12.2: The Direction of Spontaneous Heat Transfer

The idea that thermal energy can be transferred from a warmer body to a colder one, but not in the opposite direction, is a fundamental assumption in our development of the thermodynamic criteria for change. Therefore, if our theory is to be internally consistent, we must be able to deduce this principle from the criteria we have developed. Let us consider one way in which this can be done: We consider an isolated system comprised of two subsystems, A and B, that are in thermal contact with one another. We suppose that the temperatures are T_A and T_B and that $T_A \neq T_B$. If the energy of subsystem A increases, heat transfers from subsystem B to subsystem A. In this case, we know that $q_A > 0$ and $T_B > T_A$.

When we seek to analyze this process using our thermodynamic theory, we encounter a problem that arises for any spontaneous process: Since the process is not reversible, we must introduce approximating assumptions. For the present analysis, we want to estimate the entropy change that occurs in each subsystem. To do so, we suppose that an increment of heat, dq, can pass from one subsystem to the other without significantly changing the temperature of either one. It is evident that we could—by some other process—effect this change in either subsystem as nearly reversibly as we wish. (In §5, we consider such a process.) Even though the present process is not reversible, we have good reason to assume that the entropy changes in the subsystems are well approximated as dq_A/T_A and $dq_B/T_B = -dq_A/T_B$. Since the system is isolated, the process can be spontaneous only if its entropy change is positive; that is, the relevant thermodynamic criterion is $dq_A/T_A - dq_A/T_B > 0$. With $dq_A > 0$, we find $1/T_A - 1/T_B > 0$, or $T_B > T_A$. When heat is spontaneously transferred from B to A, our thermodynamic criterion also requires that subsystem B be warmer than subsystem A.