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ME 209
Basic Thermodynamics (Lecture-9)

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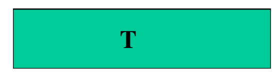
Some Definitions

- Prior to discussion on Second Law, it is instructive to define what is meant by a **Reservoir**, a **Heat Engine**, a **Heat Pump** and a **Refrigerator**
- A **Reservoir** is either a source or sink of heat characterised by its temperature.
- These are large bodies such as atmosphere, river, ocean, etc. and is usually denoted by a rectangle



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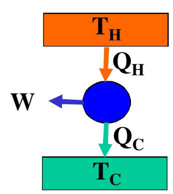
Heat Engine

- A **Heat Engine** is a device or a combination of devices that converts heat into work
- Generally, it is shown to interact with reservoirs for taking in or dumping out the heat
- Generally engines have a working fluid that normally is subjected to cyclic processes



Heat Engine

- If we apply first law for the cyclic process

$$Q_H - Q_C = W$$

- The efficiency of Engine can be defined as $\eta = \frac{W}{Q_H}$

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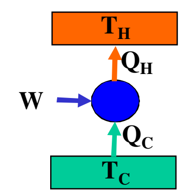
Heat Pump & Refrigerator

- A **Heat Pump or a Refrigerator** is a device or a combination of devices that converts work into heat
- In a **Heat Pump** the heat delivered to the hot reservoir is the useful output, whereas in a **Refrigerator** the heat removed from the cold space is the useful output



Heat Pump/Refrigerator

- If we apply first law for the cyclic process $Q_H - Q_C = W$
- The Coefficient of Performance of Heat Pump can be defined as $COP_{HP} = Q_H / W$
  - Similarly, for a Refrigerator $COP_{REF} = Q_C / W$

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Second Law-I

- First law or energy conservation is a book keeping law that connects two states with the heat and work interactions that may be involved in the process of change of state of the system
- It cannot say anything about the possibility of the process. For instance, first law cannot prohibit the energy of the heat engine to be 100%
- Interestingly, many of the spontaneous processes in nature have a definite direction, e.g., hot body cooling off, or high pressure tank emptying through a leak, etc.

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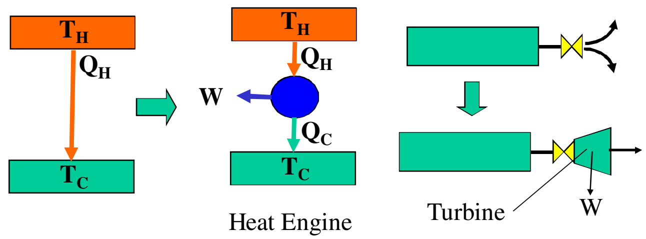
Second Law-II

- While the direction of process for a simple everyday process can be guided by experience, a guiding principle is required for complex process.
- Second law provides answers.
- If we carefully look at the above examples, we could have obtained work in both the cases



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Second Law-III

- As an engineer, we can ask how much of work ideally could have been obtained?
- Second Law provides the answer
- Second Law provides the answers for
  - Directionality
  - Conditions for equilibrium
  - Maximum possible work that can be obtained
  - Absolute temperature scale
  - Property relations
- A law that can provide answers to such diverse questions cannot be stated uniquely. It has several forms, all of which are equivalent

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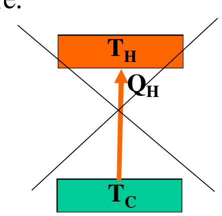
Clausius Statement

- It is **impossible** for any system to operate in such a way that the **sole result** is the energy transfer from a cold body to hot body
- The primary interpretation of the above statement is that some external work will be required to pump the heat from a lower temperature to higher temperature.



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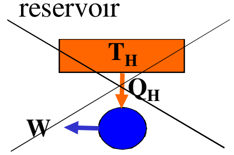
Kelvin-Planck Statement

- It is **impossible** to have an engine operating cyclically in which only interactions are work done at the expense of heat received from a single reservoir



1–T Engine is not possible

- It is fairly straight forward to prove that violation of Clausius statement leads to the violation of Kelvin-Planck statement

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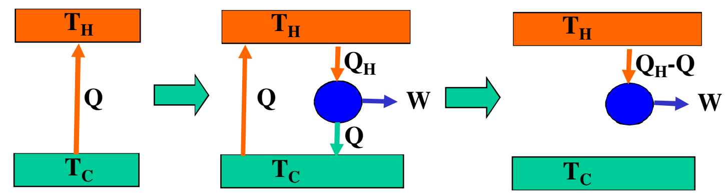
Equivalence of K-P and C Statements

Let Clausius statement be violated



- While qualitative remarks have been made, we can put the Kelvin-Planck Statement in a quantitative form as

$$\oint_{1-T} dW \le 0$$

Note that K-P prohibits positive work, but we can always have the reverse

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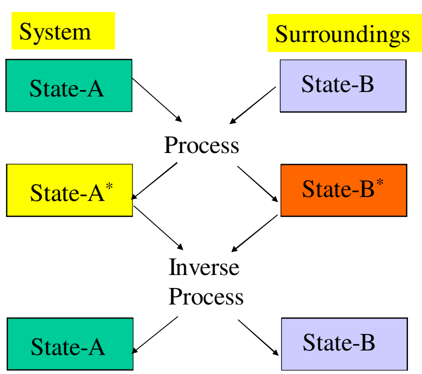
Reversible Process-I

- Let us now define the Reversible Process



If after a process the system and surroundings can be identically taken to their original states then the original process is reversible.

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Reversible Process-II

- Quasitatic adiabatic compression/expansion, Isothermal heat addition/rejection are reversible process
- Causes of Irreversibility
  - Lack of Equilibrium
    - Heat transfer with finite temperature difference
    - Free expansion (mixing of gases with $p_1 > p_2$)
  - Dissipative Work
    - Friction in system
    - Friction in surroundings
- In all the irreversible processes, either there is dissipative work or opportunity to extract work is lost

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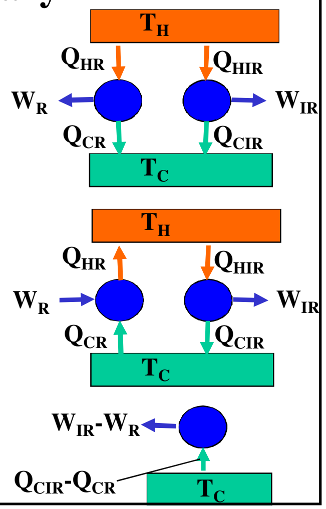
Carnot Corollary-1 - I

- Corollary-1 states that the efficiency of a reversible engine is greater than the efficiency of the irreversible engine
- Let the corollary be violated and let $Q_{HR} = Q_{HIR}$. This will imply $W_R < W_{IR}$
- Reverse the reversible engine and consider the combined system
- Violates K-P statement



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Carnot Corollary-1 - II

- Corollary-1 also states that the $COP_R > COP_{IR}$ For a heat pump/refrigerator
- Let the corollary be violated and let $Q_{HR} = Q_{HIR}$. This will imply $W_R > W_{IR}$
- Reverse the reversible HP/REF and consider the combined system
- Violates K-P statement