Summary so far *Objects redistribute their energy in ways that yield higher multiplicity for the combined system.*

or equivalently

Energy transfer processes can only happen if **total** entropy either stays the same or increases.

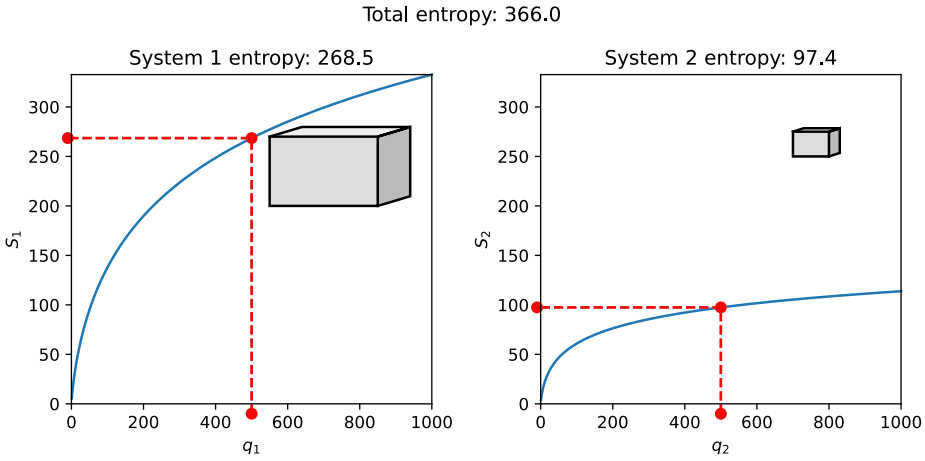
$$\Delta S_{\text{total}} \geq 0 \tag{1}$$

This is the Second Law of Thermodynamics.

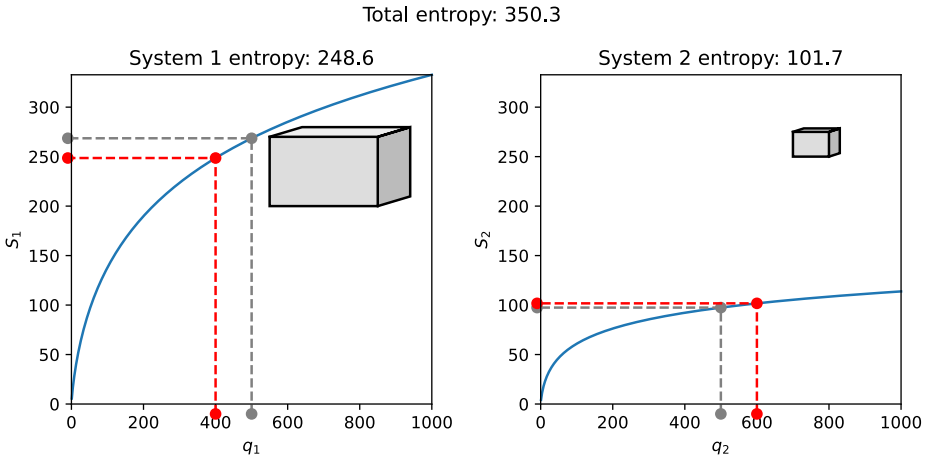
0.1 Transfering energy

Here is a six-minute video of this portion of this lecture, which features an interactive computer graph. The Python source code for this graph is here.

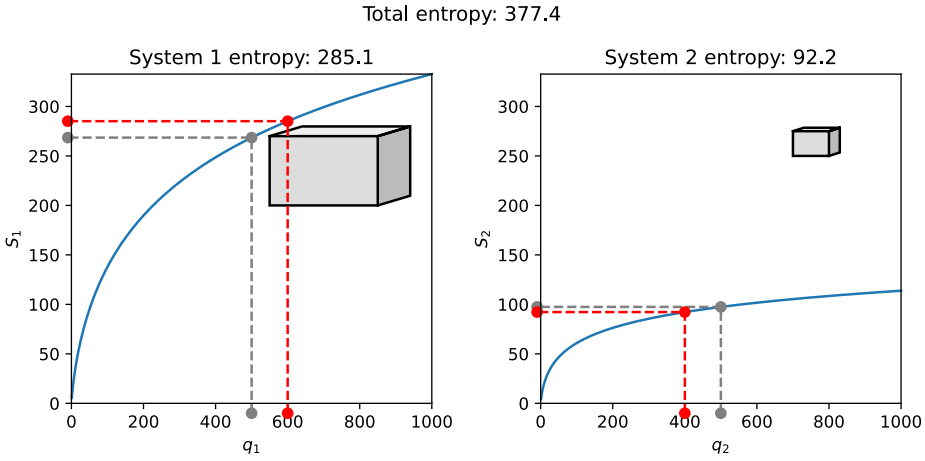
Let us consider two solid objects of different size, but the same internal energy. In the plots below, we treat the two objects as Einstein model solids with the same quantum of energy.



The larger object has greater entropy, as we expect, given the two objects have the same energy. First, we take 100 units of energy and transfer them from the large block to the smaller one. We see that the large block decreases in entropy, while the smaller block increases in entropy, as we would expect. However, the increase in entropy of the smaller block is much less than the decrease in entropy of the larger block, so this processes is not allowed by the Second Law.



Now we consider transferring the same quantity of energy in the other direction, from the small block to the large one. In this case, the entropy increase of the larger block is greater than the entropy decrease of the smaller one, and the process will happen spontaneously and irreversibly.



If we imagine transferring more and more energy from the smaller block to the larger one. The combined entropy will keep increasing, right up until the point where the slope of the two curves are equal, at which point the entropy will have reached a maximum, and the two blocks will be in equilibrium.

We conclude that energy will spontaneously move from a system with a shallower slope on its S vs U (or q) curve to a system that has a greater slope, and two systems will be in thermal equilibrium when their slopes are equal. *This is starting to sound like temperature!*

0.2 Temperature

The purpose of a temperature scale is to predict which direction heat will be transfered.

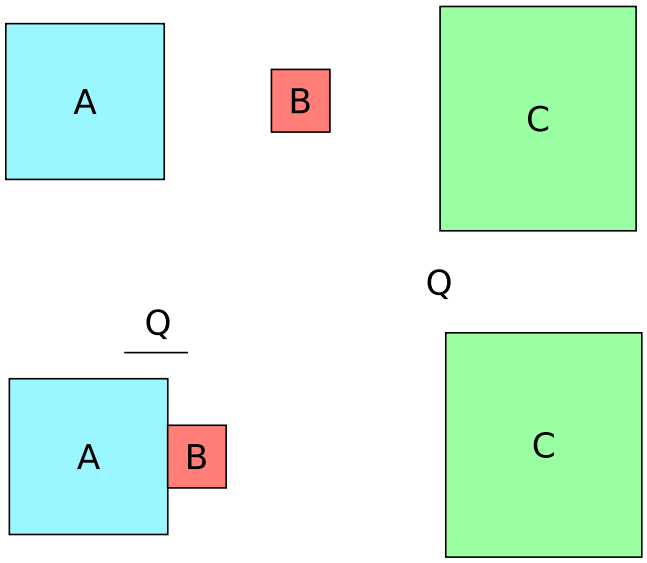


Figure 1: If box A is placed in contact with box B, heat flows from B to A. If box A is paced in contact with C, heat flows from A to C.

Rank the temperature of the three boxes.

1. $T_A > T_C > T_B$
2. $T_B > T_C > T_A$
3. $T_B > T_A > T_C$

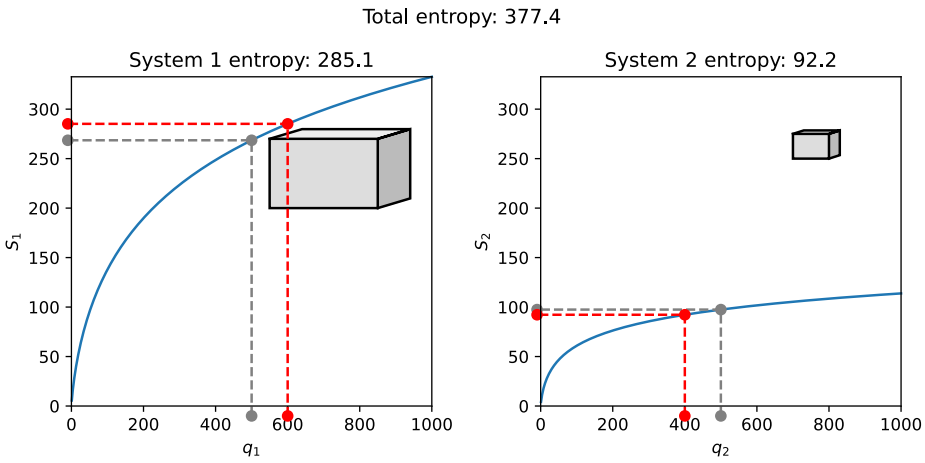
Fundamental definition of temperature

$$T = \frac{1}{\left(\frac{dS}{dU}\right)} \tag{2}$$

The SI units would be

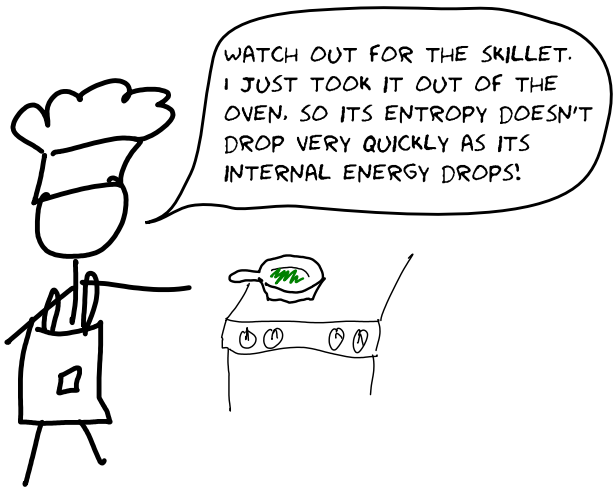
$$\frac{dS}{dU} = \frac{\text{J/K}}{\text{J}} = \frac{1}{\text{K}} \tag{3}$$

Let's look at the example from before of two Einstein solids:



The slope $\frac{dS}{dU}$ of the bigger block is greater than the slope of the smaller, which means that the *temperature* of the bigger block is less than the *temperature* of the smaller block, i.e. the bigger block is colder than the smaller one.

You can think of a cold object as being "desperate for energy." If you're going to personify thermal systems, you can do worse than to think of thermodynamics as a kind of Marxist utopia, where entropy as happiness, energy as money (which is conserved, unless you're a nation), and those who are more affluent (hotter) are always willing to share with the needier.



Conclusion