1. Engines and Refrigerators via Energy Transfer Diagrams

   Efficiency $\eta$, Coefficient of Performance $K$

2. Some Definitions: Cycle, Reservoir

3. Connection to pV-diagrams

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**Energy conservation**

$Q_H = Q_C + W_{out}$

**Efficiency**

$\eta = \frac{\text{what we want}}{\text{what we have to pay for it}} = \frac{W_{out}}{Q_H} = 1 - \frac{Q_C}{Q_H}$
Refrigerators

\[ Q_{HT} \quad \text{HOT} \]

\[ \text{inside of fridge} \quad Q_c \quad \text{COLD} \]

Cons. of Energy

\[ Q_c + W_{in} = Q_{HT} \]

Coeff. of Perf. \[ K = \frac{\text{want}}{\text{pay}} = \frac{Q_c}{W_{in}} \]
A refrigerator has a coefficient of performance equal to 4.0. This means that, for every 1kJ that I take from the wall outlet,

A) I take out 4kJ of heat energy from the inside of the fridge.
B) I take out 5kJ of heat energy from the inside of the fridge.

An engine has an efficiency equal to 0.20. This means that, for every 1.0kJ of “waste heat” that I produce, that I have gotten ______ of work.

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

\[ Q_{in} = Q_c + W_{out} \]
\[ \eta = \frac{W}{Q_{in}} = \frac{W}{W + Q_c} = \frac{1}{5} \]

\[ W = \frac{1}{5}Q_c + \frac{4}{5}Q_c \]
\[ 4W = Q_c \]
5. A refrigerator requires 200 J of work and exhausts 600 J of heat per cycle. What is the refrigerator’s coefficient of performance?

\[
\begin{align*}
W_{\text{in}} &= 200 \text{ J} \\
Q_{\text{H}} &= 600 \text{ J} \\
Q_{\text{C}} &= 400 \text{ J}
\end{align*}
\]

\[
K = \frac{Q_{\text{C}}}{Q_{\text{in}}} = 2
\]
2. Def: Reservoir: Const. temp heat source/sink.

Cycle: P \rightarrow V

Engine: CCW
Fridge: Ccw

Closed path

3. P \rightarrow V

Engine:

\[ Q = n \cdot C_p \cdot \Delta T \]

\[ \Delta E = 0 = Q + W \]

\[ Q > 0 \]

A → B: heat is going from env. → gas
B → C: env. → gas
C → D: gas → env.
D → A:

\[ Q_H = |Q_{11}| + |Q_{21}| \]

\[ Q_c = |Q_{31}| + |Q_{41}| \]
Suppose you have an engine consisting of 4 steps:
1. isobaric expansion, then 2. adiabatic expansion, then
3. isobaric compression, then 4. isochoric heating.

i. Draw the process on a pV diagram.

ii. Answer the following clicker question:
   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

   \[ Q_1 = nC_p \Delta T > 0 \]
   \[ Q_2 = 0 \]
   \[ Q_3 < 0 \]
   \[ Q_4 > 0 \]

iii. Give an expression for the efficiency in terms of
     \( W_{\text{net,by}} \), \( Q_1 \), \( Q_2 \), \( Q_3 \), and \( Q_4 \).

\[
\eta = \frac{W_{\text{out}}}{Q_1} = \frac{W_{\text{net,by}}}{Q_1 + Q_4} = 1 - \frac{|Q_3|}{Q_1 + Q_4} = \frac{Q_1 + Q_4 + Q_3}{Q_1 + Q_4}
\]