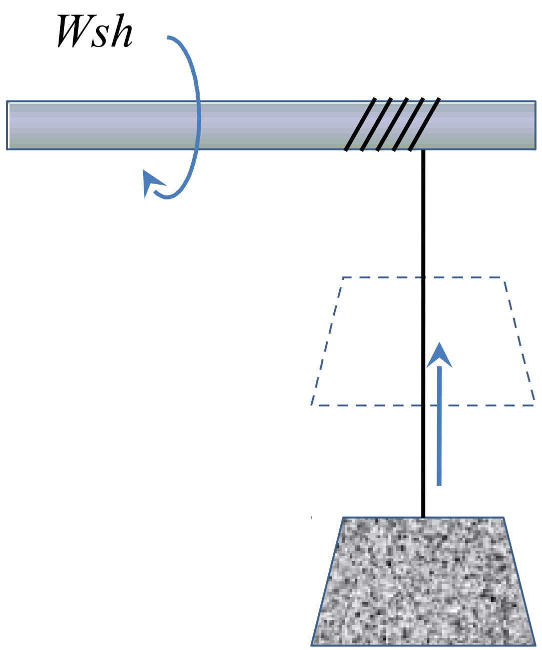
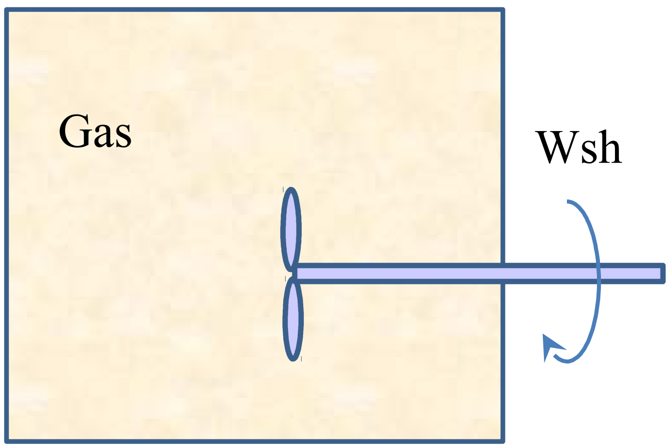
- Recap: Lecture 14: 24th February 2014, 1130-1230 hrs.
  - Entropy change and entropy generation
  - Increase of entropy principle
  - Tds equations
  - Entropy change of liquids, solids and ideal gases
  - Third law of thermodynamics
  - Entropy and energy transfer

Third law of thermodynamics

- The entropy of a pure crystalline at absolute zero temperature is zero since there is no uncertainty about the state of the molecules at that instant: the third law of thermodynamics.
- The entropy determined relative to this point is called absolute entropy.
- A pure crystalline substance at absolute zero temperature is in perfect order, and its entropy is zero.

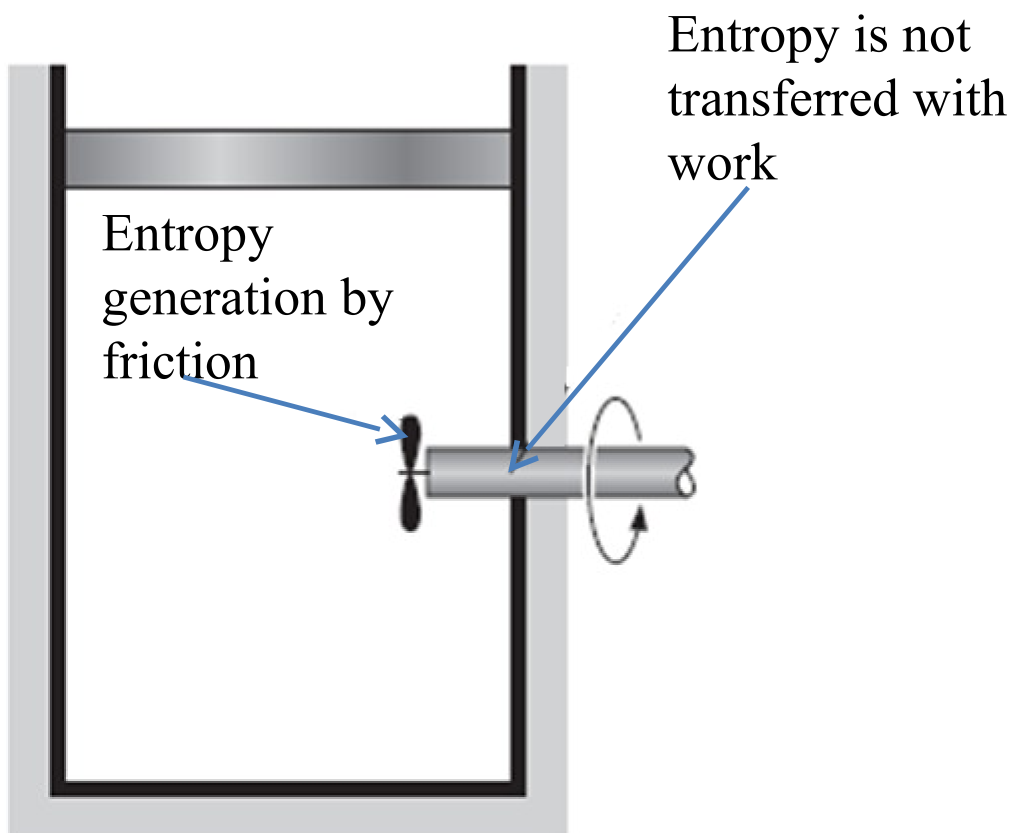
Entropy and energy transfer





Raising of a weight by a rotating shaft does not generate entropy, and so energy is not degraded during this process (if we assume frictional effects can be neglected).

The work done on a gas increases the entropy of the gas, and thus energy is degraded during this process.

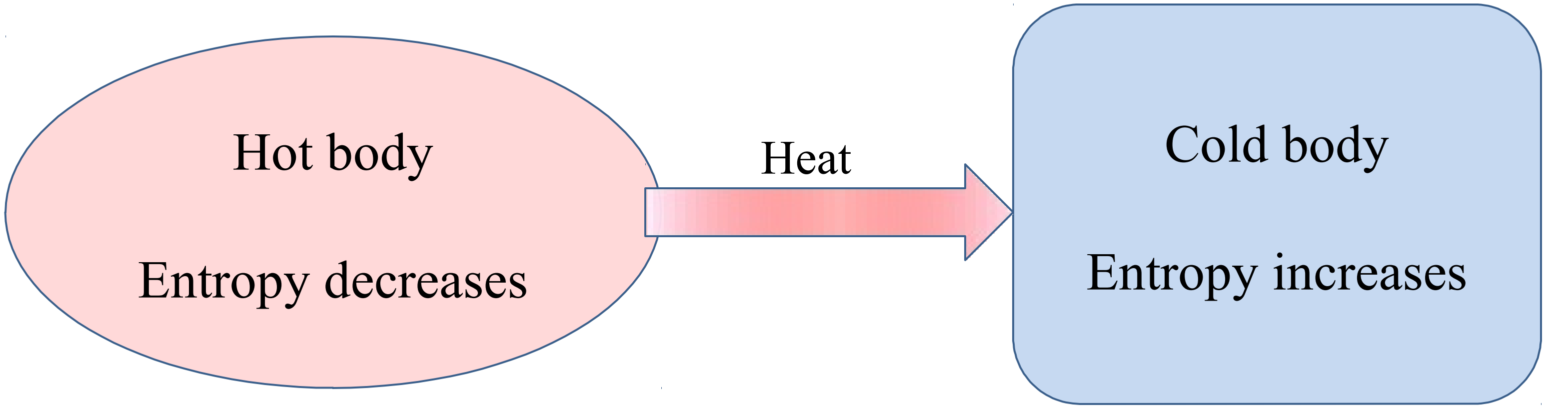


No entropy accompanies work as it crosses the system boundary. But entropy may be generated within the system as work is dissipated into a less useful form of energy.

Entropy and energy transfer

- This decrease in quality is always accompanied by an increase in entropy.
- Heat is a form of disorganized energy, and hence, there is increase in entropy with heat.
- Processes can occur only in the direction of increased overall entropy or molecular disorder.
- That is, the entire universe is getting and more chaotic every day.

Entropy and energy transfer



- During a heat transfer process, the net entropy increases.
- This is because, the increase in the entropy of the cold body is more than the decrease in the entropy of the hot body.

Entropy and energy transfer

- Work is entropy-free, and no entropy is transferred by work.
- Closed systems
  - Energy is transferred by both heat and work, whereas entropy is transferred only by heat (closed systems).
  - Only energy is exchanged during work interaction whereas both energy and entropy are exchanged during heat transfer.
- Open systems
  - Entropy transfer in open systems: heat and mass flow.

Entropy balance

- Entropy balance for any system undergoing any process is:

$$\underbrace{S_{in} - S_{out}}_{\substack{\text{Net entropy transfer}\\ \text{by heat and mass}}} + \underbrace{S_{gen}}_{\substack{\text{Entropy}\\ \text{generation}}} = \underbrace{\Delta S_{system}}_{\substack{\text{Change in}\\ \text{entropy}}}$$

This can also be expressed in the rate form as,

$$\underbrace{\dot{S}_{in} - \dot{S}_{out}}_{\substack{\text{Rate of net entropy}\\ \text{transfer by heat and mass}}} + \underbrace{\dot{S}_{gen}}_{\substack{\text{Rate of entropy}\\ \text{generation}}} = \underbrace{\Delta \dot{S}_{system}}_{\substack{\text{Rate of change}\\ \text{in entropy}}}$$

Entropy balance

For a closed system :

$$\sum \frac{Q}{T} + S_{gen} = \Delta S_{system} = S_2 - S_1$$

The entropy change of a closed system is equal to the sum of the net entropy transferred through the system boundary by heat transfer and the entropy generated within the system boundaries.

Entropy balance

For an open system :

$$\sum \frac{Q}{T} + \sum m_i s_i - \sum m_e s_e + S_{gen} = \Delta S_{system} = \left(S_2 - S_1\right)_{CV}$$

The entropy change of a closed system is equal to the sum of the net entropy transferred through the control volume by heat transfer, the net entropy transfer into the control volume through mass flow and the entropy generated within the system boundaries.

Exergy

- Exergy: a property that determines the useful work potential of a given amount of energy at some specified state.
- Also known as availability or available energy.
- The work potential of the energy contained in a system at a specified state is the maximum useful work that can be obtained from the system.
- Work = *f (initial state, process path, final state)*

Exergy

- Work output is maximized when the process between two specified states is executed in a reversible manner.
- The system must be in the dead state at the end of the process to maximize the work output.
- A system that is in equilibrium with its environment is said to be at the dead state.
- At the dead state, the useful work potential (exergy) of a system is zero.

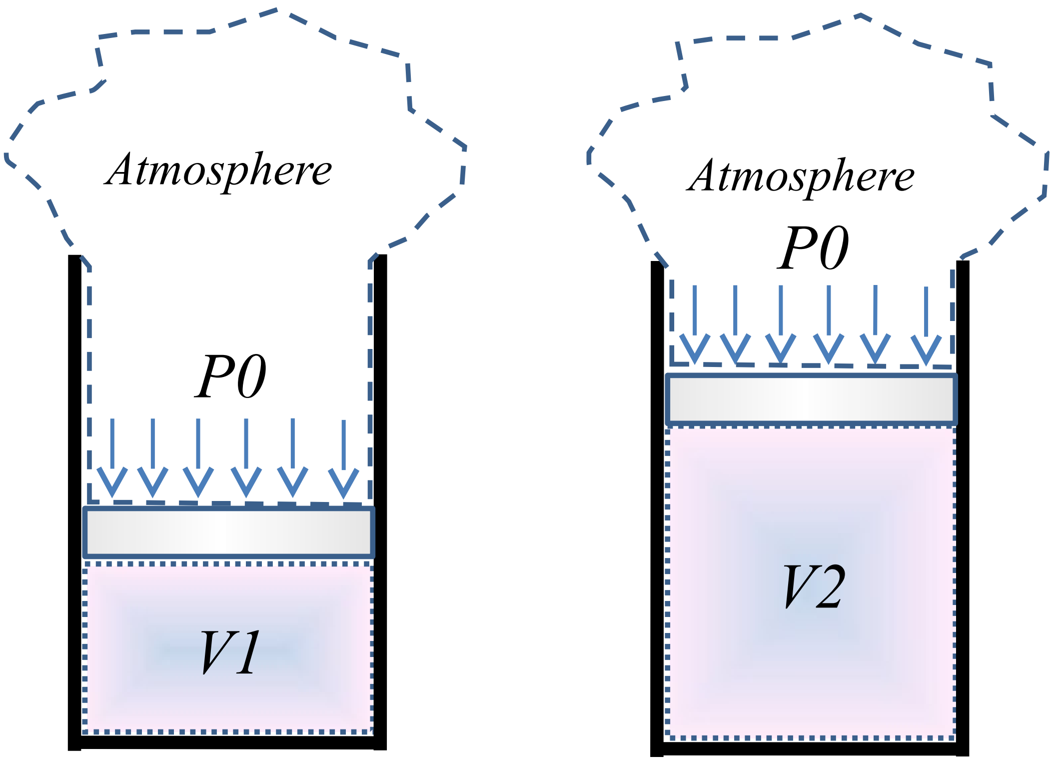
Exergy

- Exergy does not represent the amount of work that a work-producing device will actually deliver upon installation.
- It represents the upper limit on the amount of work a device can deliver without violating any thermodynamic laws.
- There will always be a difference between exergy and the actual work delivered by a device.
- This difference represents the room engineers have for improvement.

Exergy

- Exergy is a property of the system–environment combination and not of the system alone.
- Altering the environment is another way of increasing exergy, but not easy
- The atmosphere contains a tremendous amount of energy, but no exergy.
- Unavailable energy is the portion of energy that cannot be converted to work by even a reversible heat engine.

Reversible work and irreversibility



Surroundings work, $W_{surr} = P0(V2-V1)$

Useful work, $W_u = W - W_{surr} = W - P0(V2-V1)$

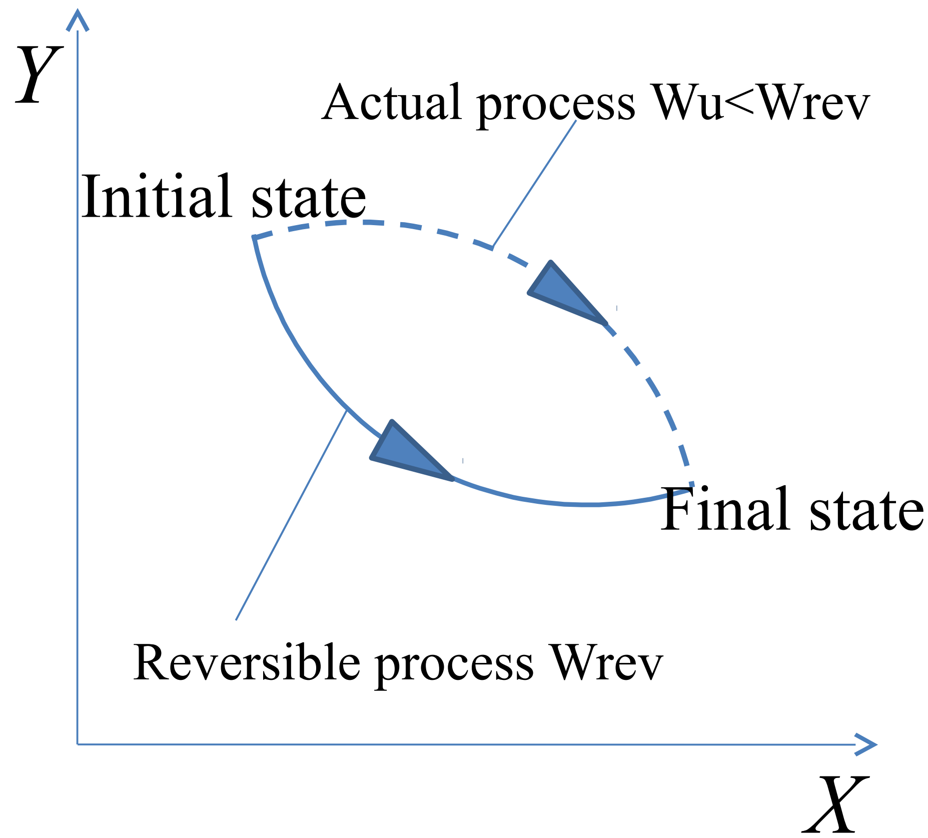
Reversible work and irreversibility

- *Wsurr* represents a loss during expansion process and gain during compression.
- The work done by or against the atmospheric pressure has significance only for systems that involve moving boundary work.
- It has no significance for cyclic devices and systems whose boundaries remain fixed during a process such as rigid tanks and steady-flow devices.

Reversible work and irreversibility

- Reversible work, W_{rev}: the maximum amount of useful work that can be produced as a system undergoes a process between the specified initial and final states.
- When the final state is the dead state, the reversible work equals exergy.
- For processes that require work, reversible work represents the minimum amount of work necessary to carry out that process.

Reversible work and irreversibility



Irreversibility= Reversible work – Useful work

$$I = Wrev - Wu$$