Chapter 4 - Engines and refrigerators

Heat engines

A heat engine is a device that absorbs heat and converts part of that energy to work, for example the steam turbine. The amount of converted heat is the difference between the absorbed heat and the waste heat expelled. The absorbed heat comes from a *hot reservoir*, and the waste heat is dumped in a *cold reservoir*. The temperatures of these reservoirs are fixed. The efficiency of a heat engine is the ratio between the benefit and the cost:

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

The efficiency cannot be greater than 1, and only if $Q_c = 0$. This gives raise to the phrase: "You cannot win". Since the engine works in cycles, the entropy it expels must be at least as much as the entropy it absorbs. The entropy extracted from the hot reservoir is Q_h/T_h, while the entropy expelled is Q_c/T_c. This leaves us with The maximum efficiency as a function of temperatures can be expressed as

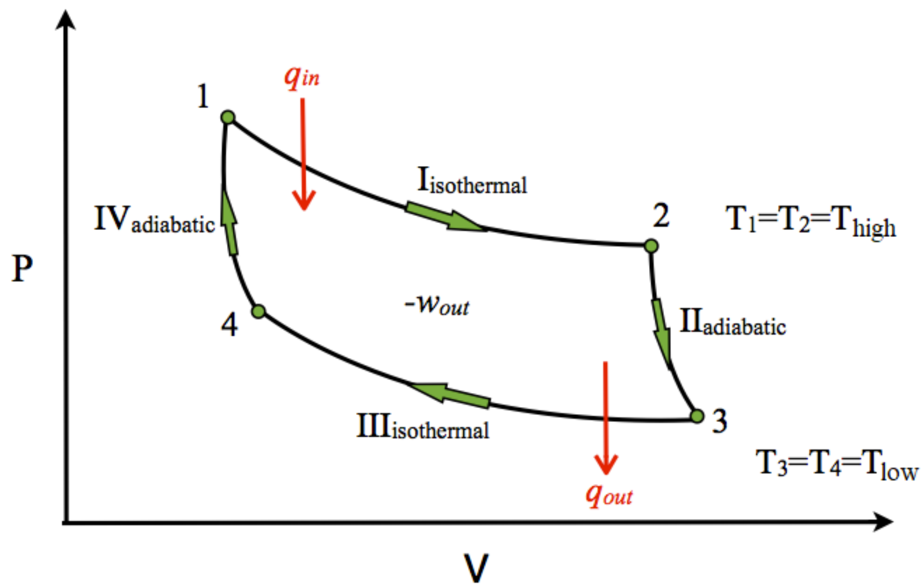
$$\frac{Q_c}{T_c} \geq \frac{Q_h}{T_h} \Rightarrow \frac{Q_c}{Q_h} \geq \frac{T_c}{T_h} \Rightarrow \underline{e \leq 1 - \frac{T_c}{T_h}}$$

The Carnot cycle

Imagine an engine whose working substance is a gas. To achieve the highest efficiency, we let the temperature of the gas be just above T_h (to minimise change in entropy during heat flow). Similarly, it must also be just below T_c. The temperature of the gas, T_g, is constant, so we must allow isothermal expansion and contraction when it heats up and cools down. Between the expansion and contraction, heat transfer cannot be allowed. We therefore have four steps:

1. Isothermal expansion at T_h
2. Adiabatic expansion from T_h to T_c
3. Isothermal compression at T_c
4. Adiabatic compression from T_c to T_h

This cycle is known as the **Carnot cycle**. Although very efficient, this cycle is horribly impractical.



Refrigerators

A refrigerator is basically a heat engine working in reverse. The **coefficient of performance** of a refrigerator is defined, again, as the benefit/cost-ratio:

$$COP = \frac{Q_c}{W}$$

The maximum COP is given as

$$COP \leq \frac{T_c}{T_h - T_c}$$

To make a refrigerator with maximum COP, one can use the Carnot cycle in reverse. The working substance must now be slightly colder than T_c when heat is being absorbed, and slightly hotter than T_h when heat is being expelled. again, very impractical, as the heat flow is much too slow. The derivation of the last equation is very simmilar to that of the maximum efficiency of the heat engine.