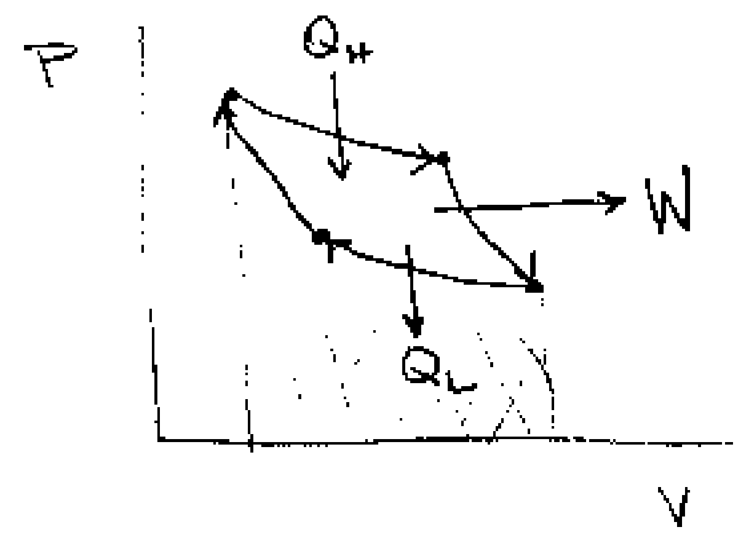
2nd law of Thermo

1^{st} law $\;{}_1Q_2 = \Delta E + {}_1W_2$

$$\oint Q = \oint W$$



heat engine –

a device that operates in a cycle

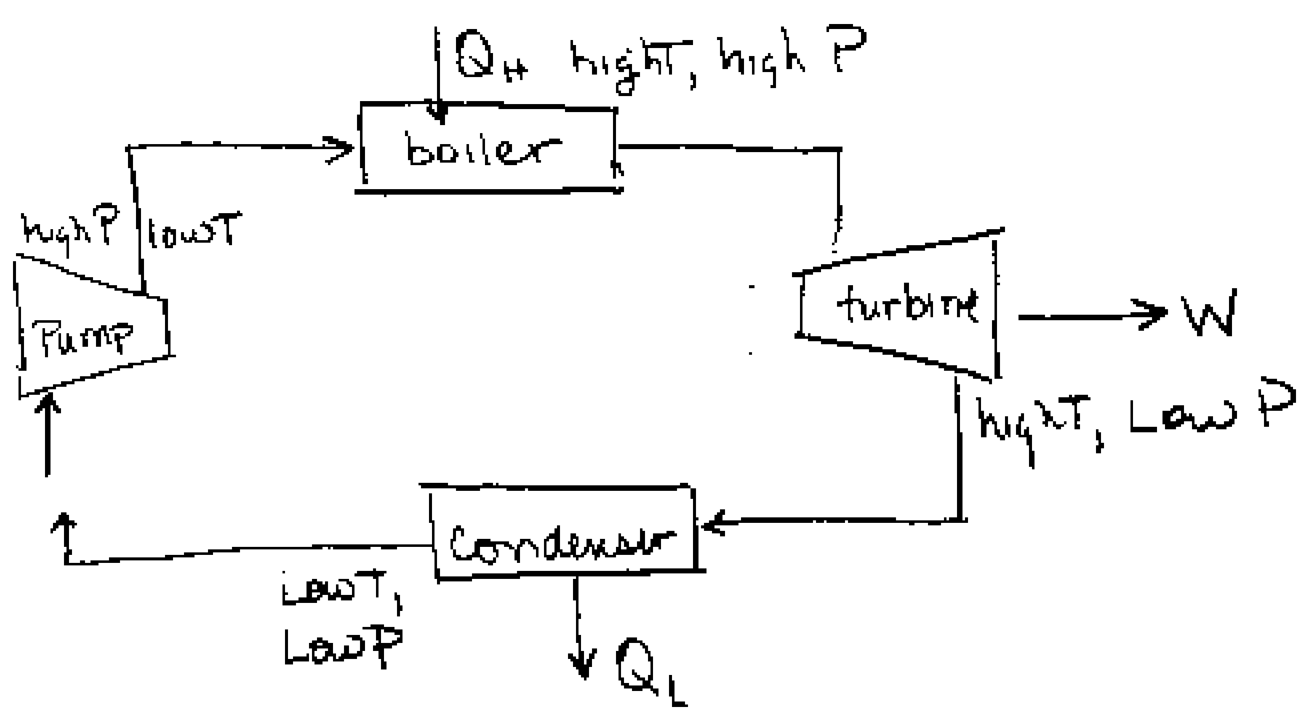
& does a certain net positive work through transfer of heat from a highTemp body to a lowTemp body

pg 194

+ loose definition

Working fluid – substance to which & from which heat is being transferred

steam power plant



Q_H heat transferred to/from high temp body
Q_L heat transferred to/from low temp body
} sign determined by definition of system

Efficiency

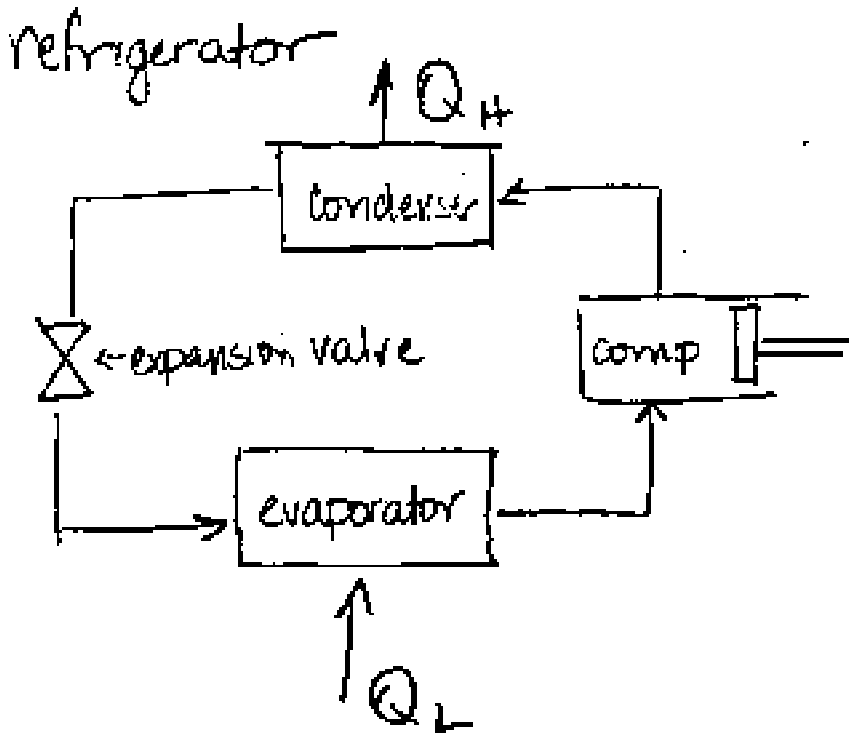
Thermal efficiency (for heat engines)

$$\boxed{\eta_{thermal} = \frac{W}{Q_H}} \quad \frac{\text{(what you want)}}{\text{what it cost you}} \quad \frac{\text{output}}{\text{input}}$$

$\oint Q = \oint W$ (if there are no losses)

$$Q_H - Q_L = W \longrightarrow \eta_{thermal} = \frac{Q_H - Q_L}{Q_H} = \boxed{1 - \frac{Q_L}{Q_H}}$$

refrigerator



Coefficient of performance ("efficiency" of a refrigerator)

$$\boxed{\beta = \frac{Q_L}{W}} = \frac{Q_L}{Q_H - Q_L} \cdot \frac{\frac{1}{Q_L}}{\frac{1}{Q_L}} = \boxed{\frac{1}{\frac{Q_H}{Q_L} - 1}}$$

for a heat pump (objective is to get heat to the hot thing)

$$\beta' = \frac{Q_H}{W} = \frac{Q_H}{Q_H - Q_L} \cdot \frac{\frac{1}{Q_H}}{\frac{1}{Q_H}} = \frac{1}{1 - \frac{Q_L}{Q_H}}$$

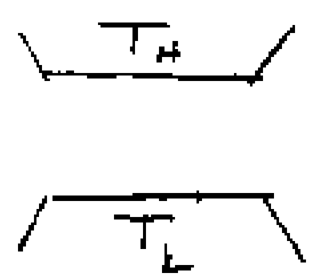
for a given cycle

$$\beta' - \beta = \frac{Q_H}{Q_H - Q_L} - \frac{Q_L}{Q_H - Q_L} = \frac{Q_H - Q_L}{Q_H - Q_L} = 1$$

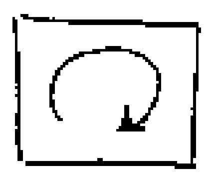
$$\boxed{\beta' - \beta = 1}$$

Some definitions & symbols

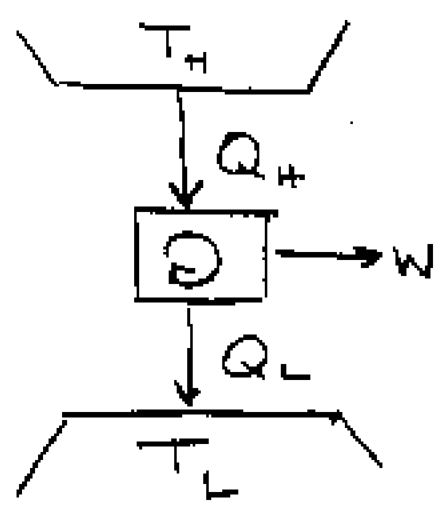
heat reservoir – a body of such a large mass that it may absorb or reject an unlimited quantity of heat without suffering an appreciable change in temperature (or in any other thermodynamic property).



Bath tub – icecube

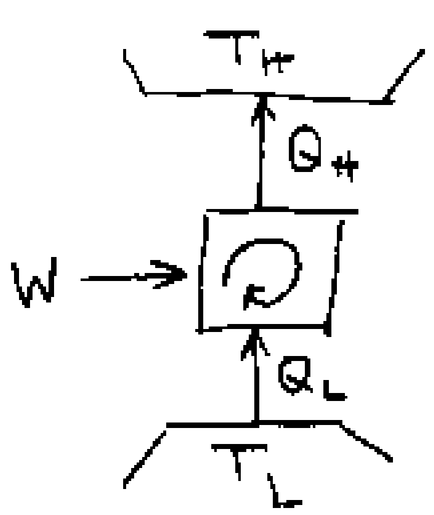


cyclic device (or combination of devices)



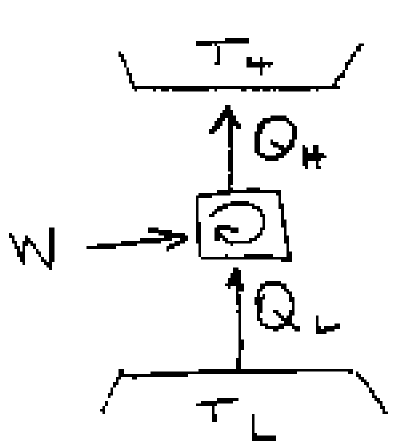
heat engine

$$\eta_{th} = \frac{W}{Q_H} = 1 - \frac{Q_L}{Q_H} \qquad \frac{\dot{W}}{\dot{Q}_H}$$



refrigerator

$$\beta = \frac{Q_L}{W} = \frac{1}{\frac{Q_H}{Q_L} - 1} \qquad \frac{\dot{Q}_L}{\dot{W}}$$

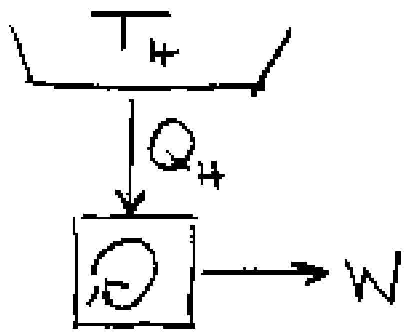


heat pump

$$\beta' = \frac{Q_H}{W} = \frac{1}{1 - \frac{Q_L}{Q_H}} \qquad \frac{\dot{Q}_H}{\dot{W}}$$

Second law of thermo

Kelvin - Planck statement

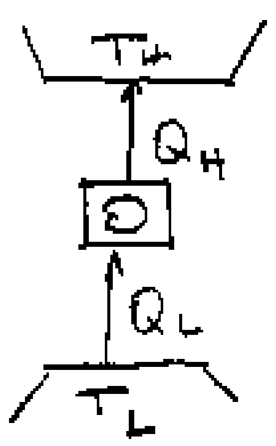


impossible

impossible to construct a device where heat is transferred from a single reservoir and converted entirely into work

(note, $\eta = \frac{W}{Q_H}$ $\therefore$ CANNOT HAVE an engine w/ $\eta = 1$ or 100%)
$\eta < 1$

Clausius statement



impossible

impossible to construct a device where heat is transferred from low T to high T without any work input. (or w/o any other effects)

(note $\beta = \frac{Q_L}{W}$, $\beta' = \frac{Q_H}{W}$
$W \neq 0$ $\therefore \beta, \beta' < \infty$)

Reversible Process

A process in which the system and surroundings can be returned to their original condition after the process has been executed
(generally quasi-equilibrium processes)

[all natural processes are irreversible]

1. it is performed quasi-statically
2. it is not accompanied by any dissipative effects

Irreversible processes & factors leading to irreversibility

1. Friction
2. unrestrained expansion
3. heat transfer across a finite temperature difference
4. mixing 2 different substances (spontaneous mixing)
5. rapid chemical reactions (spontaneous chem rxtns)
6. electric current flow through a resistance I^2R
7. magnetization or polarization with hysteresis
8. inelastic (plastic) deformation

Reminder...

Throttling process in a nutshell (SSSF)

$$h_i + \frac{v_i^2}{2} = h_e + \frac{v_e^2}{2}$$

if ΔKE is small or pipe diameters are adjusted

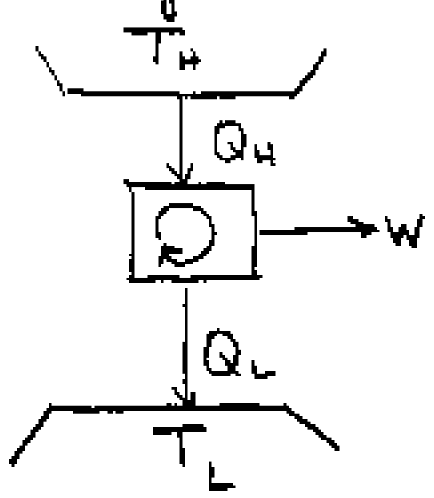
$\Delta KE = 0$

$h_i = h_e$ however there is a pressure drop.

The Carnot cycle

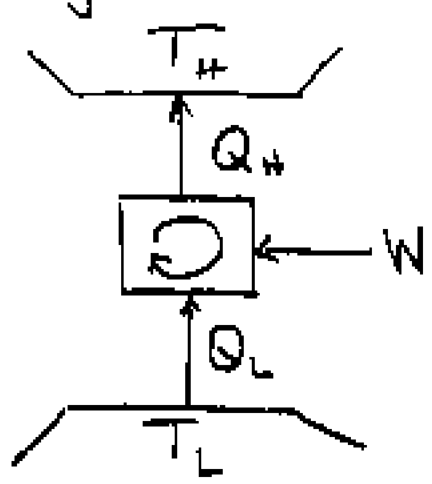
Review

Heat engine



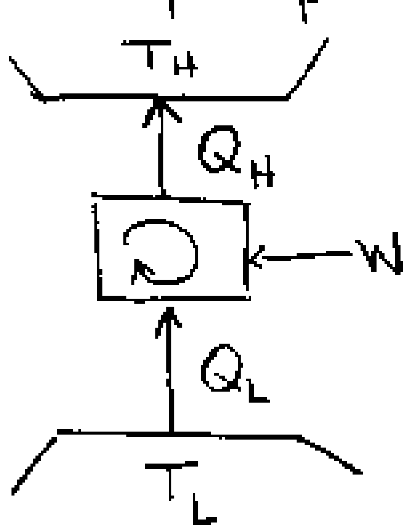
$$\eta_{thermal} = \frac{W}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

Refrigerator



$$\beta = \frac{Q_L}{W} = \frac{1}{\frac{Q_H}{Q_L} - 1}$$

heat pump



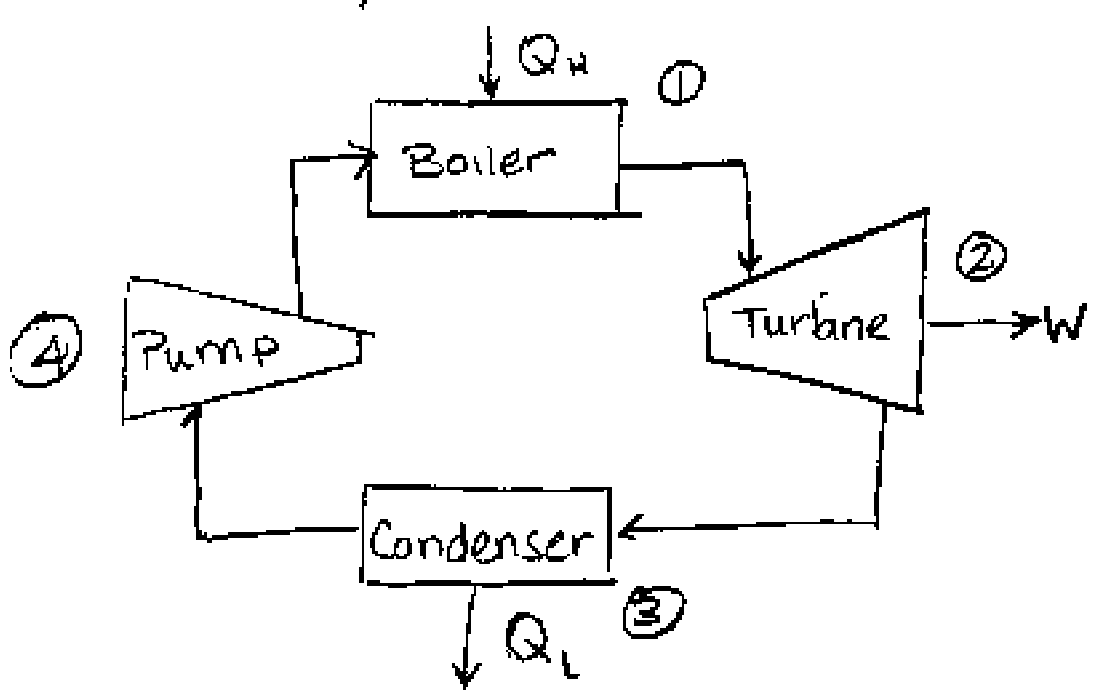
$$\beta' = \frac{Q_H}{W} = \frac{1}{1 - \frac{Q_L}{Q_H}}$$

cannot have H.E. w/ $\eta = 100\%$

what is maximum efficiency when operating between 2 temp reservoirs?

Each step in cycle must be reversible — no losses
(if each process in a cycle is reversible, the cycle is reversible)

Carnot Cycle



1) rev. isothermal proc.
heat trans from T_H
2) rev. adiabatic proc.
fluid goes from high T to low T
3) rev. isothermal proc.
heat transferred to T_L
4) rev. adiabatic proc.
fluid goes from low T to high T

completely rev,
different substances can be used
different devises.

carnot cycle
2 isothermal steps
2 adiabatic steps
all rev

All carnot cycles operating between 2 const T reservoirs have the same efficiency (regardless of the working fluid)

Carnot's theorem: *No engine operating between two given reservoirs can be more efficient than a carnot engine operating between the same two reservoirs.*

A carnot engine (HE, ref, HP) operates at the maximum possible efficiency.

Carnot Cycle

$\eta = \frac{W}{Q_H}$

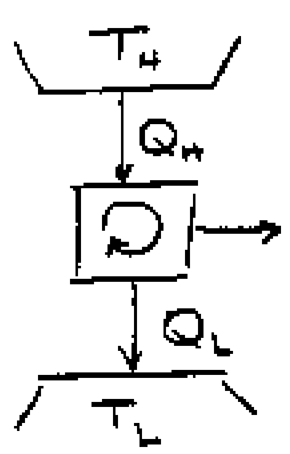
$$\boxed{\begin{array}{lll} \text{if } \eta_{claimed} < \eta_{carnot} & & \text{cycle is irreversible} \\ \text{if } \eta_{claimed} = \eta_{carnot} & & \text{cycle is reversible} \\ \text{if } \eta_{claimed} > \eta_{carnot} & & \text{cycle is impossible} \end{array}}$$

likewise for β & β'

---

finding η, β, β'

look @ HE



equality of temp scale

w/ 2 const T res.

$$\boxed{\frac{Q_H}{Q_L} = \frac{T_H}{T_L}}$$

using absolute temperatures

if rev

$Q_H = W + Q_L$

$Q_H - Q_L = W$

if irrev

$Q_H - Q_L = W_{irr} + \text{losses}$

$W_{irr} + \text{losses} = W_{rev} \qquad W_{irr} < W_{rev}$

$\eta_{carnot} = \frac{W_{rev}}{Q_H}$

$\eta_{irrev} = \frac{W_{irr}}{Q_H} \qquad \frac{W_{irr}}{Q_H} < \frac{W_{rev}}{Q_H}$

$\eta_{irrev} < \eta_{carnot}$

β_{carnot} is max β

β'_{carnot} is max β

$\boxed{\eta = \frac{W}{Q_H}}$ use this to evaluate the efficiency of a heat engine

if carnot, rev, $\therefore Q_H - Q_L = W$

and $\eta = 1 - \frac{Q_L}{Q_H} = \boxed{1 - \frac{T_L}{T_H} = \eta_{carnot}}$

$\boxed{\beta = \frac{Q_L}{W}}$ use this to evaluate the COP of a refrigerator

if carnot, rev, $\therefore Q_H - Q_L = W$

and $\beta = \frac{1}{\frac{Q_H}{Q_L} - 1} = \boxed{\frac{1}{\frac{T_H}{T_L} - 1} = \beta_{carnot}}$

$\boxed{\beta' = \frac{Q_H}{W}}$ use this to evaluate the COP of a heat pump

if carnot, rev, $\therefore Q_H - Q_L = W$

and $\beta' = \frac{1}{1 - \frac{Q_L}{Q_H}} = \boxed{\frac{1}{1 - \frac{T_L}{T_H}} = \beta'_{carnot}}$

$$\eta = \frac{W}{Q_H} \frac{\frac{d}{dt}}{\frac{d}{dt}} = \frac{\dot{W}}{\dot{Q}_H}$$

$$\beta = \frac{Q_L}{W} = \frac{\dot{Q}_L}{\dot{W}}$$

$$\beta' = \frac{Q_H}{W} = \frac{\dot{Q}_H}{\dot{W}}$$