Sharif University of Technology
School of Mechanical Engineering
Center of Excellence in Energy Conversion

Advanced Thermodynamics

Lecture 6

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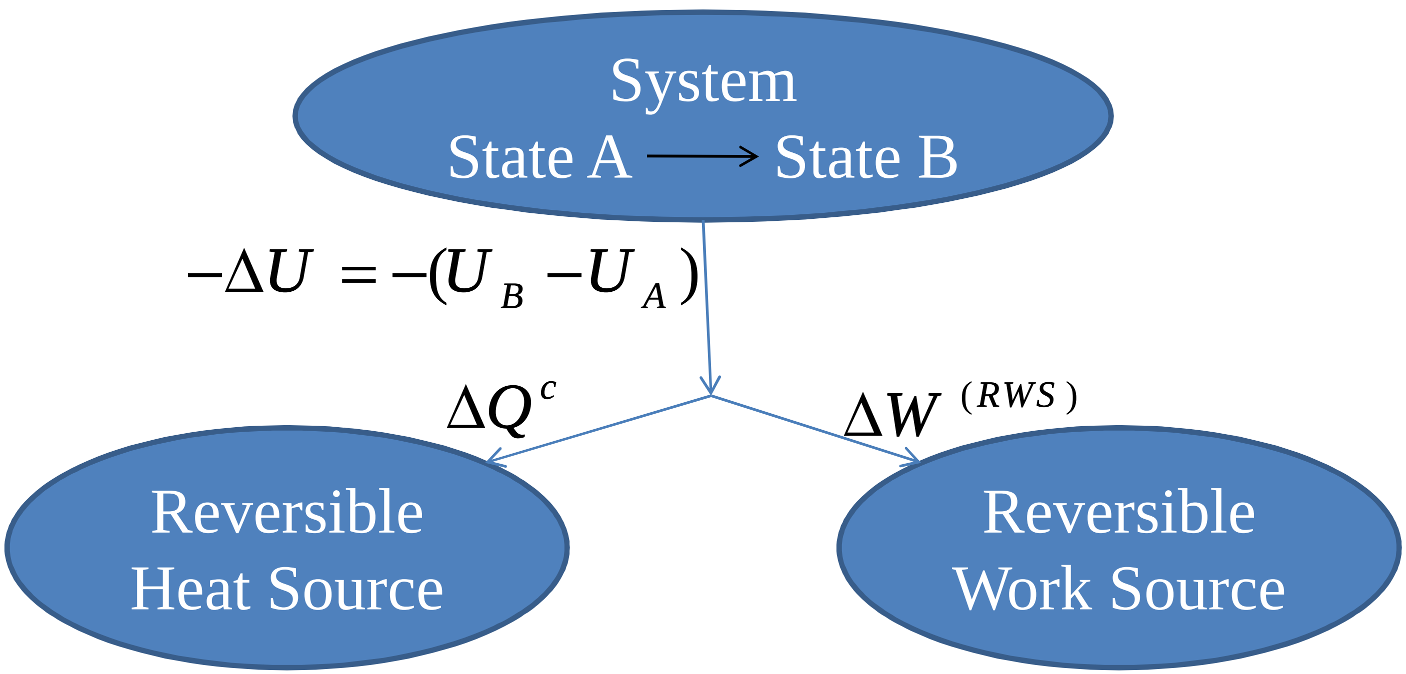
- **Reversible Work Source (RWS):**
- A system enclosed by an adiabatic impermeable wall and characterized by relaxation times sufficiently short that all processes of interest within it are essentially quasi-static.
- $dQ = T\,dS \rightarrow$ the adiabatic wall remains the entropy constant.
- **Reversible Heat Source (RHS):**
- A system enclosed by a rigid impermeable wall and characterized by relaxation times sufficiently short that all processes of interest within it are essentially quasi-static.
- The only possible flux of energy to or from RHS is in the form of heat, so that $dU = dQ = T\,dS$.
- Very large RWS and RHS is known as *reservoir*; volume and heat reservoir, respectively.
- The temperature remains constant in RHS as the pressure in RWS.

- Of all processes occurring between a given initial and a given final state of a system, the flux of heat to an associated reversible heat source is minimum and the flux of work to an associated reversible work source is maximum for reversible processes.
- The fluxes of heat and work are the same for all reversible processes between the given states.
- Consider a closed composite system as:



- If $U_B < U_A$, the energy difference will be distributed between the RWS and RHS.
- The fraction of this energy resides in the RWS is to be maximized and, simultaneously, the fraction resides in the RHS is minimized.
- The total entropy of the composite system increases in any real process, while it is unchanged in idealized reversible case.
- The final energy of the RHS is least if the process is reversible.
- The temperature of RHS is a function only of the entropy.
- It may happen, for given states and RWS, that $\Delta W^{(RWS)}$ is negative.
- In this case, the absolute value of the work done on the system is minimum.
- The excess work done in an irreversible process, over that done in a reversible process, is called dissipative work.

- Entropy changes in irreversible and reversible processes:

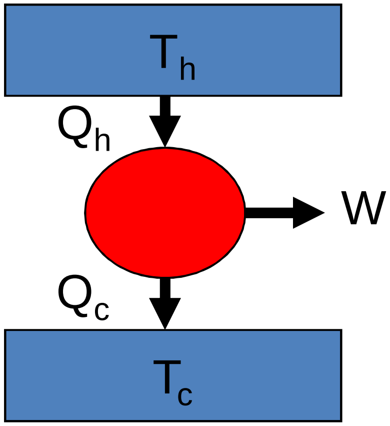
	Irreversible Processes	Reversible Processes
Total system	$\Delta S > 0$	$\Delta S = 0$
Subsystem	$S_B - S_A$	$S_B - S_A$
RWS	0	0
RHS	$\Delta S - (S_B - S_A)$	$-(S_B - S_A)$

- Energy changes in reversible processes:

Total system	0
Subsystem	$U_B - U_A$
RHS	$\Delta Q^c = \int_{S_0^c}^{S_0^c - (S_B - S_A)} T^c (S^c)\, dS^c$
RWS	$\Delta W^{(RWS)} = -\Delta Q^c - (U_B - U_A) = -\int_{S_0^c}^{S_0^c - (S_B - S_A)} T^c (S^c)\, dS^c - (U_B - U_A)$

- The simplest device to illustrate degradation of energy.
- The heat engine is a device that converts thermal energy into other useful forms, such as mechanical and electrical energy.
- A heat engine carries some working substance through a cyclic process during which:

1. Heat is absorbed from a hot reservoir
2. Work is done by the engine
3. Heat is expelled to a cold reservoir



$$W = Q_h - Q_c$$

- The thermal efficiency of a heat engine is defined as

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

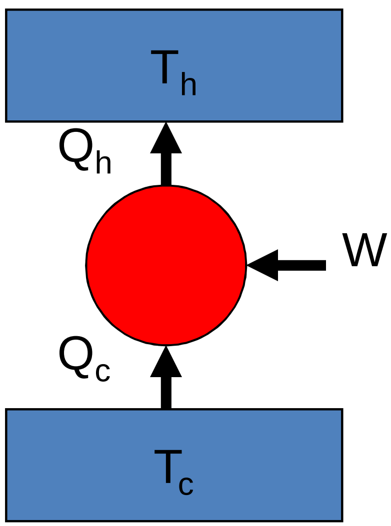
- e = 1 only when $Q_c = 0$, i.e. if all heat is converted into work, which is not possible according to the 2nd Law of Thermodynamics.

Refrigerators and Heat Pumps

- Refrigerators and heat pumps are heat engines running in reverse.

  1. Heat is absorbed from a cold reservoir
  2. Work is done by the engine
  3. Heat is expelled to a hot reservoir

- The refrigerators and heat pumps absorbs heat Q_c from the cold reservoir and expels Q_h to the hot reservoir, if and only if work W is done on the refrigerator.



- **Carnot's Theorem:** No real heat engine operating between two heat reservoirs can be more efficient than a Carnot engine operating between the same two reservoirs.

- The Carnot cycle consists of two isothermal and two adiabatic processes operating between two isotherms at T_c and T_h.

- Efficiency of a Carnot engine:

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

- Can e = 100% ?

- Coefficiency of Performance of a Carnot refrigerator:

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