Chapter 22

- Heat engine
- 2^{nd} law of thermodynamics
- Carnot engine (ideal heat engine)
- Refrigerator & heat pump
- Entropy

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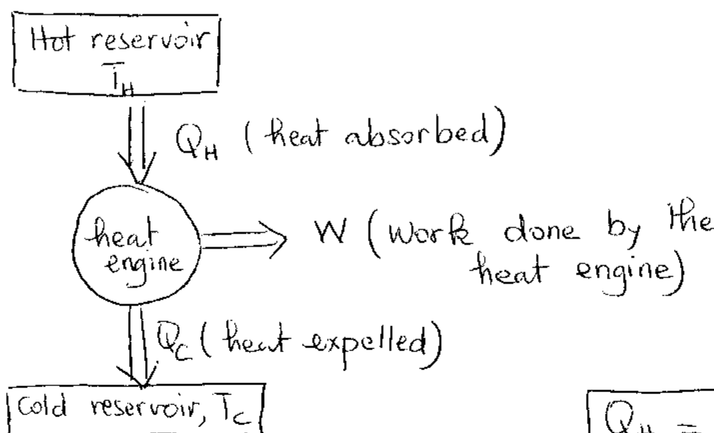
① Heat engine

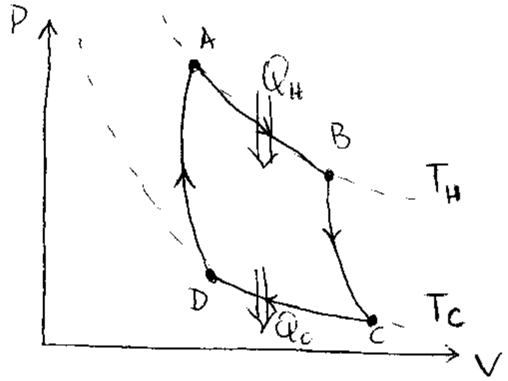


Conservation of energy $\Rightarrow$ $\boxed{Q_H = Q_C + W}$

The efficiency $e = \dfrac{W}{Q_H} = 1 - \dfrac{Q_C}{Q_H} < 1$

② 2^{nd} law of thermo. : Heat does not flow spontaneously from a cold reservoir to a hot reservoir.

③ Carnot cycle



$A \to B$ and $C \to D$ are isothermals.

$B \to C$ and $D \to A$ are adiabatics.

$A \to B$: heat is absorbed (Q_H)

$C \to D$: heat is expelled (Q_c)

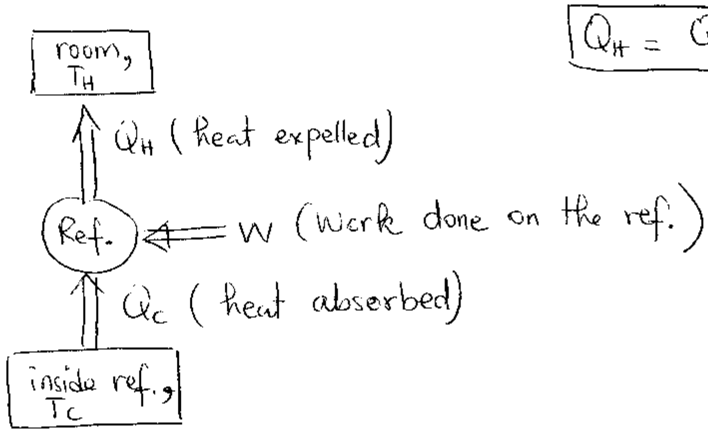
Example 22.2 in the text book proves that

$$\boxed{\frac{Q_C}{Q_H} = \frac{T_C}{T_H}} \Rightarrow \boxed{e_C = 1 - \frac{T_C}{T_H}}$$

e_c is Carnot efficiency and T is the absolute temperature.

e_c is the <u>maximum</u> possible efficiency.

④ Refrigerator and heat pump work like a heat engine in <u>reverse</u>.



$$\boxed{Q_H = Q_c + W}$$

coefficient of performance (COP)

$$\boxed{COP_{ref.} = \frac{Q_c}{W}}$$

For a heat pump $\boxed{COP_{H.p.} = \frac{Q_H}{W}}$

For <u>ideal</u> refrigerator $COP = \frac{T_c}{T_H - T_c}$

For <u>ideal</u> heat pump $COP = \frac{T_H}{T_H - T_c}$

④ Entropy

The entropy (S) is a measure of <u>disorder</u>.

* For <u>reversible</u> path $dS = \frac{dQ_r}{T}$

$$\Rightarrow \quad \Delta S = \int_i^f \frac{dQ_r}{T}$$

Entropy is a <u>state function</u>. It depends only on the initial and final states of the system (independent on the path).

* For <u>reversible</u>, adiabatic process $\boxed{\Delta S = 0}$, Called isentropic process.

* For Carnot heat engine (reversible ideal cycle)

$$\Delta S = \frac{Q_H}{T_H} - \frac{Q_c}{T_c} = 0$$

* For any reversible <u>cyclic</u> process $\Delta S = 0$

* For any quasi-static reversible process of ideal gas

$$\Delta S = n C_v \ln\left(\frac{T_f}{T_i}\right) + n R \ln\left(\frac{V_f}{V_i}\right)$$

Here we have change in pressure, volume and temperature.

* For solids and liquids (reversible):

$$\Delta S = \frac{mL}{T}$$ (change in phase only)

$$\Delta S = m c \ln\left(\frac{T_f}{T_i}\right)$$ (change in temperature only)

Irreversible processes

(i) Heat conduction $$\Delta S = \frac{Q}{T_C} - \frac{Q}{T_H}$$

(ii) Free expansion $$\Delta S = n R \ln\left(\frac{V_f}{V_i}\right)$$

(iii) Heat transfer between two objects (mixing)

$$\Delta S = m_1 c_1 \ln\left(\frac{T_f}{T_1}\right) + m_2 c_2 \ln\left(\frac{T_f}{T_2}\right)$$