{\dot{Q}_H} = \frac{0.42\,MW}{1MW} = \underline{0.42}$$

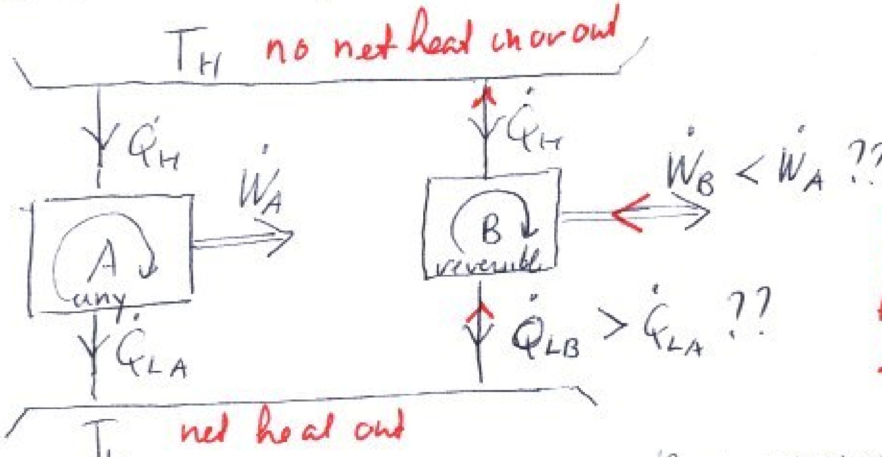
b) If the device is "reversible", what is the C.O.P of the resulting refrigerator?



$$\beta = \frac{\dot{Q}_L}{\dot{W}_{in,net}} = \frac{0.58MW}{0.42MW} = 1.38$$

S7.6 Reversible machines are equally good and the best

Assume the opposite, that a reversible heat engine B is worse than ~~reversible~~ any heat engine A; reversible or not.



A has enough power to run reversed heat pump B and then some left

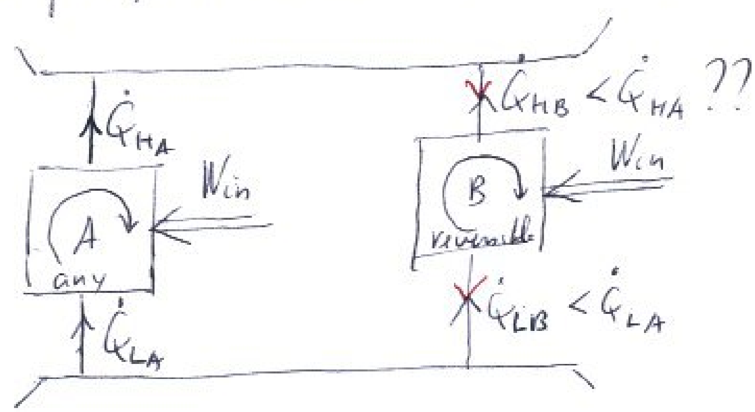
If this would be so, run engine B in reverse → heat pump

The situation would take net heat out of T_L and use it all to create net power, without dumping heat to lower temperature ~~the~~ surroundings → violates Kelvin-Planck

→ all reversible heat engines taking power from T_H and dumping it to T_L have the same efficiency

all non reversible engines have less

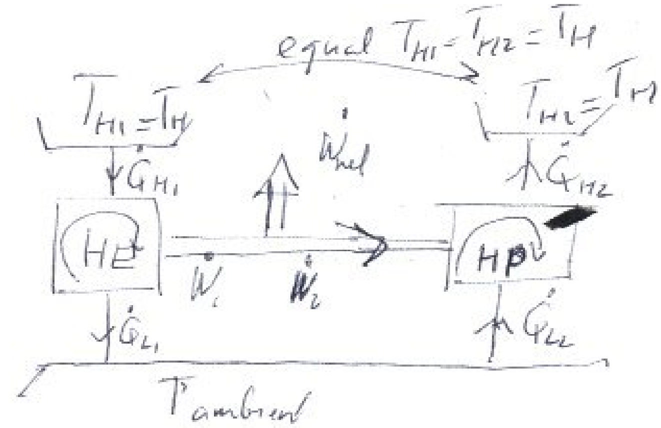
For heat pumps, or refrigeration cycles the same argument applies



if this is the case, run B in reverse → violates ~~Kelv~~ Clausius

Skip as needed

7.30
7.35



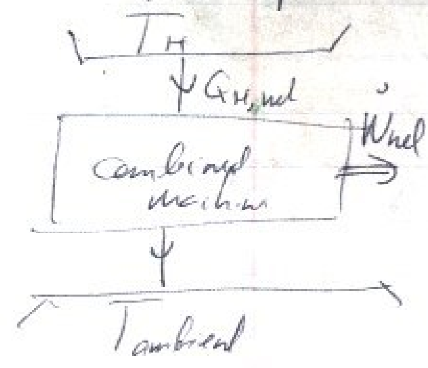
	$\dot{Q}_{H1}$	$\dot{Q}_{L1}$	$\dot{W}_1$	$\dot{Q}_{H2}$	$\dot{Q}_{L2}$	$\dot{W}_2$
a	6	4	2	3	2	1
b	6	4	2	5	4	1
c	3	2	1	4	3	1
	HE			HP		

$\dot{Q}_H - \dot{Q}_L = W$? Yes, in all six cases

Efficiencies cannot be found, since T_H / $T_{ambient}$ is not given. But we can check Kelvin Planck and Clausius.

Each individual machine is O.K. in all 3 cases. But how about the combined cycle?

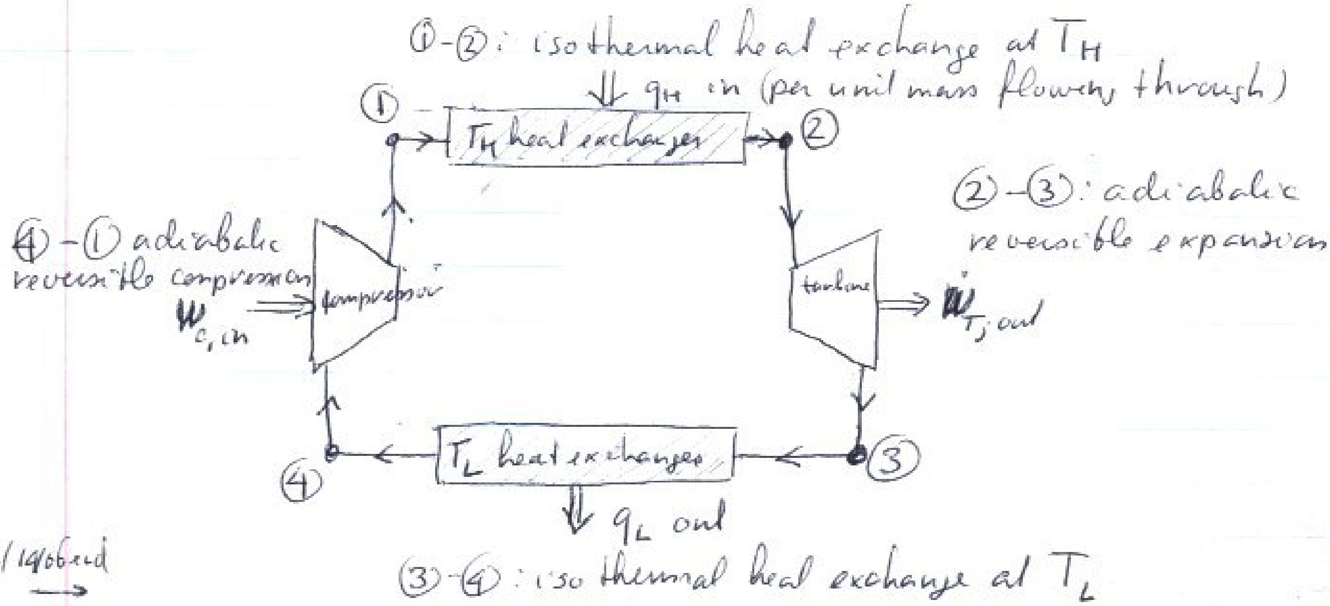
$W_{in} > 0$ for HP.
$\dot{Q}_L > 0$ for HE.



	a	b	c
$Q_{H_{net}} = Q_{H1} - Q_{H2} =$	3	1	-1
$Q_{L_{net}} = Q_{L1} - Q_{L2} =$	2	0	-1
$W_{net} = \dot{W}_1 - \dot{W}_2 =$	1	1	0
	perfectly O.K. with K.P	not O.K. with KP: cannot get all the energy $\dot{Q}_H$ back as work, some must be dumped to lower temp	Heat pump: not O.K. with Clausius: need at least some work to run heat pump

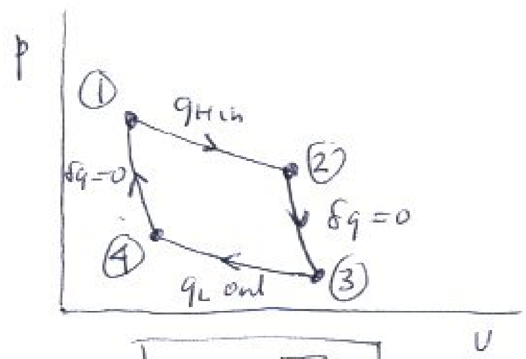
S 7.5 & 7.8 $\boxed{\text{Thermo version}}$.

Carnot cycle heat engine: A standard to compare other cycles.



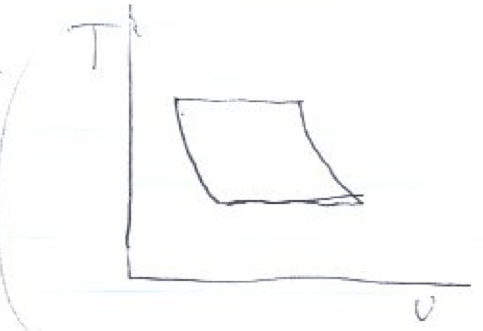
3/14/06 end →

pv-diagram for an ideal gas used in a Carnot cycle as working fluid:



For an I.G.C.C.: $\boxed{\dfrac{q_L}{q_H} = \dfrac{T_L}{T_H}}$

~~Proof (skipped in~~



Proof ~~(skipped in class)~~

For an ideal gas $\delta q = du + \delta w = c_v\,dT + p\,dv$ 1st law

$$= c_v\,dT + \frac{RT}{v}\,dv$$

So

$$q_H = \int_1^2 \delta q = \int_1^2 \underbrace{c_v\,dT}_{0 \text{ since } T \text{ constant}} + \frac{RT_H}{v}\,dv = RT_H \ln v \Big|_1^2 =$$

$$= RT_H(\ln v_2 - \ln v_1) = \boxed{RT_H \ln\frac{v_2}{v_1} = q_H} \quad (1)$$

NOTE: Easier to keep differences of logarithms 3/18/14

Similarly $q_L = RT_L(\ln v_3 - \ln v_4) = \boxed{RT_L \ln\frac{v_3}{v_4} = q_L}$ (1)

Along the adiabats, $\delta q = 0 = c_v\frac{dT}{T} + \frac{R}{v}\,dv$ $\quad U = 0$ so →

$$\text{so } \int_1^4 c_v\frac{dT}{T} + \int_1^4 \frac{R}{v}\,dv = \int_2^3 c_v\frac{dT}{T} + \int_2^3 \frac{R}{v}\,dv$$

$$R(\ln v_4 - \ln v_1) = R(\ln v_3 - \ln v_2)$$

$$\ln v_2 - \ln v_1 = \ln v_3 - \ln v_4$$

Put in (1): $\boxed{\frac{q_L}{q_H} = \frac{T_L}{T_H}}$ Q.E.D.

$$c_v\frac{dT}{T} + \frac{c_p - c_v}{v}\,dv = 0$$

$$c_v\frac{dP}{P} + \cancel{c_v\frac{dv}{v}} + c_p\frac{dv}{v} - \cancel{c_v\frac{dv}{v}} = 0$$

$$c_v \ln P_2/P_1 + c_p \ln\frac{v_2}{v_1} = 0$$

$$\ln\frac{P_2}{P_1} + \frac{c_p}{c_v}\ln\frac{v_2}{v_1}$$

$$k = n$$

$$\ln\frac{P_2}{P_1}\frac{v_2^n}{v_1^n} = 0$$

$$\frac{P_2 v_2^n}{P_1 v_1^n} = 1$$

From $\frac{q_L}{q_H} = \frac{T_L}{T_H}$ for an (ideal) Carnot cycle, it follows that

$\eta_{TH} = 1 - \frac{Q_L}{Q_H}$

$\beta = \frac{Q_L}{Q_H - Q_L}$

$\beta' = \frac{Q_H}{Q_H - Q_L}$

$$\boxed{\begin{aligned} \eta_{TH,carnot} &= 1 - \frac{T_L}{T_H} > \eta_{TH} \\ \beta_{carnot} &= \frac{T_L}{T_H - T_L} > \beta_{real} \\ \beta'_{carnot} &= \frac{T_H}{T_H - T_L} > \beta'_{real} \end{aligned}}$$

heat engine (wants big temperature ratio)

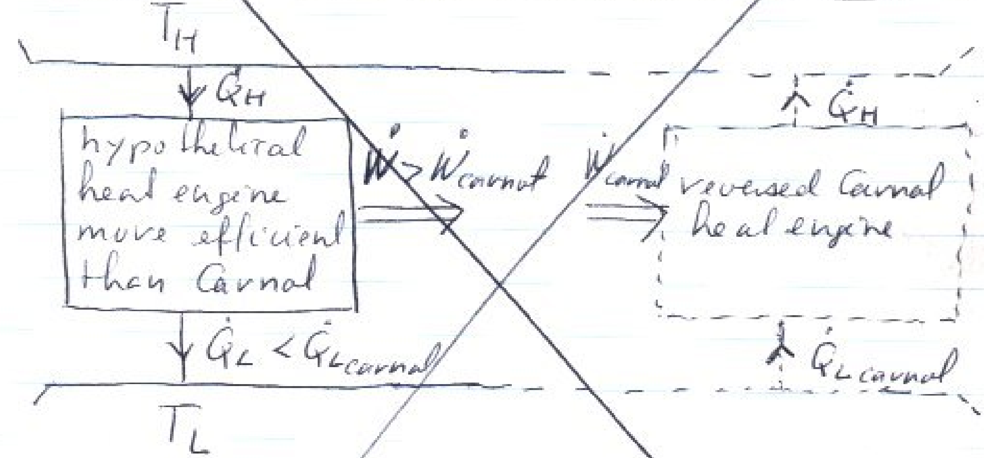
refrigeration ↑

want $T_H \approx T_L$ ↓

heat pump

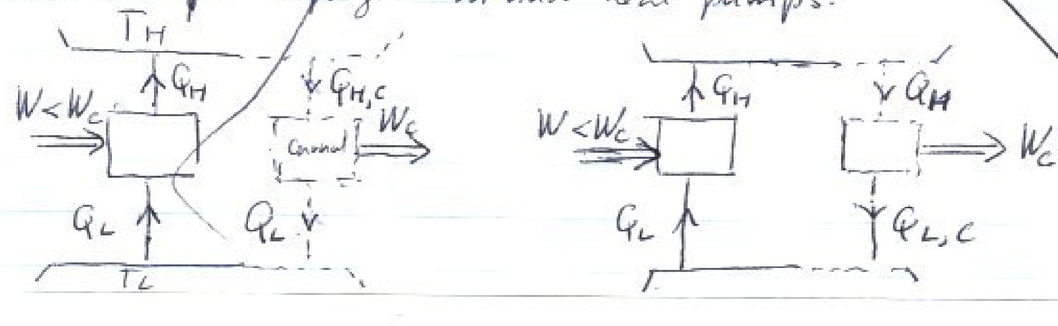
S7.6 The Carnot engine can be used as an ideal engine to test other engines

The Carnot cycle efficiencies are the highest possible. Anything else is less good. (And all Carnot cycles are equally good)

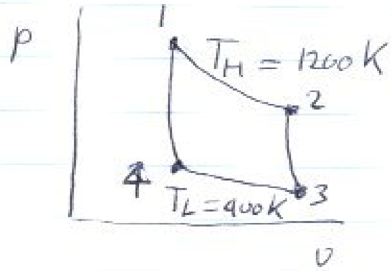


The combined machine above takes heat out of the T_L reservoir and turns it all into work, violating Kelvin-Planck

Similar for refrigeration and heat pumps:



P7.78 Ideal gas (air) Carnot cycle.



$\frac{v_2}{v_1} = 3$

Asked: q_H, q_L, η_{TH}

From "proof" formula $q_H = R T_H \ln \frac{v_2}{v_1} = 0.287 \frac{kJ}{kg\,K}\, 1200 K \ln 3$

$= \underline{\underline{378.4}} \frac{kJ}{kg}$

$\frac{q_L}{q_H} = \frac{T_L}{T_H}$ $\quad q_L = \frac{T_L}{T_H} q_H = \frac{400 K}{1200 K}\, 378.4 \frac{kJ}{kg}$

$= 126.1 \frac{kJ}{kg}$

$\eta_{TH} = 1 - \frac{T_L}{T_H} = 1 - \frac{400 K}{1200 K} = \underline{\underline{\frac{2}{3}}}$

HAD 25 MINUTES LEFT

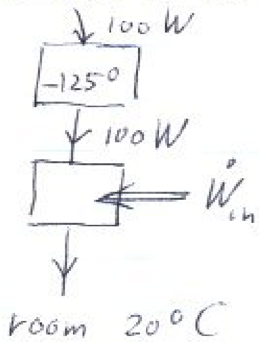
in Q4, went on in Q6

R5

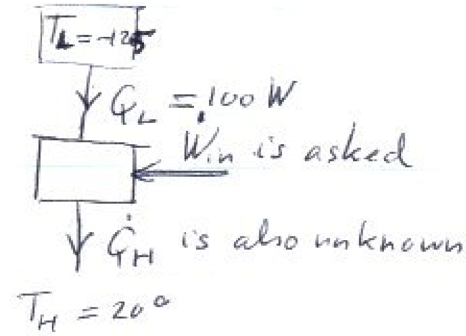
7.53 Cryogenic experiment

Asked: Engine size of a heat pump maintaining the temperature?

Questions: Where is the heat pump? What does it do



Question: What is $\dot{Q}_H$? $\dot{Q}_L$? T_H? T_L? $\dot{W}$



} only 1 can be computed from 1st law.

Questions: What is the best that can be done? What is the relevant efficiency?

SOMETHING WRONG HERE?

$$\beta = \frac{\dot{Q}_L}{\dot{W}_{in}} \qquad \beta_{carnot} = \frac{T_L}{T_H - T_L} = \frac{-125}{145} = -0.86$$

$$\dot{W}_{in} = \frac{\dot{Q}_L}{\beta} = \frac{100\text{ W}}{-0.86} = -116\text{ W}$$: run fan to keep student cool experiment

R5

Actually : must use absolute temperature

$$B = \frac{273-125}{(273+20)-(273-125)} = 1.02$$

$$\dot{W}_{in} = \frac{100\,W}{1.02} = 98\,W$$