FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE

SUBJECT: Physics 2C 2/13

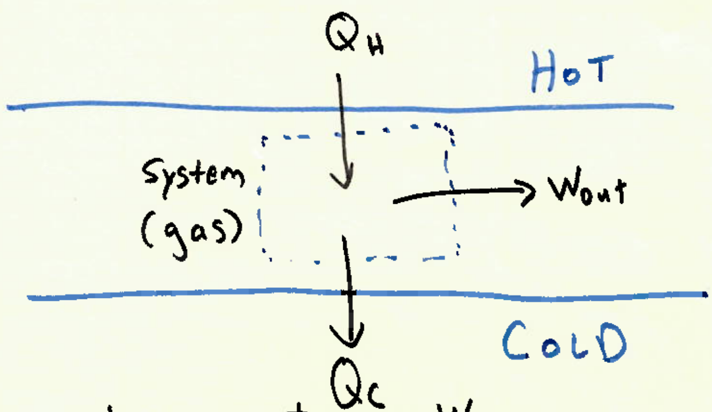
NAME:

DATE: | REVISION DATE:

1. Engines & Refrigerators via Energy Transfer Diagrams
   → Efficiency η, Coefficient of Performance K
2. Definitions: Cycle Reservoir
3. Connection to pV diagrams
4. Finding Q's and W_{by}'s from graphs

---

1. $\boxed{\text{Engines}}$



energy conserved

$Q_H = W_{out} + Q_C$

efficiency: $\eta = \dfrac{\text{what we want}}{\text{What we have to pay for it}} = \dfrac{W_{out}}{Q_H} = 1 - \dfrac{Q_C}{Q_H}$

- "waste heat" Q_C : energy not turned into "useful" work
- "perfect" engine with $\eta = 1$, $Q_C = 0$ is impossible because of 2^{nd} Law of thermo $\Delta S \geq 0$

Heat is "unordered" energy
Work is "ordered" energy

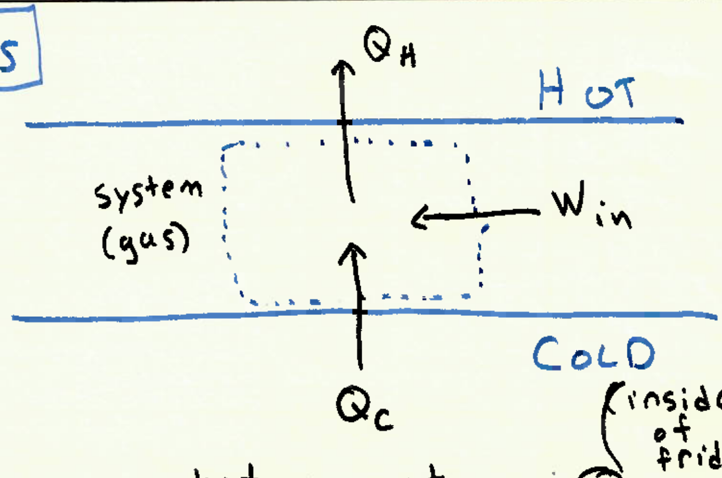
- Note: there is a "best" value for efficiency
  Carnot engine (Friday)

FERMILAB ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE

SUBJECT	NAME	DATE	REVISION DATE

Refrigerators

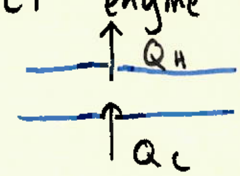


energy cons.

$Q_c + W_{in} = Q_H$

coefficient of performance : $K = \dfrac{\text{what we want}}{\text{what we pay}} = \dfrac{Q_c}{W_{in}} = \dfrac{Q_c}{Q_H - Q_c}$

- Note: Q_c, Q_H, W have slightly different meanings! (arrows are opposite directions)
- No "perfect" refrigerator with $K = \infty$, $W_{in} = 0$
  - ↳ If you combined a perfect engine w/ a perfect refrigerator:



w/ no assistance impossible!

- Carnot fridge is best possible K (Friday)

Q_H
$\downarrow$ $W_{out} \rightarrow$
$\downarrow Q_c$

An engine has an efficiency η = 0.20. This means that for every 1.0 kJ of "waste heat" produced, we get ________ of work.

$= Q_c$

$\eta = \frac{W_{out}}{Q_H} = 0.2 = \frac{1}{5}$

Cons. of energy!

A) ~~2.0 kJ~~
B) ~~5.0 kJ~~
C) 0.2 kJ
D) 0.25 kJ
E) None of these

$Q_H = W_{out} + Q_c$

$5W_{out} = W_{out} + Q_c$

$W_{out} = \frac{1}{4} Q_c$

$\uparrow Q_H$
$\leftarrow W_{in}$
$\uparrow Q_c$

$Q_H = Q_c + W_{in}$

$K = \frac{Q_c}{W_{in}}$

A refrigerator has a coefficient of performance K = 4.0. This means that for every 1 kJ that is taken from the wall outlet, ________ of heat energy is taken from the inside of the refrigerator.

$= W_{in}$

$Q_c = 4\,kJ$

$Q_H = 5\,kJ$

A) 4 kJ
B) 5 kJ
C) Neither of these

FERMILAB
ENGINEERING NOTE

SECTION	PROJECT	SERIAL-CATEGORY	PAGE

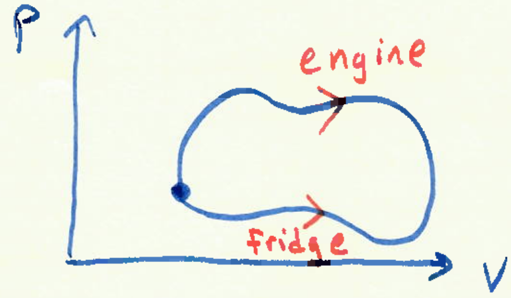
SUBJECT

NAME	
DATE	REVISION DATE

② Reservoir: Large obj. or part of environment @ const. temp.

Cycle:

closed path on pV diagram



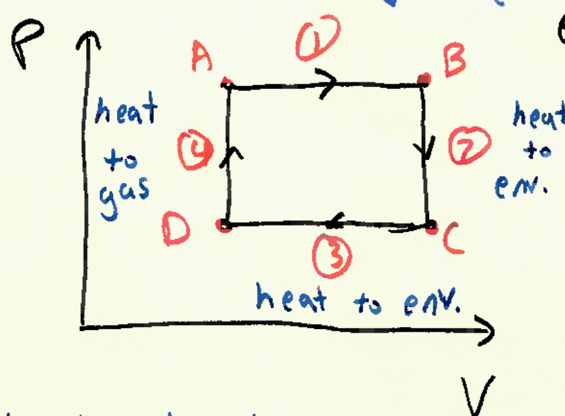
engine: CW
fridge: CCW

---

③

heat to gas $(Q = n C_{V/P} \Delta T)$

engine

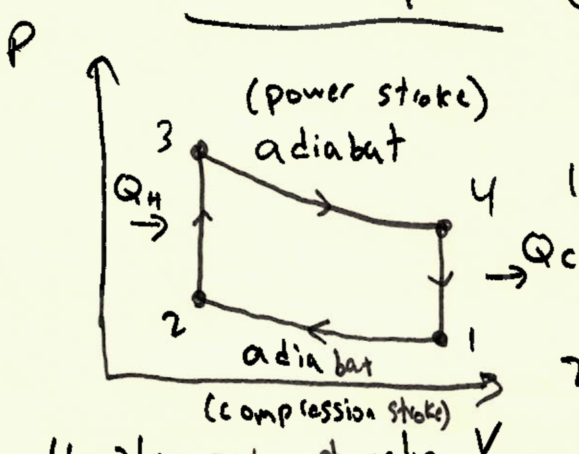


When is heat transfered to gas and when is heat transferred to environment?

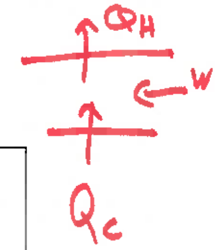
$$Q_H = |Q_1| + |Q_4|$$

$$Q_C = |Q_2| + |Q_3|$$

Otto cycle (idealized car engine)



1: fuel-air mixture in cylinder
1→2: mixture compressed by piston
2: spark plug fires
2→3: fuel burns quickly heating gas
3→4: hot, high-pressure gas pushes piston out
4→1: exhaust valve opens to lower gas temp

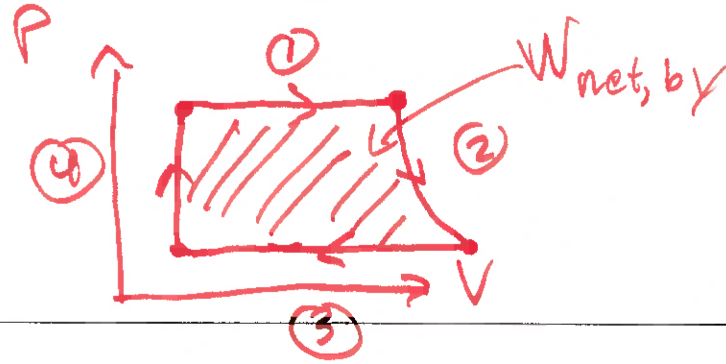


W_{in} Q_H

5. || A refrigerator requires 200 J of work and exhausts 600 J of heat per cycle. What is the refrigerator's coefficient of performance?

$$K = \frac{Q_c}{W_{in}} = \frac{400J}{200J} = \boxed{2}$$

$$Q_H = W_{in} + Q_c$$
$$600J = 200J + Q_c$$
$$Q_c = 400J$$



An engine consists of:
1. isobaric expansion, 2. adiabatic expansion, 3. isobaric compression, 4. isochoric heating.

i) Draw the pV diagram.

ii) Under which step(s) is heat added to the gas?

A) Step 1 only
B) Step 3 only
C) Step 4 only
D) Steps 1 and 4 only
E) Steps 3 and 4 only

iii) Give an expression for the efficiency in terms of ~~$W_{net,by}$~~, Q_1, Q_2, Q_3, Q_4

$$\eta = \frac{W_{net,by}}{Q_H} = \frac{W_{net,by}}{Q_1 + Q_4}$$

Note $W_{net,by} = W_{out} = Q_H - Q_C$

$$= (Q_1 + Q_4) - |Q_3|$$

$$= Q_1 + Q_4 + Q_3$$

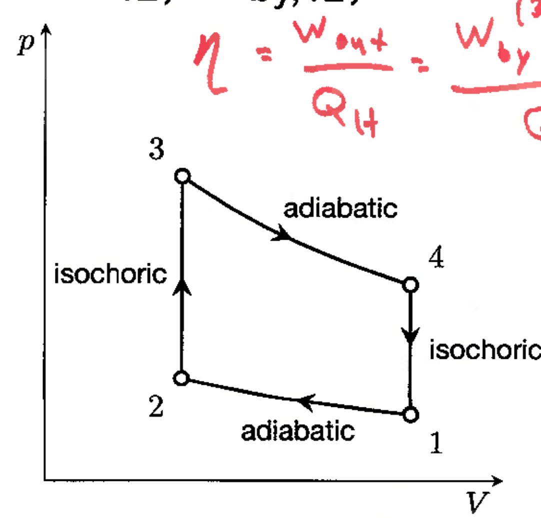
$$\boxed{\eta = \frac{Q_1 + Q_4 + Q_3}{Q_1 + Q_4}}$$

The engine in an automobile can be idealized with the Otto cycle shown below.
(i) Fill out the table.
(ii) Give an expression for the efficiency η of the engine in terms of Q_{12}, $W_{by,12}$, …

$$\Delta E_{th} = W_{on} + Q = -W_{by} + Q$$

$$\eta = \frac{W_{out}}{Q_H} = \frac{W_{by}^{(34)} + W_{by}^{(12)}}{Q_{23}}$$

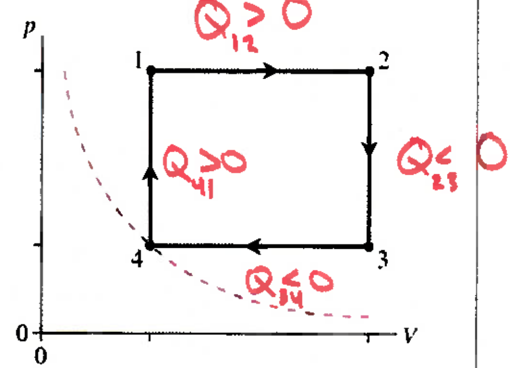
(path)	sign of Q	sign of W_{by}
12	0	−
23	+	0
34	0	+
41	−	0



Suppose you have an engine consisting of isobaric and isochoric paths alone (see the following figure). For $\eta = W_{out}/Q_H$, what is the value of Q_H?

Q_H: heat from res. to gas/system

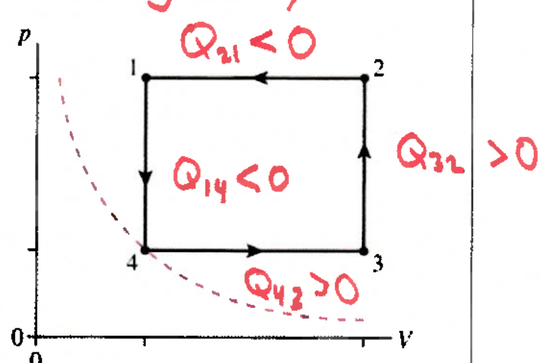
A) $Q_{41} + Q_{12}$ >0
B) $-(Q_{41} + Q_{12})$
C) $Q_{23} + Q_{34}$
D) $-(Q_{23} + Q_{34})$
E) None of the above



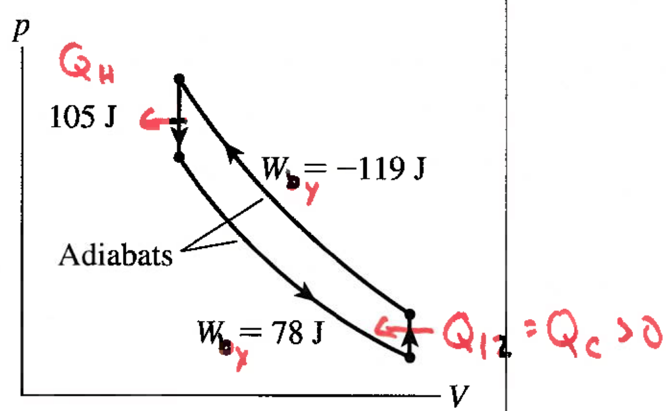
Suppose you have a refrigerator consisting of isobaric and isochoric paths alone (see the following figure). For $K = Q_C/W_{in}$, what is the value of Q_C?

Q_C: heat from ~~env.~~ res. to gas/system

A) $Q_{21} + Q_{14}$
B) $-(Q_{21} + Q_{14})$
C) $Q_{43} + Q_{32}$
D) $-(Q_{43} + Q_{32})$
E) None of the above



20. || What are (a) the heat extracted from the cold reservoir and (b) the coefficient of performance for the refrigerator shown in FIGURE EX21.20?



Q_c? FIGURE EX21.20

(a) $\Delta E_{th,\,cycle} = 0 \Rightarrow Q_{net,\,to\ gas} = W_{net,\,by\ gas}$

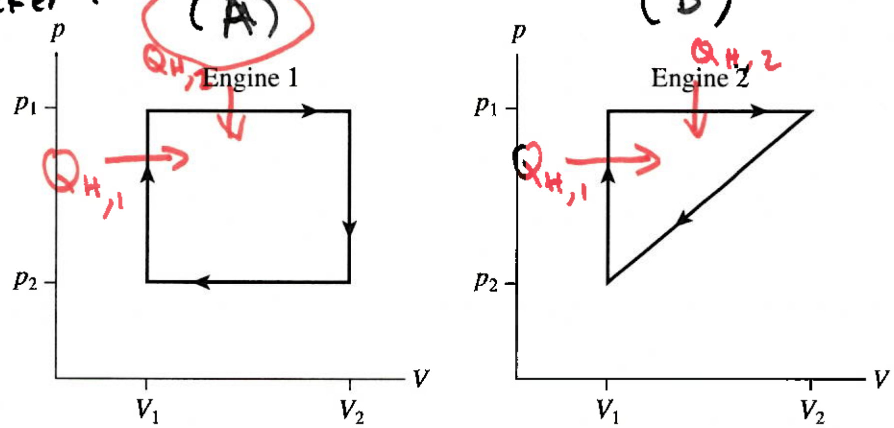
$Q_{12} - 105\,J = -119\,J + 78\,J$

$\boxed{Q_c = Q_{12} = 64\,J}$

(b) $K = \dfrac{Q_c}{W_{in}} = \dfrac{64\,J}{41\,J} = \boxed{1.56}$

6. FIGURE Q21.6 shows the thermodynamic cycles of two heat engines. Which heat engine has the larger thermal efficiency? Or are they the same? Explain.

Clicker: (A) (B) (C) same η



$$\eta = \frac{W_{out}}{Q_H} = \frac{(\text{area})}{Q_H}$$

same for both