Ch 20. The Second Law of Thermodynamics

20-1. Directions of Thermodynamic Processes

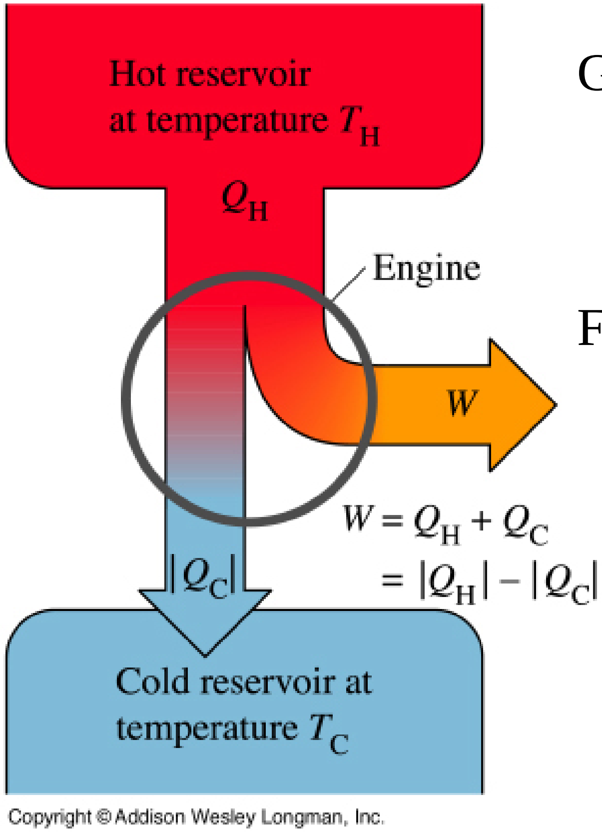
Reversible vs. Irreversible processes

Equilibrium vs. non-equilibrium processes

Converting heat into mechanical energy: how efficient?

Please read text on your own.

20-2. Heat Engine



Converts heat partly into work or mechanical energy

Goes through a cyclic process, thus $\Delta U=0$

$$W=Q=Q_H+Q_C=|Q_H|-|Q_C|$$

For the heat engine

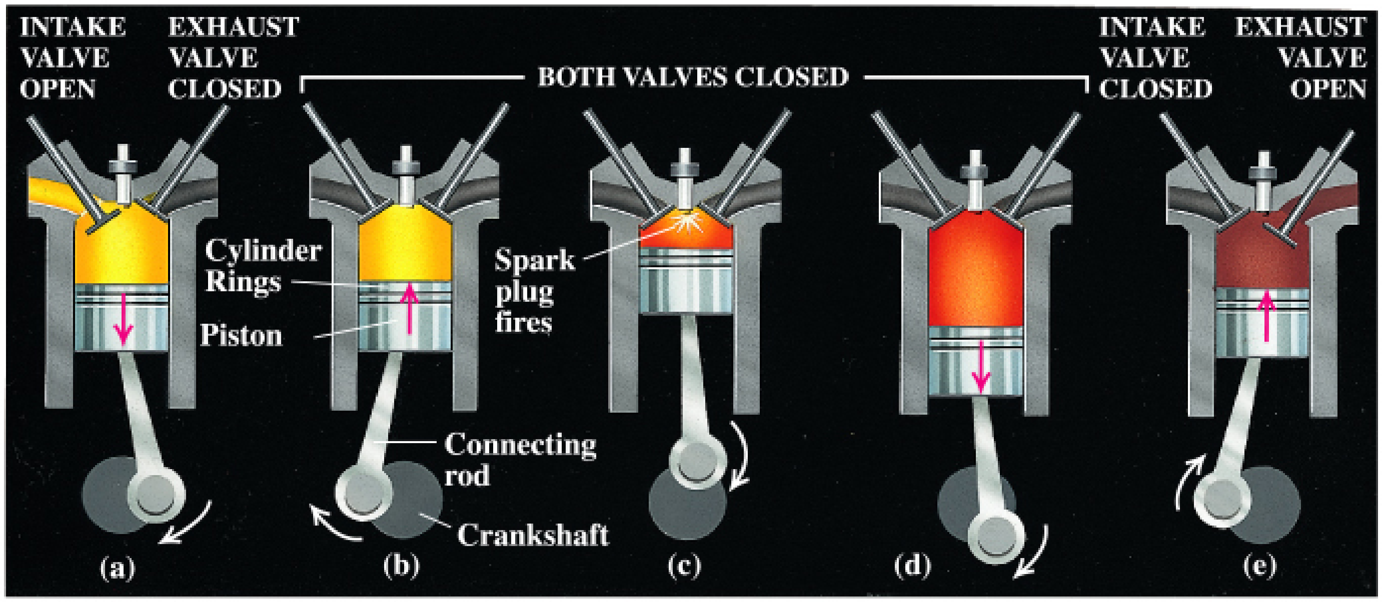
Q_H +; Q_C -

Thermal Efficiency (x100%)

$e=W/Q_H$
$=(|Q_H|-|Q_C|)/Q_H$
$=1-|Q_C/Q_H|$

$e<1$

20-3. Internal Combustion Engines



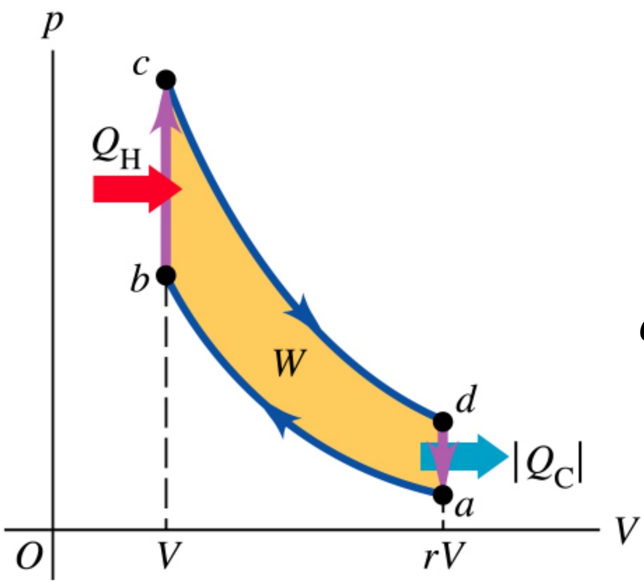
Minimum volume V

Maximum volume rV

Compression ratio r (typically 8-10)

Otto Cycle

Two adiabatic + two isochoric processes



$Q_H=nC_V(T_c-T_b) >0$

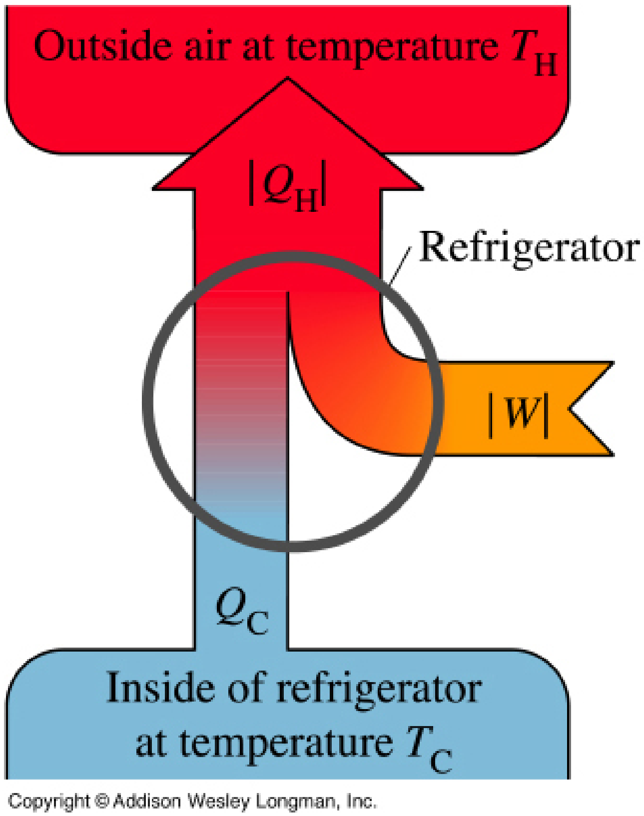
$Q_C=nC_V(T_a-T_d) <0$

$$e = \frac{Q_H + Q_C}{Q_H} = \frac{T_c - T_b + T_a - T_d}{T_c - T_b}$$

$$e = 1 - \frac{1}{r^{\gamma - 1}}$$

Read about Diesel cycle on your own.

20-4. Refrigerators



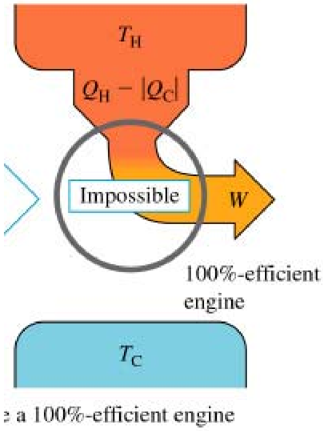
Here:
$W<0;\quad Q_H<0;\quad Q_C>0$

Coefficient of performance

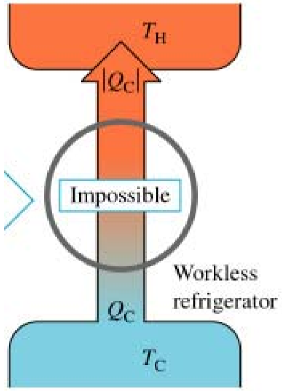
$$K = \frac{|Q_C|}{|W|} = \frac{|Q_C|}{|Q_H| - |Q_C|}$$

20-5. Second Law of Thermodynamics

"Engine Statement":
It is impossible for any system to undergo a process in which it absorbs heat from a reservoir at a single temperature and converts the heat completely into mechanical work, with the system ending in the same state in which it begins.

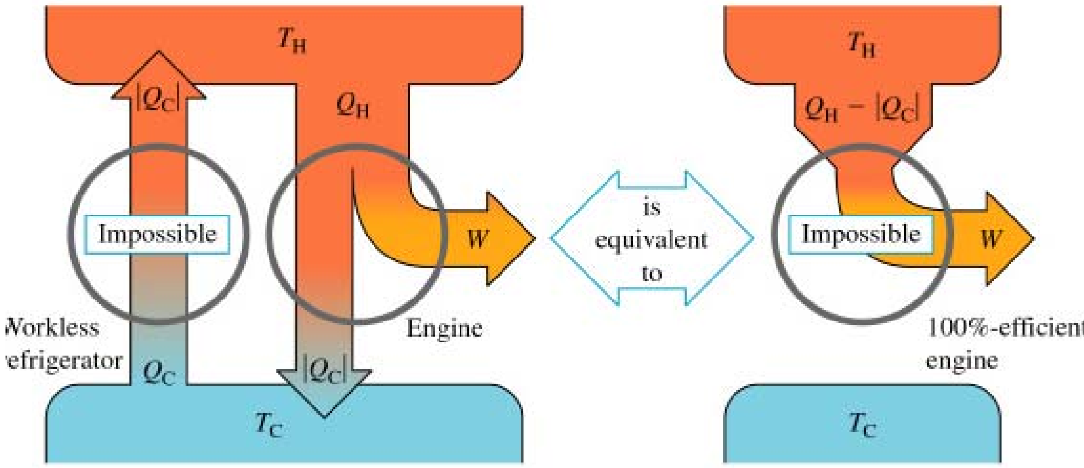


"Refrigerator Statement":
It is impossible for any process to have as its sole results the transfer of heat from a cooler to a hotter body

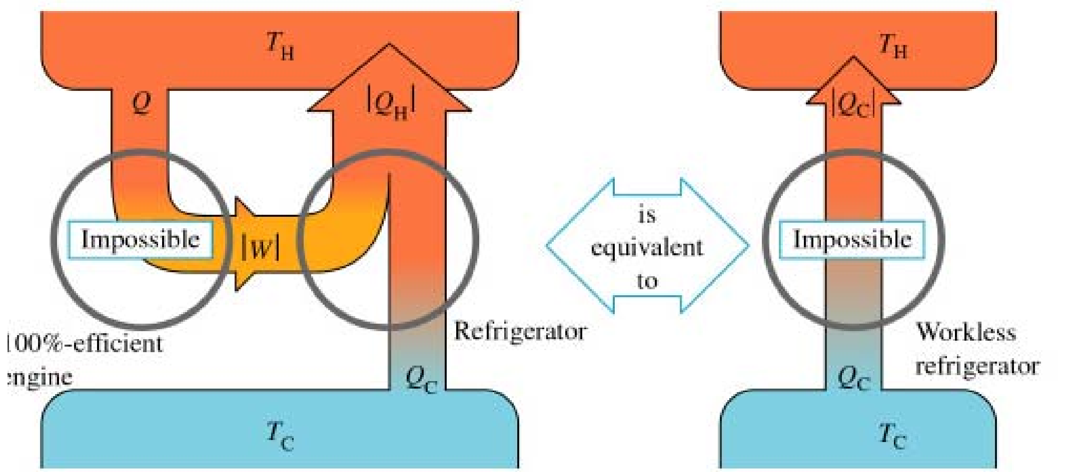


No device can transfer a given amount of heat completely into work.

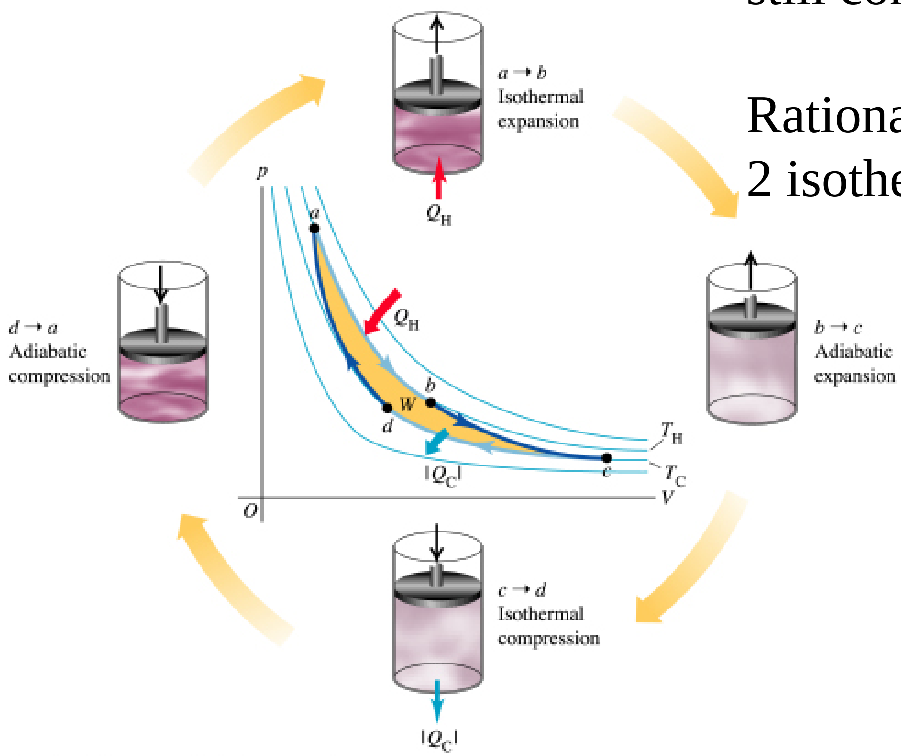
Equivalent Statements



(a) If a workless refrigerator existed, it could be used to make a 100%-efficient engine



20-6. Carnot Cycle



Ideal engine with maximum efficiency that is still consistent with the 2nd law of thermodynamics

Rationale: maximum reversible processes
2 isothermal + 2 adiabatic processes

Carnot engine

$Q_H \sim T_H$

$Q_C \sim T_C$

e_{Carnot} =1- $|Q_C/Q_H|$=1- T_C/T_H

(in Kelvin)

Real engine

$e < e_{Carnot} < 100\%$

Example

A nuclear power plant operates at 75% of its Carnot efficiency between 600 C and 350C. If the plant produces electric energy at a rate of 1.3 GW, how much exhaust heat is discharged per hour?

20-7. Entropy

S: a quantitative measure of disorder

For a reversible process

$$dS = \frac{dQ}{T}$$

$$\Delta S = \int_1^2 \frac{dQ}{T}$$

“Entropy statement of the 2nd law of thermodynamics”:
When all components taking part in a process are included, the entropy either remains constant or increases.