Supersymmetry and String Theory: Beyond the Standard Model and Supersymmetry: Theory, Experiment and Cosmology

Gordon Kane

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Supersymmetry and String Theory

Beyond the Standard Model

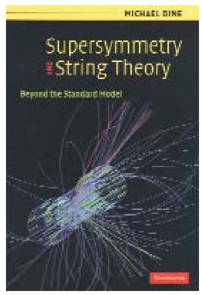
Michael Dine
Cambridge U. Press, New York, 2007. $80.00 (515 pp.).
ISBN 978-0-521-85841-0

Supersymmetry

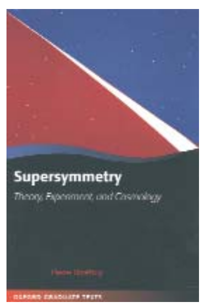
Theory, Experiment, and Cosmology

Pierre Binétruy
Oxford U. Press, New York, 2006. $100.00 (520 pp.).
ISBN 978-0-19-850954-7

Arguably the most important issue in particle physics today is the hierarchy problem. As noted by Max Planck a century ago, the only natural scale in which dimensionful quantities are formed from the speed of light, the strength of gravity, and what is now called Planck's constant is the "Planck scale," and its energy is about 10^{19} GeV. But we live at or below the electroweak scale, which is about 100 GeV—far below the Planck scale. In a world described by quantum theory, where virtual states connect all systems, how can two such widely separated scales exist? And why is the electroweak scale what it is and not much larger? Those issues form the hierarchy problem, and because the Planck scale is associated with strong gravitational interactions, the problem is related to having a quantum theory of gravity.



One of the several reasons why many physicists expect supersymmetry to be a symmetry of nature at the electroweak scale is that it solves what I like to say is three-fourths of the hierarchy problem. Supersymmetry alone does not explain why the electroweak scale has the value it does, but it successfully stabilizes the large difference between the Planck scale and the electroweak scale. The theory allows one to connect the scales perturbatively so that addressing the issue of the value of the electroweak scale makes sense. Superpartners of conventional particles are expected to be detectable at CERN's Large Hadron Collider (LHC), which is scheduled to take data in the summer of 2008.



One can either treat supersymmetry as an effective theory at the electroweak scale and basically ignore its origin in a more fundamental theory at the Planck scale, or retain the different perspective that comes from including its grounding in a fundamental theory. There are important practical differences: In the low-energy, effective theory approach, all the parameters are considered unknowns to be measured; but in the high-energy approach, the low-energy parameters are related by their origin in a fundamental, underlying, short-distance theory, and replaced by a usually much smaller set of microscopic parameters. In a low-energy, effective theory, supersymmetry appears to predict an unpleasantly large number of new particles, because each standard-model particle gets a superpartner; yet in a fundamental theory one simply has a symmetry and the new particles are all very closely related to the standard-model ones, much as antiparticles are related to particles. Having the new particles makes for a conceptually simpler world and looks complicated from the low-energy viewpoint but not from the high-energy one.

Supersymmetry and String Theory: Beyond the Standard Model by Michael Dine and *Supersymmetry: Theory, Experiment, and Cosmology* by Pierre Binétruy differ from earlier supersymmetry books (see my review in PHYSICS TODAY, December 2006, page 62)—most importantly by including the perspective of the high-energy, fundamental theory in an essential way. The presumed high-energy theory is string theory, which is appealing because it addresses all the questions in particle physics and is a quantum theory of all the forces. For example, Dine has a short section titled "What might the Standard Model come from?" Both books give a description of string theory and how it connects to a low-energy supersymmetric theory that would be one of its main visible implications. They provide a summary of the standard model, and the perspective that supersymmetry will extend it. Both authors are experts in the field who have contributed to its development.

If superpartners are indeed discovered at the LHC or even earlier at the Fermilab Tevatron collider, the central issue will become understanding how the supersymmetry is broken. The low-energy approach parameterizes the breaking in a general way using the "soft-breaking" Lagrangian. One can also study from a theoretical point of view how the supersymmetry might be broken and then predict patterns of the low-energy parameters that would allow recognition of a particular form of breaking. The books present good surveys of work on supersymmetry breaking and prepare readers to work on such questions. If supersymmetry were an unbroken theory, it would have no unpredicted parameters. All the parameters arise from the supersymmetry breaking, and measuring them will help researchers understand the breaking. The texts also contain major treatments of cosmology and important questions of physics beyond the standard model, including inflation, axions, the origin of the matter asymmetry in the universe, supersymmetry in the early universe, and connections to the string-theory moduli fields.

Binétruy has worked successfully at making his book pedagogically useful. He provides a roadmap of three paths through the book: one for researchers who want a theoretical introduction, the second for high-energy experimentalists, and the third for astrophysicists or cosmologists. The author often includes extra steps in derivations, which are helpful to a beginner or a reader coming from another field. He also provides useful hints to solving the exercises and includes a self-contained summary of basic notions of quantum field theory. His presentation of the general form of the supersymmetry soft-breaking Lagrangian is very pedagogical and physical. His 55 pages on string theory provide a good physical picture of compactifying to four dimensions and of phenomenological aspects of superstring models.

Dine's *Supersymmetry and String Theory* has more material on theoretical and nonperturbative aspects of the low-energy theory, with studies of anomalies, instantons, the strong *CP*-violation problem, monopoles, solitons, and alternative theories. His 170-page introduction to string theory covers a broad range of topics. Dine's book will be particularly attractive to theorists who want to be well informed about most of the theoretical issues related to physics beyond the standard model. A website to accompany the book (http://scipp.ucsc.edu/~dine/book/book.html) is under development, already has a useful set of errata, and is expected to have updates and solutions of selected problems.

If nature is described by a supersymmetric theory, windows are opened on early-universe cosmology and on physics at the Planck scale. Then we may be able to formulate a unified theory incorporating those fundamental areas, and we will be able to relate data from colliders to those topics, in both directions. The books by Binétruy and Dine indeed describe the state of the art and science today.

Gordon Kane
University of Michigan
Ann Arbor

Einstein
His Life and Universe

Walter Isaacson
Simon & Schuster, New York, 2007. $32.00 (675 pp.).
ISBN 978-0-7432-6473-0

When Walter Isaacson was managing editor of *Time* magazine in 1999, he canonized Albert Einstein as *Time*'s "Person of the Century"; the runners-up were Franklin D. Roosevelt and Mahatma Gandhi. Since then, much biographical material about the physicist has become accessible, and Isaacson makes good

See www.pt.ims.ca/12312-28