23.6: Entropy and Heat Conduction

Though entropy is formally not defined in a system that is not in thermodynamic equilibrium, one can imagine situations in which elements of a system interact only weakly with other elements. Each element is therefore very close to internal equilibrium, so that the entropy of each element can be defined. However, the elements are not in equilibrium with each other.

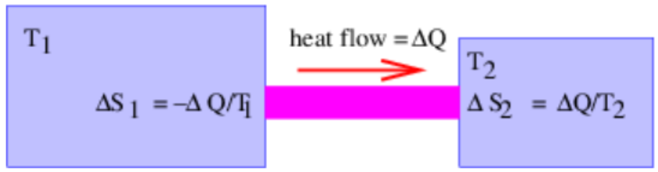

Figure 23.6.5:: The two regions at temperatures T_1 and $\mathrm{T}_2 < \mathrm{T}_1$ are connected by a thin bar that conducts heat slowly from the first to the second region. For heat $\Delta\mathrm{Q}$ transferred, the entropy of region 1 decreases according to $\Delta\mathrm{S}_1 = -\Delta\mathrm{Q}/\mathrm{T}_1$, while the entropy of region 2 increases by $\Delta\mathrm{S}_2 = \Delta\mathrm{Q}/\mathrm{T}_2$.

Figure 23.6.5 shows an example of such a situation. Since $1/\mathrm{T} = \partial\mathrm{S}/\partial\mathrm{E}$, one can write

$$\Delta S_1 = -\Delta Q/T_1 \tag{23.6.1}$$

since heat flowing out of region 1 results in a decrease in internal energy $\Delta\mathrm{E}_1 = -\Delta\mathrm{Q}$. Likewise, we find that

$$\Delta S_2 = \Delta Q/T_2 \tag{23.6.2}$$

since the internal energy of region 2 increases by $\Delta\mathrm{E}_2 = \Delta\mathrm{Q}$. The total change of entropy of the system is therefore

$$\Delta S = \Delta S_1 + \Delta S_2 = \Delta Q\left(\frac{1}{T_2} - \frac{1}{T_1}\right) \tag{23.6.3}$$

From our experience, we know that heat will only flow from region 1 to region 2 if $\mathrm{T}_1 > \mathrm{T}_2$. However, equation (23.6.3) shows that the net entropy change is positive when this is true. Conversely, if $\mathrm{T}_1 > \mathrm{T}_2$, then the net entropy change would be negative and heat would be flowing spontaneously from lower to higher temperatures. Thus, the statement that heat cannot spontaneously flow from lower to higher temperatures is equivalent to the statement that the entropy of an isolated system must not decrease. An alternative statement of the second law of thermodynamics is therefore heat cannot spontaneously flow from lower to higher temperatures.

If entropy increases in some process, we call it irreversible. Spontaneous heat flow is always irreversible. However, in the limit in which the temperature difference is very small, the entropy increase due to heat flow is also small. Of course, the rate of flow of heat is also quite slow in this case. Nevertheless, this situation forms a useful idealization. In the idealized limit of very small, but nonzero temperature difference, the flow of heat is said to be reversible because the generation of entropy is negligible.

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