Physics 2c Lecture 6

Chapter 22

Today we talk about heat engines, heat pumps, and refrigerators.

Next lecture, we discuss 2nd law of thermodynamics.

Different approach from last lecture(s)

Last lecture we discussed PV diagram for a cyclic process, and discovered that net work could be done.

Today, we start with the premise of wanting to build an engine based on heat exchange between two objects of differing temperature, and then design a cyclic process that satisfies our needs.

Heat Engine

Heat:

Energy transferred between objects of different temperature.

Engine:

Machine that converts energy into work.

Heat Engine:

Machine that extracts work from the energy transferred between objects of different temperature.

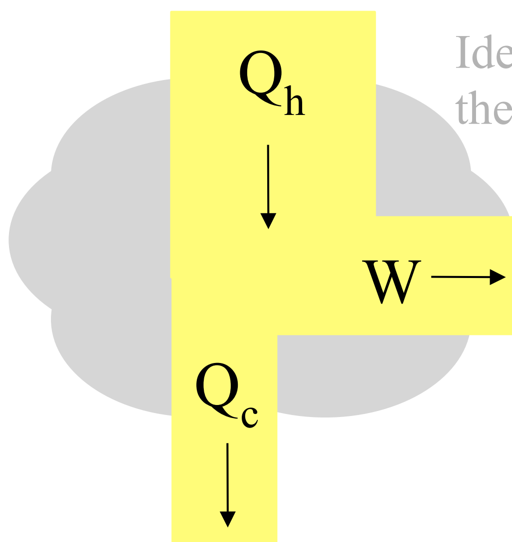
Mental Model

- High T: temperature of burning gas.
- Low T: ambient temperature, i.e. temperature of exhaust.

- Gas expands after ignition
- Turns crank and cools off during expansion
- Heat from the temperature difference is converted into mechanical energy.

Schematic of a heat engine

Thermal bath of temperature T_h



Ideal gas going through thermodynamic cycle.

Energy conservation requires:

$W = Q_h - Q_c$

For an engine, we want maximal efficiency:

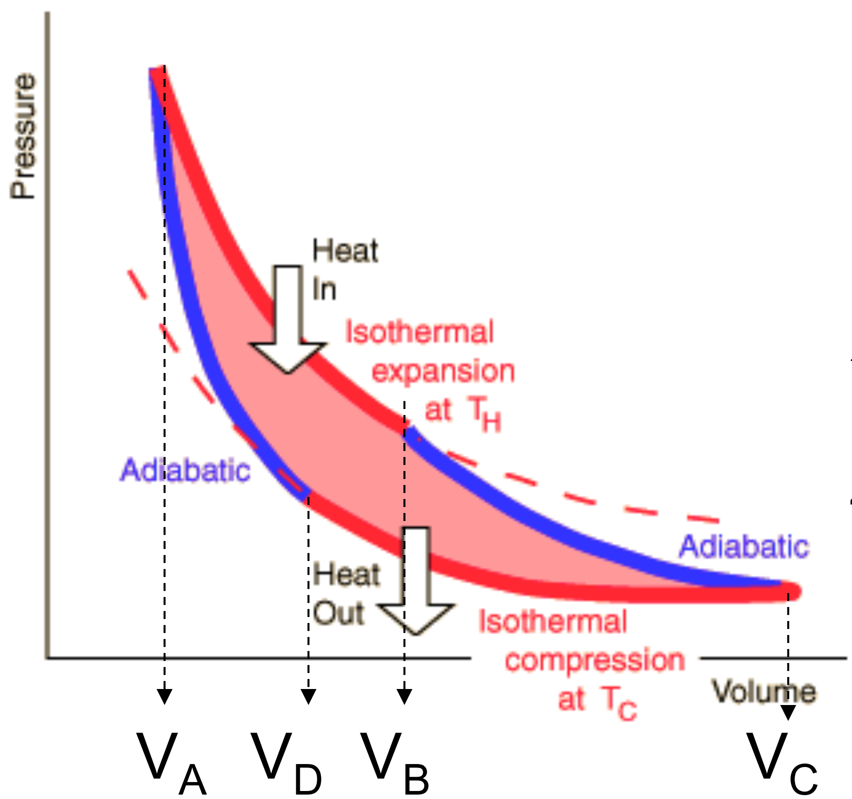
$(Q_h - Q_c) / Q_h$

Thermal bath of temperature T_c

Let's go through an example!

Carnot Engine

Carnot engine, a 4 step process



1. Isothermal Expansion (V_A -> V_B)
2. Adiabatic Expansion (V_B -> V_C)
3. Isothermal Compression (V_C -> V_D)
4. Adiabatic Compression (V_D -> V_A)

Efficiency of Carnot Engine

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

Note: I'm defining both Q's here as positive, thus implicitly "dropping a minus sign on the floor"!

Heat during expansion

$$Q_h = nRT_h \ln \frac{V_B}{V_A}$$

Heat during compression

$$Q_c = nRT_c \ln \frac{V_C}{V_D}$$

Note: I picked up the minus sign off the floor in order to Invert the ratio inside the log.

The signs

- Q_C = heat for going from V_D -> V_c
- $-Q_C$ = heat for going from V_C -> V_D

$$Q = nRT \ln \frac{V_{final}}{V_{initial}}$$

$$Q(V_C \rightarrow V_D) = nRT_c \ln \frac{V_D}{V_C} = -Q_C$$

Connect volume ratio via adiabat

$$T_h V_B^{\gamma-1} = T_C V_C^{\gamma-1}$$

$$T_h V_A^{\gamma-1} = T_C V_D^{\gamma-1}$$

Next: divide the two eq.

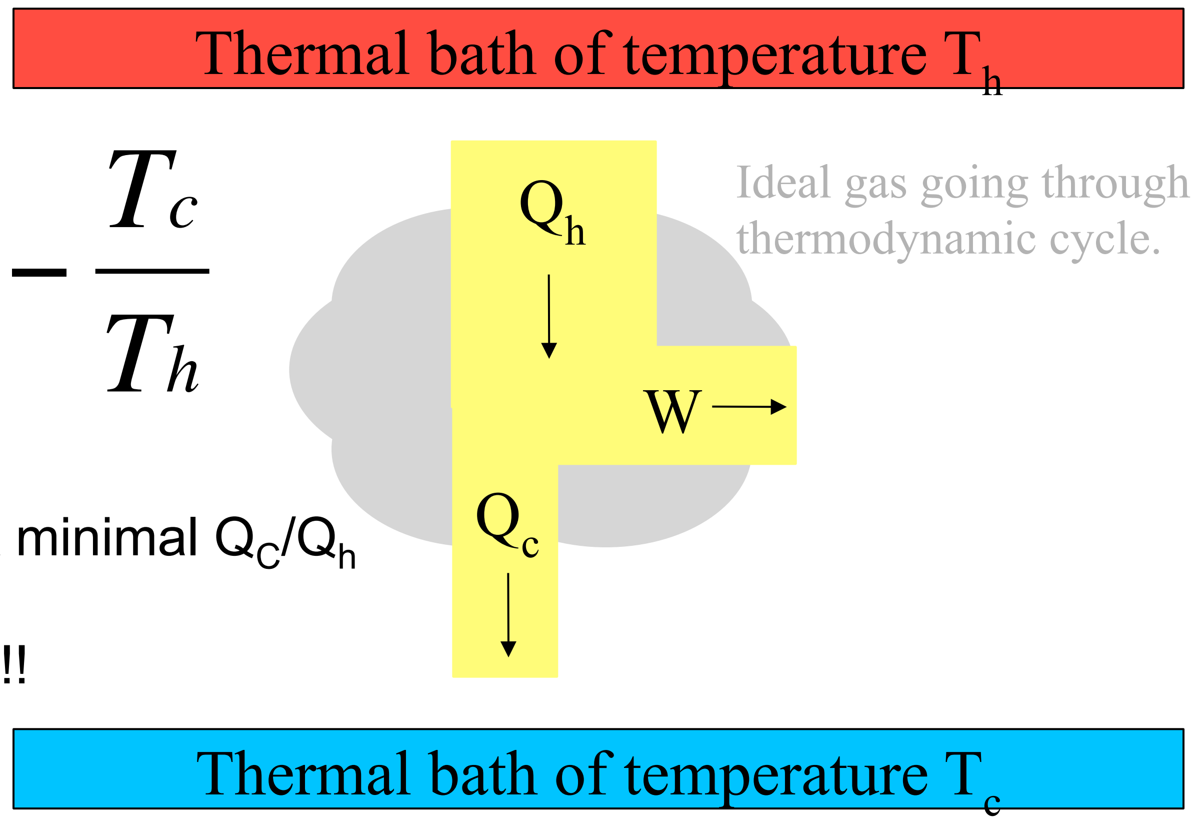
$$\ln\left(\frac{V_B}{V_A}\right) = \ln\left(\frac{V_C}{V_D}\right)$$

Pulling the pieces together

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

Schematic of a heat engine

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



For maximum eff. you want minimal Q_C/Q_h

This implies minimal T_c/T_h !!!

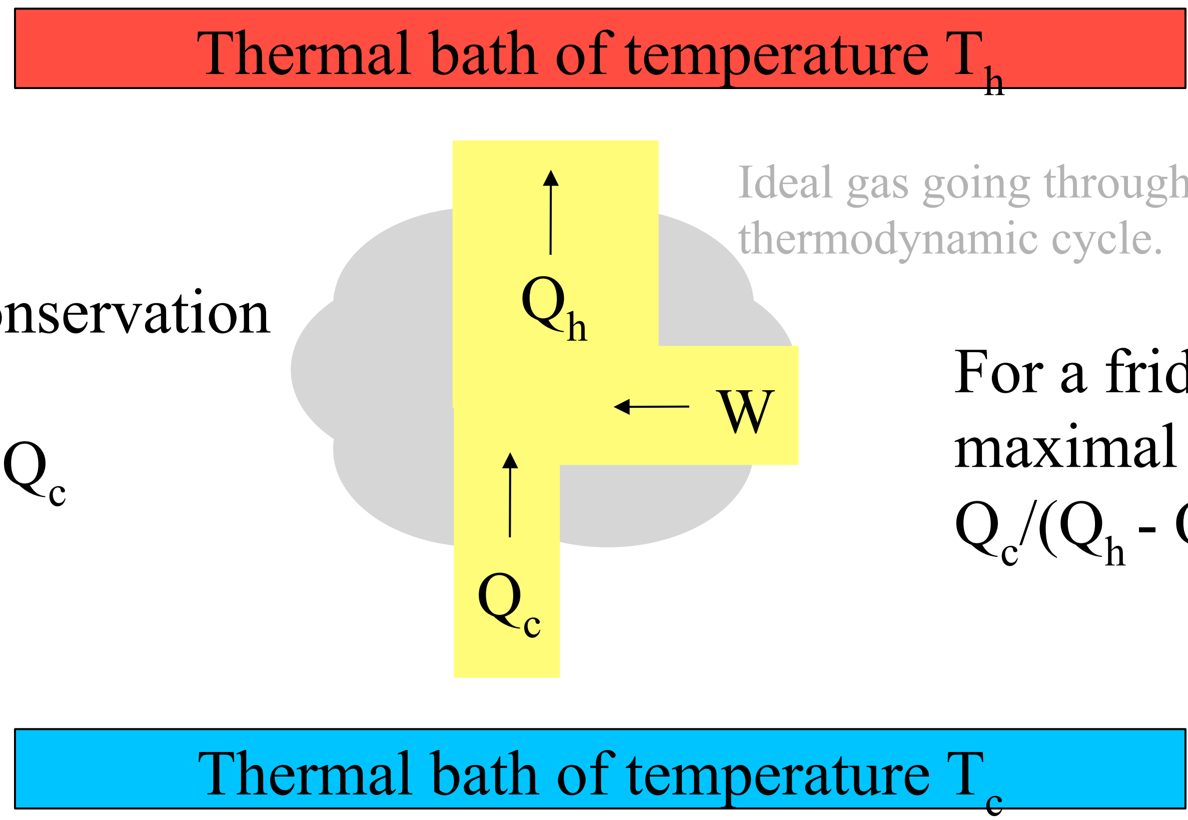
Objective of Fridge/heat pump

- Use work to move heat from a cold place to a hot place.

Schematic of a refrigerator (or heat pump)

Energy conservation requires:

$W = Q_h - Q_c$



For a fridge, we want maximal coeff. of perf.: $Q_c/(Q_h - Q_c)$

How good a heat pump do you have?

$$COP = \frac{Q_c}{W} = \frac{Q_C}{Q_h - Q_c} = \frac{T_C}{T_h - T_C}$$

COP = Coefficient of Performance

Carnot refrigerator

Carnot fridge is a 4 step process:

1. Isothermal Expansion @ low T
2. Adiabatic Compression
3. Isothermal Compression @ high T
4. Adiabatic Expansion

Difference to engine lies in the temperature chosen for isothermal expansion and compression.

Comparing Fridge & Engine

Engine	Fridge
obtain work	expend work
move heat from hot to cold	move heat from cold to hot
max. eff. for max. dT	max. COP for min. dT