Engines

•In physics, the word *engine* normally refers to a *heat engine*, a system that extracts *heat* from the environment and does *work*.

•Since $\Delta E_{int}=0$ for a closed cycle, $Q + W = 0$ for the cycle, or the work done BY the engine, $W_{eng} = Q$.

•(Heat) engines contain a *working substance* that actually does the work (for example, an ideal gas that does work on expanding).

•An *ideal engine* is an engine in which every process is *reversible*; there is no friction or other dissipative losses in the system.

•One particularly important example of an ideal engine is the *Carnot engine*, which undergoes a *Carnot cycle* to extract heat to do work.

Engine Efficiency

- The net heat flow, Q (or Q_{net} in the textbook), is simply the amount of heat transferred to the system from the high temperature reservoir, $|Q_H|$ less the amount of heat the system dumps to the low temperature reservoir, $|Q_L|$.

- The *efficiency*, *e*, of a heat engine is the ratio of the net work done by the engine in one closed cycle, divided by the amount of heat the engine absorbs from the hot reservoir:

$$e = \frac{W_{eng}}{|Q_H|} = 1 - \frac{|Q_C|}{|Q_H|}$$

- This efficiency is always smaller than 1, which leads to the following form of the Second Law of Thermodynamics: *It is impossible to construct a heat engine that converts 100% of the heat input into work.*

Carnot Engine

• A *Carnot engine* is an ideal heat engine which goes through a closed *cycle* consisting of four steps:

1. *Isothermal expansion* (absorbs heat Q_H from a high temperature reservoir at T_H).
2. *Adiabatic expansion* (Q=0).
3. *Isothermal compression* (expels heat Q_L into a low temperature reservoir at T_L).
4. *Adiabatic compression* (Q=0).

• The system does *positive work* during steps 1 and 2, and *negative work* (positive work is done on the system) during steps 3 and 4.

• Because this is a closed cycle, ΔE_{int} for the cycle is *zero*, so $W=|Q_H|-|Q_L|$; the work done by the engine depends on the *difference* between the amount of heat flowing *into* the engine from the high temperature reservoir, and the amount of heat flowing out of the engine into the *low* temperature reservoir.

• For a Carnot engine, the efficiency is:

$$\varepsilon_C = \frac{|Q_H| - |Q_L|}{|Q_H|} = 1 - \frac{|Q_L|}{|Q_H|} = 1 - \frac{T_L}{T_H}$$

Refrigerators

- A *refrigerator* is simply a heat engine working in *reverse*; *work* W is done on the refrigerator to *extract* some *heat* from a low temperature reservoir and *expel* the heat into a high temperature reservoir.

- The *coefficient of performance* of a refrigerator (K) is given by: $K = \frac{|Q_L|}{|W|}$

- If we consider a refrigerator which is a *Carnot engine run backwards* (reverse the thermodynamic cycle), the coefficient of performance for a Carnot refrigerator is:

$$K_C = \frac{|Q_L|}{|Q_H| - |Q_L|} = \frac{T_L}{T_H - T_L}$$

- One can consider hooking up a Carnot refrigerator to any heat engine to prove the following claim.

- The *maximum* possibly efficiency of any heat engine operating between T_H and T_L is the *Carnot efficiency* between those two temperatures.

- This restriction arises from the *Second Law of Thermodynamics*.