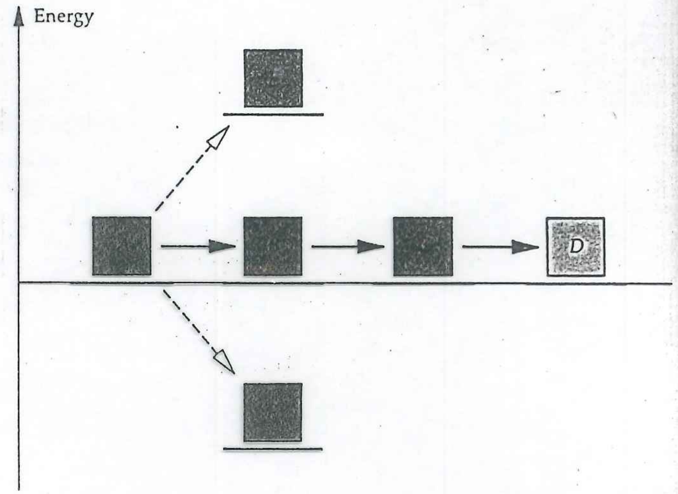
Toward Corruption

The progress of science is marked by the transformation of the qualitative into the quantitative. In this way not only do notions become turned into theories and lay themselves open to precise investigation, but the logical development of the notion becomes, in a sense, automated. Once a notion has been assembled mathematically, then its implications can be teased out in a rational, systematic way. Now, we have promised that this account of the Second Law will be nonmathematical, but that does not mean we cannot introduce a quantitative concept. Indeed, we have already met several, temperature and energy among them. Now is the time to do the same thing for spontaneity.

The idea behind the next move can be described as follows. The Zeroth Law of thermodynamics refers to the *thermal equilibrium* between objects ("objects," the things at the center of our attention, are normally referred to as *systems* in thermodynamics, and we shall use that term from now on). Thermal equilibrium exists when system *A* is put in thermal contact with system *B*, but no net flow of energy occurs. In order to express this condition, we need to introduce the idea of the *temperature* of a system, which we define as meaning that if *A* and *B* happen to have the same temperature, then we know without further ado that they are in thermal equilibrium with each other. That is, the Zeroth Law gives us a reason to introduce a "new" property of a system, so that we can easily decide whether or not that system would be in thermal equilibrium with any other system if they were in contact.

The First Law gives us a reason to carry out a similar procedure, but now one that leads to the idea of "energy." We may be interested in what states a system can reach if we heat it or do work on it. We can assess whether a particular state is accessible from the starting condition by introducing the concept of *energy*. If the new state differs in energy from the initial state by an amount that is different from the quantity of work or heating that we are doing, then we know at once, from the First Law, that that state cannot be reached: we have to do more or less work, or more or less heating, in order to bring the energy up to the appropriate value. The energy of a system is therefore a property we can use for deciding whether a particular state is accessible (see figure on next page).

This suggests that there may be a property of systems that could be introduced to accommodate what the Second Law is telling us. Such a property would tell us, essentially at a glance, not whether one state of the system is accessible from the other (that is the job of the energy acting through the First Law), but whether it is *spontaneously* accessible. That is, there ought to be a property that can act as the signpost of natural, spontaneous change, change that may occur without the need for our technology to intrude into the system in order to drive it.



An isolated system may in principle change its state to any other of the same energy (the four colored boxes in the horizontal row), but the First Law forbids it to change to states of different energy (the brown-tinted boxes).

There is such a property. It is the *entropy* of the system, perhaps the most famous and awe-inspiring thermodynamic property of all. Awe-inspiring it may be: but the awe should not be misplaced. The awe for entropy should be reserved for its power, not for its difficulty. The fact that in everyday discourse "entropy" is a word far less common than "energy" admittedly makes it less familiar, but that does not mean that it stands for a more difficult concept. In fact, I shall argue (and in the next chapter hope to demonstrate) that the entropy of a system is a simpler property to grasp than its energy! The exposure of the simplicity of entropy, however, has to await our encounter with atoms. Entropy is difficult only when we remain on the surface of appearances, as we do now.

Entropy

We are now going to build a working definition of entropy, using the information we already have at our disposal. The First Law instructs us to think about the energy of a system that is free from all external influences; that is, the constancy of energy refers to the energy of an *isolated system*, a system into which we cannot penetrate with heat or with work, and which for brevity we shall refer to as the *universe* (see figure on facing page). Similarly, the entropy we define will also refer to an isolated system, which we shall call the universe. Such names reflect the hubris of thermodynamics: later we shall see to what extent the "universe" is truly the Universe.