Chapter 4

Heat Engine → absorbs heat, produces work

can not convert all of it to work.

Heat comes in increase the entropy of the engine } → to start the cycle over, entropy must be taken out of the engine

$\underbrace{\text{to start the cycle over, entropy must be taken out of the engine}}_{\text{heat exhausted}}$

$$\Delta U_{cycle} = 0 = Q + W_{gas}$$

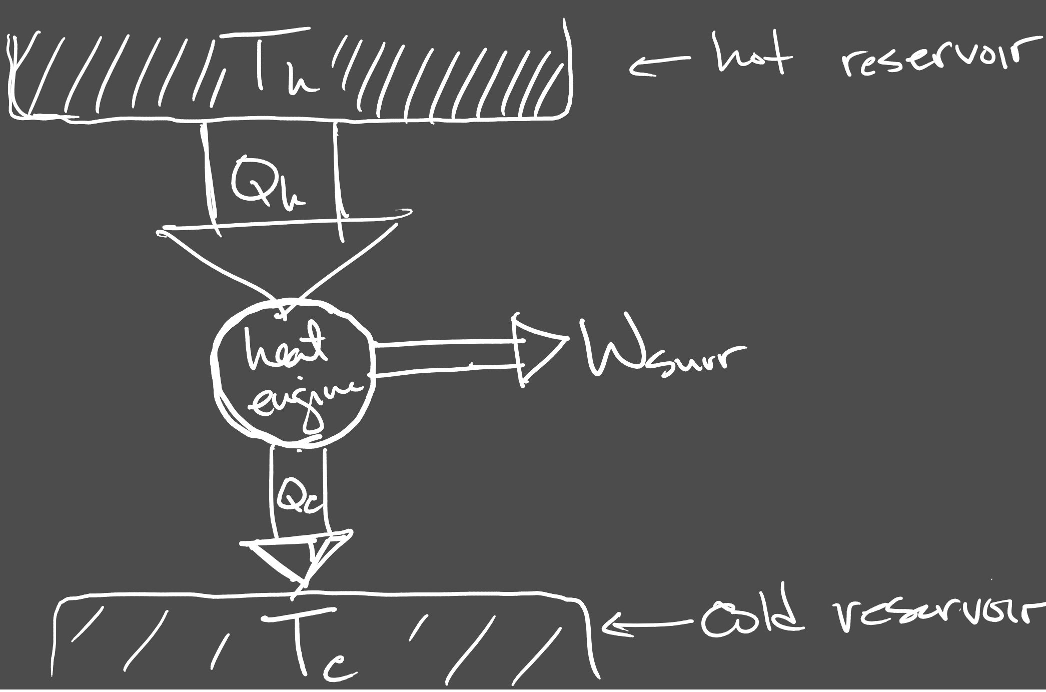
$$0 = \underset{\text{heat in}}{Q_h} - \underset{\text{heat out}}{Q_c} + W_{gas}$$

$$-W_{gas} = Q_h - Q_c$$

$$\boxed{W_{surr} = Q_h - Q_c}$$ 1st Law of Thermo

$$\text{efficiency} \equiv \frac{\text{what you get}}{\text{what you pay for}} = \frac{\text{benefit}}{\text{cost}}$$

$$e = \frac{W_{surr}}{Q_h} = \frac{Q_h - Q_c}{Q_h} = 1 - \frac{Q_c}{Q_h}$$



$$\Delta S_{in} = \frac{Q_h}{T_h}$$

$$\Delta S_{out} = \frac{Q_c}{T_c}$$

at best, w/ no new entropy created

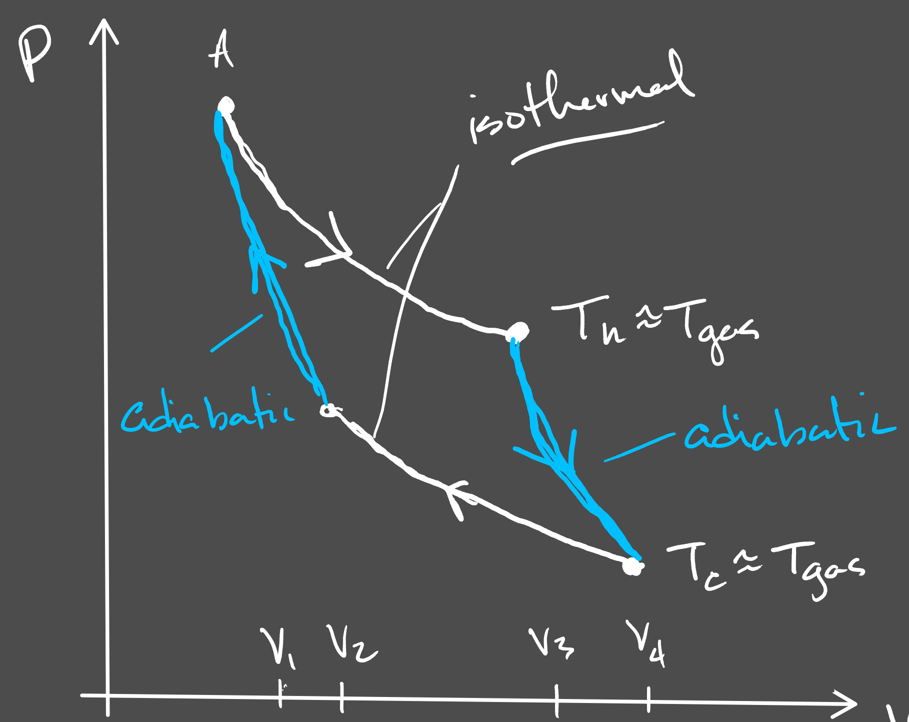
$$\Delta S_{in} = \Delta S_{out}$$

$$\frac{Q_h}{T_h} = \frac{Q_c}{T_c}$$

more realistically

$$\frac{Q_h}{T_h} \leq \frac{Q_c}{T_c}$$

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



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

how can we acheive max efficiency

$$\underbrace{\frac{Q_h}{T_h}}_{S \text{ removed from res}} = \underbrace{\frac{Q_h}{T_{gas}}}_{S \text{ gained by working substance}}$$

→ $T_h = T_{gas}$

no heat will tranfer

→ $T_{gas} + dT = T_h$

↓

keep this T_{gas} constant

isothermal expension

for exhaust,

$$\frac{Q_c}{T_c} = \frac{Q_c}{T_{gas}}$$

4.5 isothermal expansion

$$\cancel{dU}^{0} = đQ + đW$$

$$đQ = -đW = p\,dV$$

$$p = \frac{Nk_BT}{V}$$

$$Q = Nk_BT\int_{V_i}^{V_f}\frac{dV}{V} = Nk_BT\ln\left(\frac{V_f}{V_i}\right)$$

$$Q_h = Nk_BT_h\ln\left(\frac{V_3}{V_1}\right)$$

$$Q_c = Nk_BT_c\ln\left(\frac{V_2}{V_4}\right)$$

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

$$1 - \frac{T_c\ln\left(\frac{V_2}{V_4}\right)}{T_h\ln\left(\frac{V_3}{V_1}\right)} = 1 - \frac{T_c}{T_c}$$ only if $\underbrace{\frac{V_2}{V_4} = \frac{V_3}{V_1}}_{\text{prove this}}$ ✓

adiabatic expansion ✓

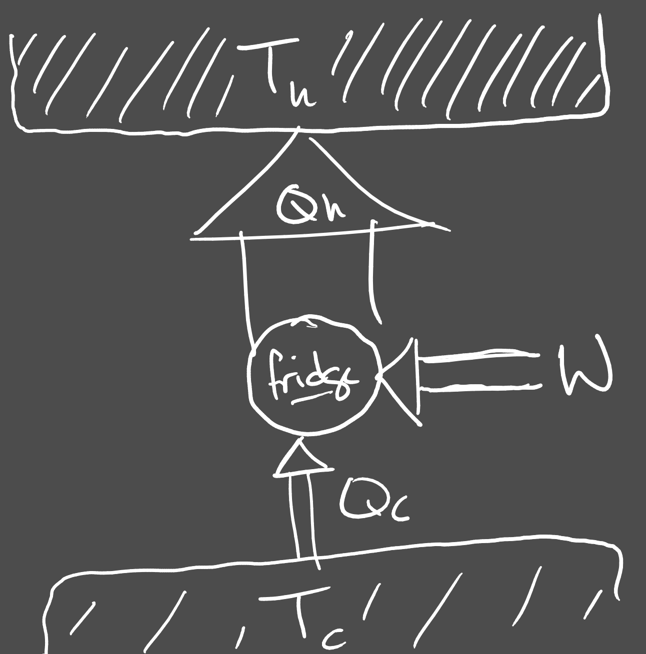
$$V_f T_f^{f/2} = V_i T_i^{f/2}$$

Refrigerator → operates oppositely to the heat engine

→ W in from surroundings

Q_c out of cold res.

Q_h into hot res.



fridge | air conditioner | heat pump

operate in the same way, difference is what you want efficiency ⇒ coefficient of performance

$$COP = \frac{\text{what you get}}{\text{what you want}} = \frac{Q_c}{W} \Big\} \text{ fridge}$$

heat pump

$$COP = \frac{Q_h}{W}$$

$$COP = \frac{Q_c}{W} = \frac{Q_c}{Q_h - Q_c} = \frac{1}{\frac{Q_h}{Q_c} - 1}$$

1st law of thermo

$$\frac{Q_h}{T_s} \geq \frac{Q_c}{T_c} \Rightarrow \frac{Q_h}{Q_c} \geq \frac{T_h}{T_c}$$

$$COP \leq \frac{1}{T_h/T_c - 1}$$

$$COP \leq \frac{T_c}{T_h - T_c}$$

Ex. kitchen freezer

$T_c = 255\ K$

$T_h = 295\ K$

$$COP \leq \frac{255}{40} \leq 6.3 \geq \frac{Q_c}{W}$$

each joule of work moves 6.3 J of heat out of the freezer

What heat is dumped into the kitchen?

$$Q_h = Q_c + W = \underline{7.3\,J}$$

4.10) Heat leaks into fridge at a rate of 300 Watts. What is the power drawn from the wall?

$$COP = \frac{Q_c}{W} = \frac{Q_c/\Delta t}{W/\Delta t} = \frac{300\text{ Watts}}{P_{wall}} = COP$$

Power

$$P_{wall} = \frac{300\,W}{7.3} = 41\text{ Watts}$$ ← electrical power from outlet.

#10, 15