FERMILAB
ENGINEERING NOTE

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SUBJECT: Physics 2C 2/14

NAME:

DATE: REVISION DATE:

① Carnot Cycles: Maximum η and K
② Easy problem
③ More involved problem

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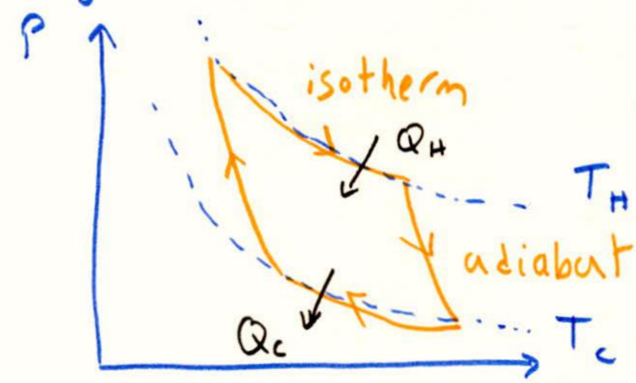
① Given T_H and T_c, what's the best engine that can be built? (max η)



Carnot

1. isothermal exp.
2. adiabatic exp.
3. isothermal comp.
4. adiabatic comp.

$$\eta = \frac{W_{out}}{Q_H} = \frac{Q_H - Q_c}{Q_H} = \frac{T_H - T_c}{T_H}$$

carnot

only for Carnot!

$$\eta_{\substack{any\\engine}} \le \eta_{Carnot}$$

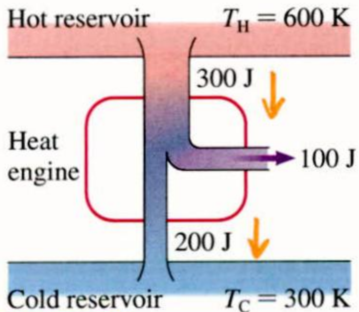
$$K = \frac{Q_c}{W_{in}} = \frac{Q_c}{Q_H - Q_c} = \frac{T_c}{T_H - T_c}$$

only for Carnot!

- Carnot = ideal, <u>reversible</u> engine

(contrast w/ otto cycle which has rapid cooling/heating not along adiabat)

The following shows an energy-exchange diagram for a theoretical engine. Is it possible?



A) No: violates only 1st law
B) No: violates only 2nd law
C) No: violates both
D) Yes, possible

$\boxed{\text{1st Law}}$ $Q_H = W_{out} + Q_C$

$300J = 100J + 200J$ ✓

$\boxed{\text{2nd Law}}$ $\eta_{actual} \le \eta_{carnot}$ ✓

$\eta_{actual} = \frac{W_{out}}{Q_H} = \frac{100J}{300J} = \frac{1}{3}$

$\eta_{carnot} = \frac{T_H - T_C}{T_H} = \frac{600-300}{600} = \frac{1}{2}$

$K = \frac{T_c}{T_H - T_c}$

32. ‖ A $\boxed{\text{Carnot refrigerator}}$ operating between −20°C and +20°C extracts heat from the cold reservoir at the rate 200 J/s. What are (a) the coefficient of performance of this refrigerator, (b) the rate at which work is done on the refrigerator, and (c) the rate at which heat is exhausted to the hot side?

Note can just solve over $\boxed{\text{1 sec.}}$ then convert Joules to watts

fridge: $T_c = -20°C = 253\,K$
$T_H = +20°C = 293\,K$

$Q_c = 200\,J$

(a) $K = \frac{T_c}{T_H - T_c} = \frac{253K}{40K} = \boxed{6.325}$

(b) $K = \frac{Q_c}{W_{in}} \Rightarrow W_{in} = \frac{Q_c}{K} = \frac{200J}{6.325} = 31.6J$

$\boxed{P_{in} = 31.6\,W}$

(c) $Q_H = Q_c + W_{in} = 200\,J + 31.6\,J$

$= 232\,J$

$\boxed{P_H = 232\,W}$

$1.25 = \frac{C_p}{C_v}$ and $C_p = C_v + R$

57. ‖ **FIGURE P21.57** shows the cycle for a heat engine that uses a gas having $\gamma = 1.25$. What is the engine's thermal efficiency? ← this is the goal but let's break it up

(Given p_0, V_0)

(a) Find C_P and C_V

(b) Find $Q_H = \boxed{}$ (just one)

(c) Find $\boxed{W_{by}^{(23)}}$ ⊕, $\boxed{W_{by}^{(12)}}$ ⊖, and $W_{out} = W_{by}^{(23)} + W_{by}^{(12)}$

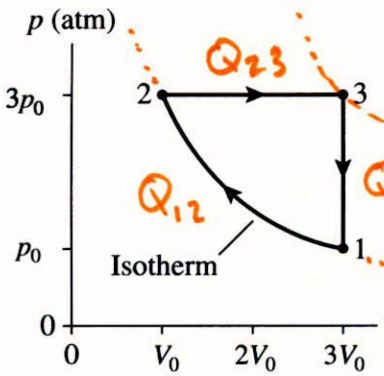
(d) Find η_{actual}

(e) Compare with $\boxed{\eta_{Carnot}} = 1 - \frac{T_C}{T_H} = 1 - \frac{T_1}{T_3}$

$= 1 - \frac{P_1 V_1}{P_3 V_3}$

$= 1 - \frac{P_0 (3V_0)}{(3P_0)(3V_0)}$

$= 1 - \frac{1}{3} = \boxed{\frac{2}{3}}$



(a) $C_p = 5R$, $C_v = 4R$

(b) $Q_H = Q_{23} = n C_p \Delta T = 5nR\Delta T$

$= 5\Delta(PV) = 5(P_3 V_3 - P_2 V_2)$

$= 5[(3p_0)(3V_0) - (3p_0)V_0)]$

$= \boxed{30 p_0 V_0}$

(c) $W_{by}^{(23)} = (3p_0)(2V_0) = 6 p_0 V_0$

$W_{by}^{(12)} = nRT_1 \ln\left(\frac{\frac{1}{3}V_0}{V_0}\right) = -nRT_1 \ln(3)$

$= -3p_0 V_0 \ln(3)$

(d) $\eta = \frac{W_{out}}{Q_H} = \frac{p_0 V_0 [6 - 3\ln(3)]}{30 p_0 V_0} = \frac{2 - \ln(3)}{10} \approx 9\%$

$< 67\%$ ✓