Thermodynamics
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Lecture 78
Entropy Part 5

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Entropy (contd.)

We will look at the concept of entropy in a bit more detail.

(Refer Slide Time: 00:36)

Principle of increase of entropy

$dS \geq \delta Q / T$

From the first law,

$\delta Q_{sys} = \delta Q_{surr} = \delta Q$

$dS_{sys} \geq \delta Q / T$

$dS_{surr} = -\delta Q / T_o$

$ds_{net} = ds_{sys} + ds_{surr}$

$\Rightarrow ds_{net} = \delta Q / T + (-\delta Q / T_o)$

$\Rightarrow ds_{net} = \delta Q (1/T - 1/T_o) \geq 0$

$\Rightarrow ds_{gen} = \delta Q (1/T - 1/T_o)$

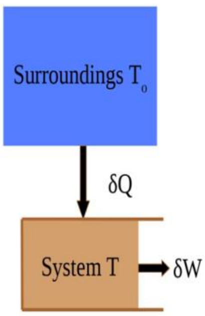

Figure 1.

An isolated system does not have any interaction with the surroundings. The entropy of an isolated system can remain constant or increase, but it cannot decrease.

Figure 1 shows a system at temperature T and surroundings at temperature T_0. There is a transfer of heat from surroundings to the system. Hence, $T_0 > T$. The system does work on the surroundings. The heat transfer for the surroundings equals heat transfer for the system. We can write $\delta Q_{sys} = \delta Q_{surr} = \delta Q$ (considering only magnitudes). We know that, for a process, $dS \geq \frac{\delta Q}{T}$. For the system, $dS_{sys} \geq \frac{\delta Q}{T}$. The heat transfer for the surroundings, which is huge in size, can be assumed isothermal as its temperature does not change because of the heat transfer. Hence, the process is reversible for the surroundings. Hence, $dS_{surr} = -\frac{\delta Q}{T_0}$ (the heat transfer is negative for the surroundings). The net change in entropy is, $dS_{net} = dS_{sys} + dS_{surr} = \frac{\delta Q}{T} + \left(-\frac{\delta Q}{T_0}\right) = \delta Q\left(\frac{1}{T} - \frac{1}{T_0}\right) \geq 0 \left(as\ \frac{1}{T} > \frac{1}{T_o}\right)$. If $T=T_0$, then $dS_{net} = 0$ because the heat transfer is isothermal and hence reversible. When $T > T_0$, there is a finite temperature difference between the surroundings and the system, and $dS_{net} > 0$. If $T < T_0$, then δQ_{sys} would be negative and δQ_{surr}would be positive. In that case also, $dS_{net} \geq 0$. Hence, as long as there is heat transfer through finite temperature difference between the system and surroundings, net change in the entropy which is the sum of the entropy change for the system and surroundings is greater than zero. In other words, the entropy change for the universe is greater than zero. The entropy change for the universe is zero if the process is reversible for the system as well as the surroundings. Hence, for heat transfer through a finite temperature difference, entropy generated is $dS_{gen} = \delta Q\left(\frac{1}{T} - \frac{1}{T_0}\right)$. Entropy is not conserved unlike energy.

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$dS \geq \delta Q / T$

$dS = \delta Q / T + dS_{gen}$

According to the Clausius' inequality, $dS \geq \frac{\delta Q}{T}$. The equality is for a reversible process, whereas the inequality is for an irreversible process. For the irreversible process, we can write $dS = \frac{\delta Q}{T} + dS_{gen}$. For a reversible process, $dS_{gen} = 0$. For an irreversible process, $dS_{gen} > 0$. δQ can be positive or negative based on our sign convention.

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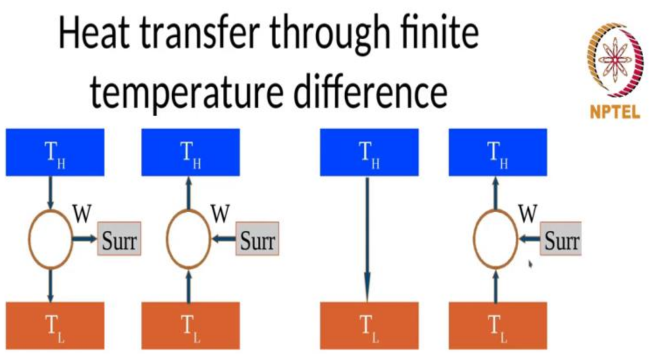

Figure 2.

Figure 2 shows heat sources at temperature T_H and heat sinks at temperature T_L. There can be heat transfer from the heat source to the heat sink by running a Carnot's engine between them. There can also be heat transfer from the heat sink to the heat source if we run the same Carnot's engine in reverse (as a heat pump) between them. The directions of heat and work interactions for the Carnot's engine and the reverse Carnot's engine (heat pump) would be opposite of each other, but the magnitudes would be equal. This is reversible heat transfer. It does not leave any trace on the system as well as surroundings. The process is internally and externally reversible.

We can also transfer heat from the heat source to the heat sink by bringing them in contact. Heat transfer happens spontaneously. There is no work interaction involved. However, if we want to transfer the same amount of heat back to the heat source from the heat sink, we need to run a heat pump which needs work input. This reverse process is not spontaneous. The work input to the pump comes from the surroundings. Here, we cannot just reverse the process and transfer the same amount of heat from the heat sink to the heat source without affecting the surroundings. Hence, this heat transfer process is irreversible as it leaves a trace on the surroundings through the work input needed for the pump. Hence, the heat transfer through a finite temperature difference is an irreversible process.