letters

Empirical incompleteness and the search for a theory of everything

What I see in Nature is a magnificent structure that we can comprehend only very imperfectly. —Albert Einstein

As the high-energy physics community gears up for the flood of new data from the Large Hadron Collider (LHC), now may be a good time to ponder the existence of a theory of everything or, more bombastically, a final theory.

The dream that the human mind can attain a complete description of natural phenomena predates what we now call physics. The Pythagoreans of ancient Greece sought to describe nature through the relations between numbers and geometry. In 1596 Johannes Kepler proposed a description of the solar system based on nesting the five platonic solids interspersed with spherical shells. To him, the scheme solved the mystery of creation: why there were only six planets and what their relative distances were. (By tweaking the ordering of the solids he got an amazing 5% accuracy.[1]) Kepler's mistake was to give too much credence to what was observationally known in his time. The discovery of a new planet, and the consequent ruin of his geometrical explanation, was unthinkable.

We can learn something from Kepler. Believing that God had to use the most perfectly symmetric objects in his blueprint for creation, Kepler tried to geometrize the cosmos. Although much of the success of physics undoubtedly derives from the application of symmetry concepts to nature, symmetry was more than a tool to Kepler. It was dogma. Is modern physics falling into a similar trap?

First, let me provide a disclaimer. Contrary to widespread popular belief, a theory of everything, a complete description of how elementary particles interact, can't really cover "everything." It would be foolish to believe that one could step up from fundamental particles to explain why Earth has a single moon or why humans evolved here.

A complete description of something is implicitly final: It implies that nothing else fundamental to it and capable of changing our views remains to be discovered. To imagine such a complete description as an achievable goal in an empirical science is, to me, untenable. Were we to construct a complete theory of everything by unifying the four known interactions, nothing else fundamental in particle physics could be discovered. The assumption is that no other possible forces of nature and no deeper level of more fundamental particles lurk behind our current ignorance. How can we be sure? For example, the running of the coupling constants—the property that the strengths of the interactions become comparable at high energies—even if true, doesn't exclude other possible forces.

Our knowledge of physical reality is based on what we can measure. Even though our instruments are always getting more accurate, we are bound by empirical incompleteness. The LHC, amazing as it is, will probe physics some 12 orders of magnitude below the grand unification scale of about 10^{16} GeV. That's a huge gap. Cosmology will surely help, as we gain an improved understanding of dark matter and dark energy. Still, it's hard to imagine that our instruments will one day be able to measure all there is to measure. So how do we determine that we have a complete theory?

Many say that Albert Einstein was fated to fail in his search for unification because he left out the two nuclear forces. Even if supersymmetry is discovered and we find a unified description of the four known interactions, could we state that we are done? Think of how Kepler would have reacted had he known of the existence of Uranus and Neptune.

Certainly we should search for more simplified descriptions of reality. We will only know how far we can go by trying, and there is much to discover. The standard model of particle physics, with its 20-plus free parameters, still holds many secrets. In the coming years, we can expect the LHC and the many ongoing and future cosmological experiments to bring us new challenges and possibly allow us to reach new partial unifications. But the notion that nature possesses an overarching symmetry, although aesthetically appealing, need not be right. Apologies to John Keats, but beauty need not be truth. Judging from all the symmetry violations in the weak interactions, perhaps we should rethink what we call beautiful in nature.

The standard model is not a true unification, as it mixes three symmetry groups. Proton decay and magnetic monopoles, the experimental signatures of the almost four-decades-old grand unified theories, have so far failed to materialize. Gravity, many now speculate, may not be a fundamental force.[2] The expectation of a complete unification based on a single symmetry group is the modern incarnation of the age-old Pythagorean dream. We have to wonder if nature really is so tidily packaged or if that is just how we would like it to be.[3]

References

1. O. Gingerich, *Icarus* **11**, 111 (1969).
2. T. Konopka, F. Markopoulou, S. Severini, *Phys. Rev. D* **77**, 104029 (2008); P. Hořava, *J. High Energy Phys.* **03**, 020 (2009); E. Verlinde, http://arxiv.org/abs/1001.0785.
3. M. Gleiser, *A Tear at the Edge of Creation: A Radical New Vision for Life in an Imperfect Universe*, Free Press, New York (2010).

Marcelo Gleiser
(mgleiser@dartmouth.edu)
Hanover, New Hampshire

Letters are encouraged and should be sent by e-mail to ptletters@aip.org (using your surname as "Subject"), or by standard mail to Letters, PHYSICS TODAY, American Center for Physics, One Physics Ellipse, College Park, MD 20740-3842. Please include your name, affiliation, mailing address, e-mail address, and daytime phone number on your attachment or letter. You can also contact us online at http://www.physicstoday.org/pt/contactus.jsp. We reserve the right to edit submissions.

HBCUs need better marketing

Quinton Williams's Opinion piece about undergraduate physics programs at historically black colleges and universities (HBCUs; PHYSICS TODAY, June 2010, page 47) inspired me to write this response and challenge.

I gathered from the piece that some,