3. THE STRONG AND THE WEAK

To make sense of this growing list of subatomic particles, physicists turned to what are called symmetries and conservation rules. In physics, as in everyday life, some things never change. The total amount of energy, for instance, remains the same after a physical process as it was before. Physicists say that energy is "conserved;" energy may change forms in the process, but the total amount of it remains the same. Such a principle, first established in classical physics, holds true in the realm of quantum mechanics, too. An apparent violation of energy conservation in weak radioactive decays, for example, led to the proposal of the neutrino as one way to spirit off the missing energy.

Other physical quantities are conserved, too—such as momentum, angular momentum, and electric charge. Unless sufficient force is applied to retard its motion, a car continues speeding forward because of momentum conservation. A top keeps spinning about its axis (until the force of friction slows it down) due to the conservation of angular momentum. And nobody has yet seen electric charge evaporate. If you put an amount of charge into one end of a copper wire, the same amount eventually comes out the other end.

These may seem like trivial statements, but to physicists such conservation is profound evidence of underlying *symmetries* in the laws of nature. Energy is conserved because these laws do not change with time; momentum is conserved because they do not change with position. So the mathematical expressions of these laws cannot contain terms that depend on time or position. Physicists say the laws are "symmetric" in time and space. They mean that a change in these variables does not alter the outcome of processes governed by these laws.

Conservation rules hold true in the subatomic realm, too. Because angular momentum is conserved, for example, a spin-1 particle cannot decay into a spin-0 and a spin-1/2 particle. Conservation of angular momentum means the laws of nature do not depend on one's orientation; they cannot contain any terms that depend on angle. Similarly, we never witness any interactions where net electric charge is created or destroyed—the total charge remaining afterwards is always the same as it was beforehand.

As one way to understand the forces between subatomic particles, physicists of the 1950's began to identify other physical quantities that were conserved in their interactions. Some of these quantities do not have analogues in classical physics, either. Once established, conservation rules implied additional symmetries of the laws governing the forces. The concept of symmetry has proved crucial to high-energy physics. Indeed, much of the recent progress in finding new levels of simplicity in nature has gone hand-in-hand with the elucidation of new kinds of symmetry.

The property of strangeness mentioned in the last chapter surfaced because the so-called strange particles—kaons and lambdas, for example—were always produced in pairs. This happens because the two particles carry equal but opposite amounts of strangeness, $+1$ and -1, so that the sum before an interaction is the same as the sum after, or 0.

When the strong force governs an interaction as above, strangeness is indeed conserved. But when the weak force gets into the act, strangeness is *not* necessarily conserved. The neutral kaon produced in the process depicted above can decay via the weak force into two pions, both of which

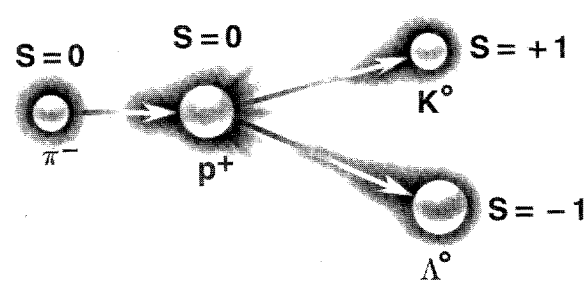

Figure 5. The total amount of strangeness remains the same when a pion and proton collide to produce a kaon and a lambda.