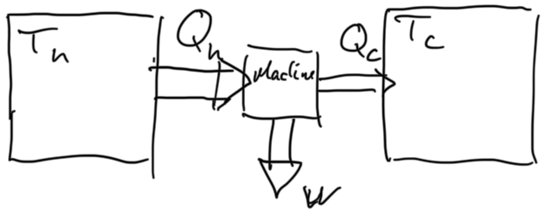
Engines & refrigerators



Reservoirs : $dT = 0$

Machine is cyclic : $\oint dU$, dS

Efficiency $\quad e = \frac{W}{Q_h} \le 1$

1st law : $\quad Q_h = Q_c + W$

$$e = \frac{Q_h - Q_c}{Q_h} = 1 - \frac{Q_c}{Q_h} \qquad Q_c \to 0$$

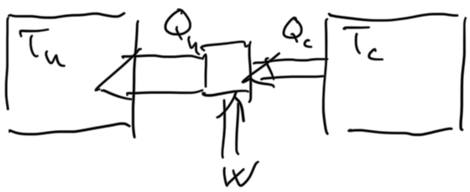
2nd law : $\quad$ Entropy with heat flow $\quad dS = \frac{Q}{T}$

Machine $dS = 0 \qquad S_{out} \ge S_{in}$

$$\frac{Q_c}{T_c} \ge \frac{Q_h}{T_h} \Rightarrow \frac{Q_c}{Q_h} \ge \frac{T_c}{T_h}$$

$$e = 1 - \frac{Q_c}{Q_h} = 1 - \frac{T_c}{T_h}$$

Refrigerator



cyclic $dU = 0$
machine $dS = 0$

1st law $\quad W + Q_c = Q_h$

2nd law $\quad \frac{Q_h}{T_h} \ge \frac{Q_c}{T_c} \Rightarrow \frac{Q_h}{Q_c} \ge \frac{T_h}{T_c}$

Fridge e : Coeff of performance $\quad COP = \frac{Q_c}{W} = \frac{Q_c}{W} = \frac{1}{\frac{Q_h}{Q_c} - 1}$

maximize $\frac{Q_c}{W} \qquad \le \frac{1}{\frac{T_h}{T_c} - 1} = \frac{T_c}{T_h - T_c}$

$$COP \le \frac{T_c}{T_h - T_c} \quad \lessgtr 1$$

Heat pump maximize $\frac{Q_h}{W} \qquad e < \frac{T_h}{T_h - T_c} \underline{> 1}$

Carnot cycle $e \geq 1 - \frac{T_c}{T_h}$

Work medium $Q \to$ [⁚] $\to W$ $\qquad Q \to$ [gas |] $\to$ $PV = NkT$

Least entropy production $\qquad Q = T\,dS$

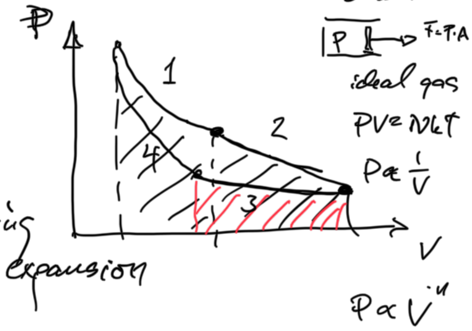
$dS = \frac{Q}{T}$

1st heat $\to$ gas at const. temp.

$T_h \qquad T_g = T_h - \delta \qquad \delta$ small $\to dS$ small

Isothermal + expansion

$W = -P \cdot \Delta V$



2 Let gas work without producing heat $Q = 0$ adiabatic expansion

$P \propto V^{-n}$

3 Compress isothermally $W = P\Delta V \qquad T_g = T_c + \delta$

4 Do work on gas without heat $Q = 0$ adiab. compression

Carnot cycle $e = 1 - \frac{T_c}{T_h}$