ESO 201A: Thermodynamics
2016-2017-I semester

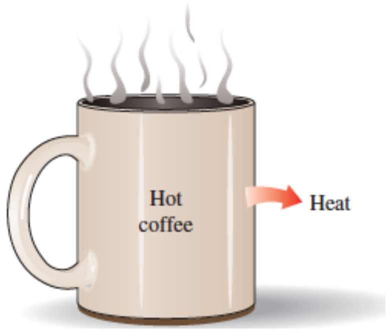
The Second Law of Thermodynamics: part 1

Dr. Jayant K. Singh
Department of Chemical Engineering
Faculty Building 469,
Telephone: 512-259-6141
E-Mail: jayantks@iitk.ac.in
home.iitk.ac.in/~jayantks/ESO201/index.htm

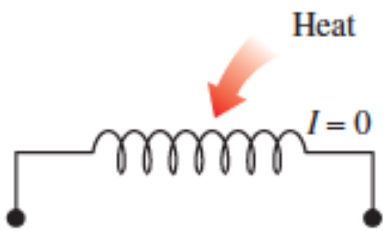
Learning Objectives

- Introduce the second law of thermodynamics.
- Identify valid processes as those that satisfy both the first and second laws of thermodynamics.
- Discuss thermal energy reservoirs, reversible and irreversible processes, heat engines, refrigerators, and heat pumps.
- Describe the Kelvin–Planck and Clausius statements of the second law of thermodynamics.
- Discuss the concepts of perpetual-motion machines.
- Apply the second law of thermodynamics to cycles and cyclic devices.
- Apply the second law to develop the absolute thermodynamic temperature scale.
- Describe the Carnot cycle.
- Examine the Carnot principles, idealized Carnot heat engines, refrigerators, and heat pumps.
- Determine the expressions for the thermal efficiencies and coefficients of performance for reversible heat engines, heat pumps, and refrigerators.

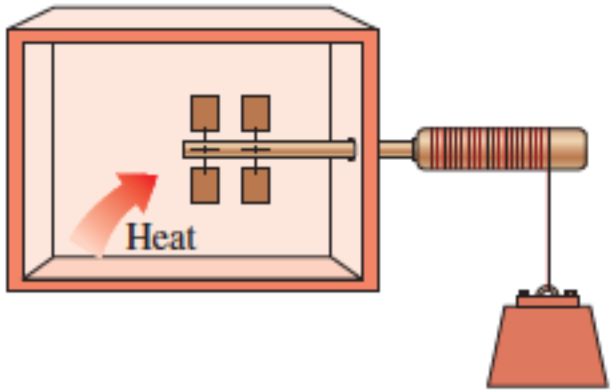
Direction of a process



A cup of hot coffee does not get hotter in a cooler room.



Transferring heat to a wire will not generate electricity.



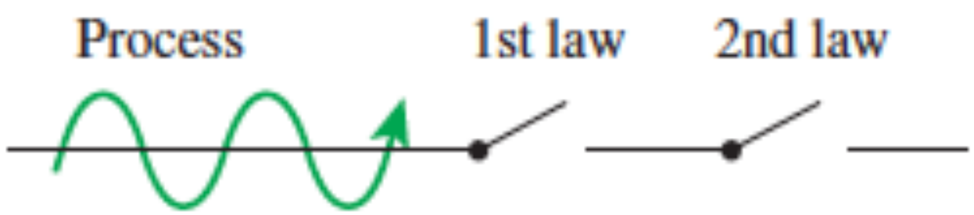
Transferring heat to a paddle wheel will not cause it to rotate.

All these processes satisfy the first law.
However doesn't’t ensure the process to occur.

Direction of a process

- Thus, a process proceeds in a certain direction, and not in the reverse direction
- 1st law places no restriction on the direction of the process, and satisfying 1st law does not ensure that the process can actually occur.

- The direction or whether a process can take place is given by the second law of thermodynamics. Changing the direction would mean violation of the second law!
- Thus process can occur only when 1st and 2nd laws are satisfied.



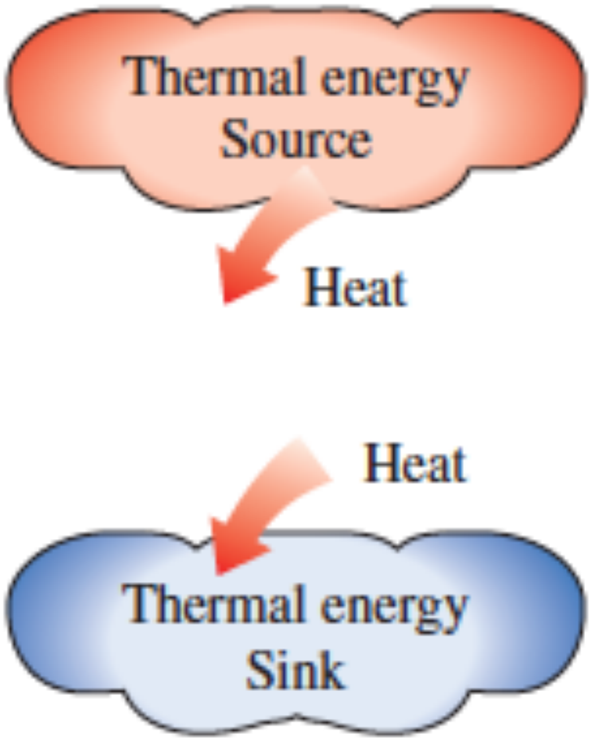
To understand the 2nd law, let us first understand heat engines

Heat Engines

Thermal reservoirs

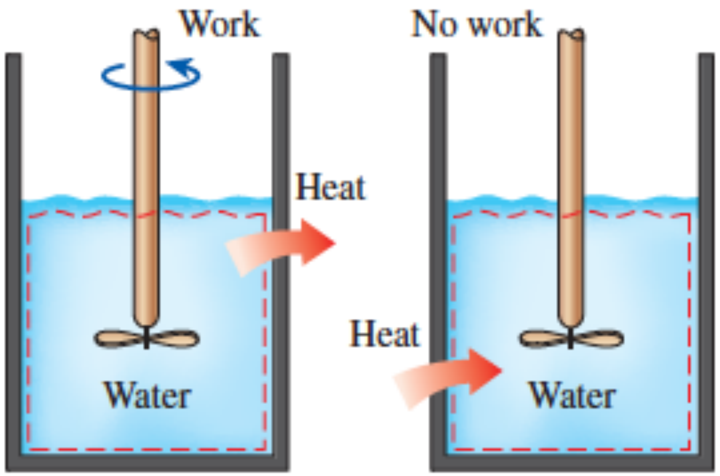
- Hypothetical body with large thermal energy capacity (c_p*m) that can supply or absorb finite amount of heat without undergoing any change in temperature

  -atmosphere, ocean, river, lake



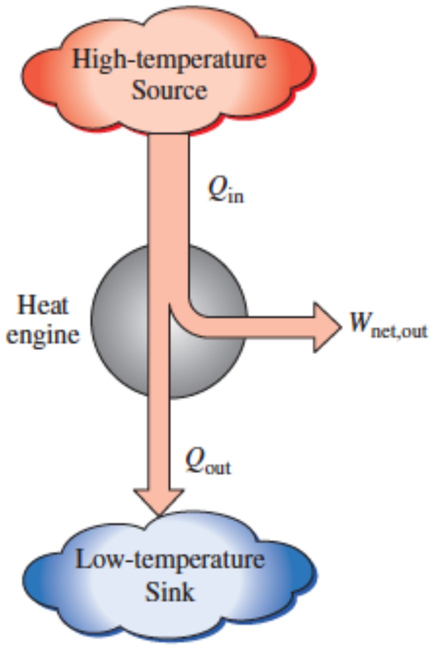
- Need not be large body. Any body with thermal capacity is large relative to the heat absorbed, or supplied

Heat Engines



Work can always be converted to heat directly and completely, but the reverse is not true.

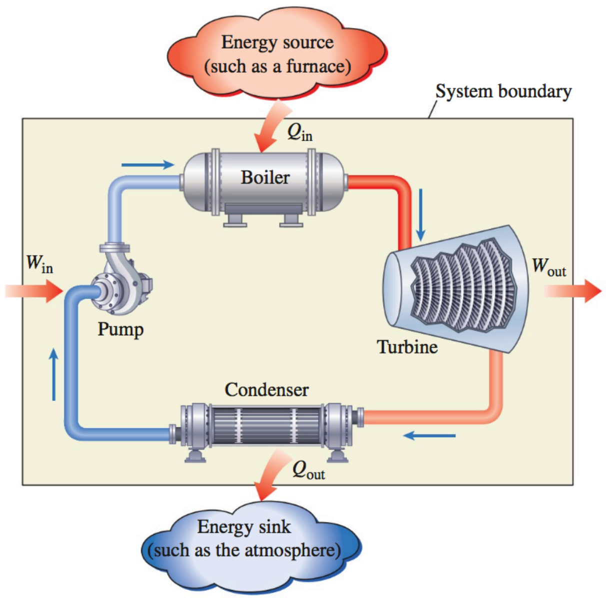
Thus converting heat to work require a special device *heat engines*



- Receive heat from high temperature sources, Q_{in}
- Convert part of this heat to work, $W_{net,\ out}$
- Reject the remaining heat to low temperature sink, Q_{out}
- Operates on a cycle

Heat Engines

- HE uses a fluid to/from which heat is transferred while undergoing a cycle, also called *working fluids*
- HE also refers to devices such as gas turbine, car engines (internal combustion engine) which do not follow thermodynamic cycle (undergoes mechanical cycle)
- **Example- steam power plant –external combustion engine:**



Schematic of a steam power plant.

Q_{in} = amount of heat supplied to boiler from source

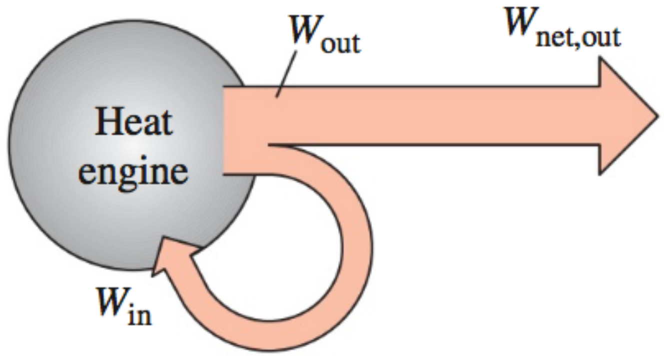
Q_{out}=Amount of heat rejected to sink

W_{out}=amount of work delivered by steam as it expands in turbine

W_{in}=amount of work required to compress water to boiler's pressure

Heat Engines

- All values are positive as the direction is define.
- Net work output of the power plant



$$W_{net,out} = W_{out} - W_{in} \quad (kJ)$$

- Considering the system, no mass enters and exits the system (closed system)
- For a cyclic process, change in internal energy is zero
- Thus :

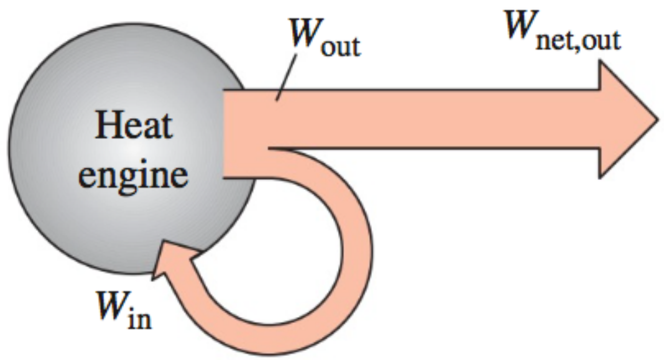
$$W_{net,out} = Q_{in} - Q_{out} \quad (kJ)$$

Heat Engines

•Note : Q_{out} is wasted in order to complete the cycle. Q_{out} is never zero.

•Thus $W_{net,out} < Q_{in}$

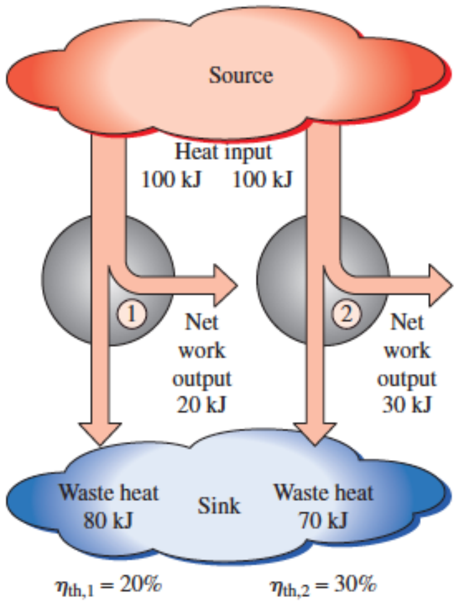
• Fraction of heat transferred to HE is converted to work.



- Thermal efficiency: the fraction of heat input that is converted to net work output is a measure of HE performance

$$\text{Thermal efficiency} = \frac{\text{Net work output}}{\text{Total heat input}}$$

$$\eta_{th} = \frac{W_{net,out}}{Q_{in}} \qquad \eta_{th} = 1 - \frac{Q_{out}}{Q_{in}}$$



Cyclic devices

HE, refrigerators and heat pumps : operate at high T (T_H) reservoir and low T (T_L) reservoir.

Generalization:

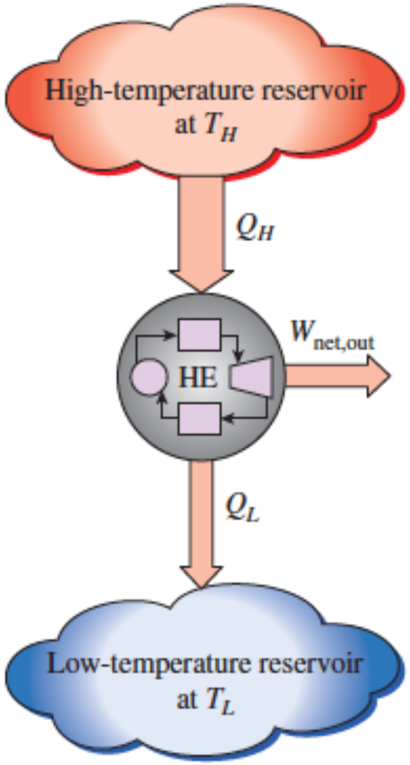
Q_H = magnitude of heat transfer between the cyclic device and the high-temperature medium at temperature T_H

Q_L = magnitude of heat transfer between the cyclic device and the low-temperature medium at temperature T_L

$$W_{\text{net,out}} = Q_H - Q_L$$

Q_H, Q_L are +ve

$$\eta_{\text{th}} = \frac{W_{\text{net,out}}}{Q_H} \quad \text{or} \quad \eta_{\text{th}} = 1 - \frac{Q_L}{Q_H}$$



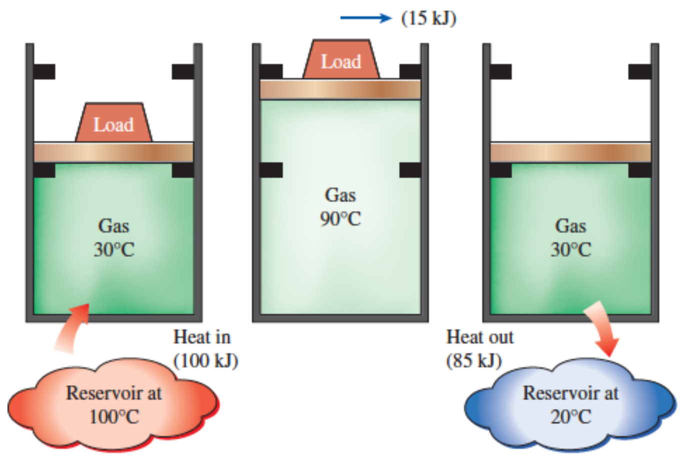
$\eta < 1$

$\eta = 0.25$ *spark ignition automobile engine (converts 25% of chemical energy of gasoline to mechanical work)*

$\eta = 0.4$ *for diesel engines, large gas-turbine plants*

$\eta = 0.6$ *for large combined gas-steam power plants*

Saving Q_{out} ?



Every heat engine must *waste* some energy by transferring it to a low-temperature reservoir in order to complete the cycle, even under idealized conditions.

A heat-engine cycle cannot be completed without rejecting some heat to a low-temperature sink.

In a steam power plant, the condenser is the device where large quantities of waste heat is rejected to rivers, lakes, or the atmosphere.

Can we not just take the condenser out of the plant and save all that waste energy?

The answer is, unfortunately, a firm ***no*** for the simple reason that without a heat rejection process in a condenser, the cycle cannot be completed.

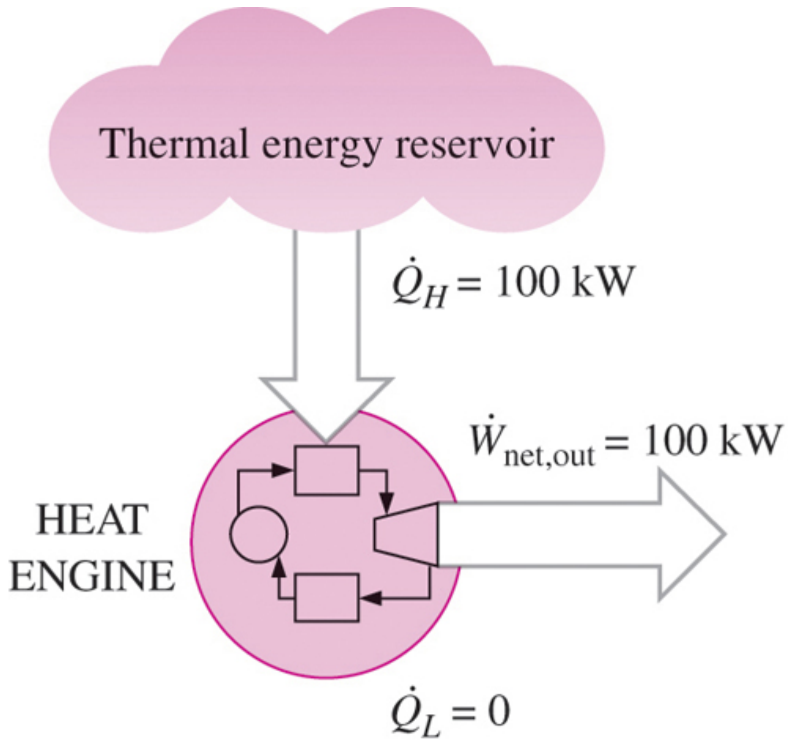
Requirement of two reservoirs for continuous operation-basis for Kelvin-Planck expression for 2nd law of thermodyanmics

The Second Law of Thermodynamics: Kelvin–Planck Statement

It is impossible for any device that operates on a cycle to receive heat from a single reservoir and produce a net amount of work.

No heat engine can have a thermal efficiency of 100 percent, or as *for a power plant to operate, the working fluid must exchange heat with the environment as well as the furnace.*

The impossibility of having a 100% efficient heat engine is not due to friction or other dissipative effects. It is a limitation that applies to both the idealized and the actual heat engines.



A heat engine that violates the Kelvin–Planck statement of the second law.

Next lecture

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