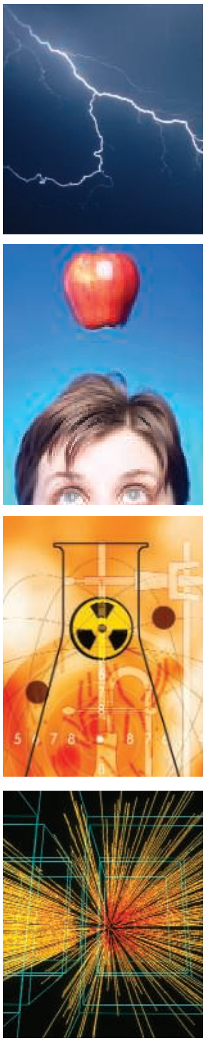
Can the Laws of Physics Be Unified

At its best, physics eliminates complexity by revealing underlying simplicity. Maxwell's equations, for example, describe all the confusing and diverse phenomena of classical electricity and magnetism by means of four simple rules. These equations are beautiful; they have an eerie symmetry, mirroring one another in an intricate dance of symbols. The four together feel as elegant, as whole, and as complete to a physicist as a Shakespearean sonnet does to a poet.

The Standard Model of particle physics is an unfinished poem. Most of the pieces are there, and even unfinished, it is arguably the most brilliant opus in the literature of physics. With great precision, it describes all known matter—all the subatomic particles such as quarks and leptons—as well as the forces by which those particles interact with one another. These forces are electromagnetism, which describes how charged objects feel each other's influence: the weak force, which explains how particles can change their identities, and the strong force, which describes how quarks stick together to form protons and other composite particles. But as lovely as the Standard Model's description is, it is in pieces, and some of those pieces—those that describe gravity—are missing. It is a few shards of beauty that hint at something greater, like a few lines of Sappho on a fragment of papyrus.



Fundamental forces. A theory that ties all four forces together is still lacking.

The beauty of the Standard Model is in its symmetry; mathematicians describe its symmetries with objects known as Lie groups. And a mere glimpse at the Standard Model's Lie group betrays its fragmented nature: SU(3) × SU(2) × U(1). Each of those pieces represents one type of symmetry, but the symmetry of the whole is broken. Each of the forces behaves in a slightly different way, so each is described with a slightly different symmetry.

But those differences might be superficial. Electromagnetism and the weak force appear very dissimilar, but in the 1960s physicists showed that at high temperatures, the two forces "unify." It becomes apparent that electromagnetism and the weak force are really the same thing, just as it becomes obvious that ice and liquid water are the same substance if you warm them up together. This connection led physicists to hope that the strong force could also be unified with the other two forces, yielding one large theory described by a single symmetry such as SU(5).

A unified theory should have observable consequences. For example, if the strong force truly is the same as the electroweak force, then protons might not be truly stable; once in a long while, they should decay spontaneously. Despite many searches, nobody has spotted a proton decay, nor has anyone sighted any particles predicted by some symmetry-enhancing modifications to the Standard Model, such as supersymmetry. Worse yet, even such a unified theory can't be complete—as long as it ignores gravity.

Gravity is a troublesome force. The theory that describes it, general relativity, assumes that space and time are smooth and continuous, whereas the underlying quantum physics that governs subatomic particles and forces is inherently discontinuous and jumpy. Gravity clashes with quantum theory so badly that nobody has come up with a convincing way to build a single theory that includes all the particles, the strong and electroweak forces, and gravity all in one big bundle. But physicists do have some leads. Perhaps the most promising is superstring theory.

Superstring theory has a large following because it provides a way to unify everything into one large theory with a single symmetry—SO(32) for one branch of superstring theory, for example—but it requires a universe with 10 or 11 dimensions, scads of undetected particles, and a lot of intellectual baggage that might never be verifiable. It may be that there are dozens of unified theories, only one of which is correct, but scientists may never have the means to determine which. Or it may be that the struggle to unify all the forces and particles is a fool's quest.

In the meantime, physicists will continue to look for proton decays, as well as search for supersymmetric particles in underground traps and in the Large Hadron Collider (LHC) in Geneva, Switzerland, when it comes online in 2007. Scientists believe that LHC will also reveal the existence of the Higgs boson, a particle intimately related to fundamental symmetries in the model of particle physics. And physicists hope that one day, they will be able to finish the unfinished poem and frame its fearful symmetry.

–CHARLES SEIFE

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