A High-Strung Theory

Physicists contemplating the nitty-gritty of a unifying theory find it stringy

By DIETRICK E. THOMSEN

For centuries physicists have sought a single theory that would encompass and explain everything in physics. Now they believe they are really on the track of such a unification theory. The latest approach, known as superstring theory, has generated a great deal of enthusiasm as physicists have learned that it promises to solve problems long thought intractable. Specifically, it is the first attempt at a unified theory that includes gravity in a mathematically "natural" way. However, it does so by changing the basic concepts on which the game of mathematical physics has been based for three centuries. It also reverses the order of procedure that physicists have heretofore used in searching for unity.

Superstring theory proposes that elementary particles, the basic elements of matter, should be represented by strings, short one-dimensional things, instead of being represented by zero-dimensional geometric points as has been the custom for 300 years. As Isaac Newton worked out the mathematics of his theory of gravity, he pointed out that the physical sizes of the sun and planets were negligible compared with the distances between them. He therefore neglected the physical extents of those bodies; for the sake of mathematics he reduced their dimensions to zero, making them geometric points. This simplified the mathematics a great deal, and it worked. It worked so well that it has been extended to other domains of physics and, in our own day, to subatomic particles. Traditionally physics has been a world of point bodies, point particles and the forces between those points.

Superstring theory proposes to change this tradition. What it says is that for the most elementary particles of matter, you cannot reduce all three dimensions to zero, even if only for the sake of mathematics. One dimension remains: a little string, characteristically 10^{-33} centimeters long. It's very tiny, but it changes the basis of things. As Steven Weinberg of the University of Texas at Austin put it in Berkeley, Calif., at the recent Twenty-Third International Conference on High-Energy Physics, physicists are having to learn branches of mathematics and varieties of geometry and topology that they have never used before in mathematical physics. The theories they make in this way look radically different from either the classical or quantum theories of old.

Furthermore, superstring starts from the top and moves down rather than progressing from the bottom up. Instead of beginning with observed phenomena, and step by step finding larger and larger unifying principles to include more and more of them, it starts by postulating the unity in a very grandiose scheme and then tries, by breaking up that scheme in various ways, ultimately to come up with the diversity of physics as we observe it. This way of proceeding raises serious difficulties for attempts to verify the theory experimentally. It also makes it difficult to use observed phenomena to choose among theoretical alternatives that seem equally good mathematically.

The present disunity of physics is best exemplified by the division of physical phenomena into the domains of four different kinds of force. Why should force come in four (or, some believe, five) kinds? Force or interaction — which is the way one object influences another, or the way one object changes into something else — is a single concept. Yet in physics as we observe it, interaction comes in varieties called strong, weak, electromagnetic and gravitational. Each of these presides over a different set of phenomena, affecting different bodies, and each has a different intrinsic strength.

Physicists want to believe that these four separate domains are fragments of an underlying and perhaps historic unity. They hope that a theory can be devised that will exhibit that unity. The program has a historical aspect also. Perhaps in the past when the universe was hot and dense, there was a time when the strengths of all the interactions were equal — there seems to be some evidence that as the energy goes up, the strengths converge. At such a time of equality, the four interactions would have been indistinguishable from one another, and their unity would have been manifest. Thus the search for the underlying unity is also a way of recapitulating the evolution of the universe.

In this quest, physicists have customarily used mathematical symmetry groups. Patterns of symmetry are apparent in the phenomena governed by the different kinds of force. Mathematicians have dealt with such patterns in the theory of what they call symmetry groups, and it turns out that certain such groups, already well known to mathematicians, can be used to describe each of the areas of physical phenomena. Electromagnetism is represented by one particular group, the phenomena of the weak interaction by another, and so on.

Physicists tend to believe that the present diverse state of physics, with different symmetry groups representing different pieces of the totality of phenomena, is the result of a process of symmetry-breaking. An arrangement is most symmetrical when all its elements are identical. If one of them is not identical, the symmetry is broken. Mathematically a symmetry break can mean that a large and very general symmetry group breaks into smaller ones, each of which preserves part but not all of the original symmetry.

Historically the universe started out hot and very symmetric, with not much differentiation of basic material phenomena and forces. One large symmetry group described it all. As the universe cooled, symmetry breaks occurred and smaller symmetry groups came out. As they did, a single kind of force differentiated itself into several kinds; matter differentiated itself into a larger and larger variety of particles. Why the breaks occurred is not stated; they are called spontaneous. They are something that happens as the universe cools, just as in the cooling of a mixture of liquids one substance crystallizes out at one temperature, another at another temperature.

What theoretical physicists have tried to do is work the historic scheme backward. Taking two of the symmetry groups apparent today, they try to find a larger one that could be the one from which these groups broke off. Then the theorists try to fit in a third symmetry group, and so on until they have put the whole jigsaw puzzle back together and have arrived at the primal symmetry of the universe. This way of proceeding has successfully demonstrated the unity of the weak and electromagnetic interactions; Weinberg, Sheldon Glashow of Harvard

University and Abdus Salam of the International Center for Theoretical Physics in Trieste, Italy, won a Nobel Prize for it.

The next step, bringing together this electro-weak group with that of the strong interactions, has not fared so well. Known as SU(5) Grand Unification Theory because SU(5) is the name of the group that is supposed to do the unifying, it predicts phenomena such as radioactive decay of the proton. But because physicists have not been able to find such phenomena, the hope that this would be a route to the final total unification seems to be fading.

Superstring comes as a new hope. According to John H. Schwarz of Caltech in Pasadena, one of the physicists who have done the most work on the theory, one reason for superstring's promise is that it predicts everything that SU(5) theory predicts successfully but doesn't predict the things, such as proton decay, at which SU(5) has failed. Furthermore, says Schwarz, it can be made to contain the successful unification of electromagnetism and the weak interaction, and it is compatible with quantum chromodynamics, the very successful theory of how the strong interaction operates. It thus reproduces everything we know today, and it does much more.

Superstring takes the historical process from the start forward. It begins with a grand symmetry group representing a primordial state of very high energy. It then proceeds by a succession of symmetry breaks to break this down to the series of groups we have today. There are several routes by which this breaking can take place, and one of the problems is that the differences lie in the very high-energy range that experimenters have no hope of reaching, so that an experimentally conditioned choice among the routes seems unlikely.

Some of the stages of some of the routes make some rather weird predictions. One of the most famous is shadow matter (SN:5/11/85,p.296). This form of matter interacts with ordinary matter — the sort familiar to us — only by way of gravity. That means it interacts with us extremely feebly and is virtually undetectable. It could be all around us and we wouldn't know it.

It is also at this very high-energy level that gravity comes into the theory, or falls out of it, depending on your point of view. Theorists had not been sure how to get gravity into the total unification scheme, but they generally agreed that the energy level where it would join the others was around 10^{19} billion electron-volts (10^{19} GeV). This is 16 powers of 10 greater than the 1,000 GeV that experiment is so far able to reach. Theorists also agree that a theory that could successfully incorporate gravity must include a particular symmetry known as supersymmetry.

Supersymmetry involves a doubling of all the subatomic particles we know. Each kind of subatomic particle obeys one of two statistical laws, known as Bose-Einstein statistics and Fermi-Dirac statistics. Supersymmetry says that every known particle that obeys Bose-Einstein statistics has a supersymmetric partner that is its mirror image but obeys Fermi-Dirac statistics, and vice versa for known particles that obey Fermi-Dirac statistics. Superstring theories contain supersymmetry. In fact, the definition of "superstring" is that it contains supersymmetry. String theories that don't contain supersymmetry are possible but not very interesting.

Schwarz says there are six possible superstring theories to choose from. "Only six," Weinberg notes — for a theoretical physicist that's refreshingly few choices. In five of these theories the strings always form closed loops; the sixth has both loops and open-ended strings. It is the loops-only theories that Schwarz expects to be interesting from a physical point of view. The loop with its fundamental length of 10^{-33} centimeters and a basic mass of 10^{19} GeV is the fundamental unit of matter. The string can vibrate, and the subatomic particles that exist represent different modes of vibration of this basic string.

That there is an amount of mass built into the theory in a fundmental way is another advantage. Right now there is no good explanation of why the different particles have the masses they do, even though mass is perhaps the most fundamental quality of matter. Superstring theory may not give physicists an understanding of why the individual masses are what they are, but it may at least give an understanding of the ratios of the masses and why one kind of particle is so much heavier or lighter than another.

Superstring theories are 10-dimensional. They involve nine spacelike dimensions and one timelike dimension. The world we perceive has three spacelike and one timelike dimensions. Physicists generally suppose that the extra six dimensions are very tightly curved, rolled up into a very microscopic ball around each point in space so that we are unable to perceive them. In an interview with Science News, Schwarz made a very tentative suggestion as to how this might have come about. Suppose, he said, the universe started out with nine spacelike dimensions and they all expanded for a short while; then somehow six of them got stuck, and the other three continued to expand.

Weinberg points out that these looping strings will fundamentally change the way physicists make field theories. A field theory involves any physical quantity that can vary according to location in space. If the strength and direction of a certain force vary from place to place, then physicists who know the location of a given body can calculate the strength and direction of the force on it — or up to now they could. The field formulas depended on points in space and time. In superstring, they depend on the configuration of the strings in the appropriate geometry — how they happen to loop and twist.

This requires physicists to learn mathematics they never had to use before, and in that Weinberg sees a danger. Many of the brightest young theoretical physicists are rushing to superstring theory and exerting themselves to learn this mathematics. Thus, while their education is deep in "beautiful" mathematics, he says, it is narrow. And then, looking down at his notes: "Deep and narrow is a grave — it says here." He hopes that new experimental developments may entice some of these young people back into the satisfactions of direct interaction with experiment and so broaden their horizons.

It is just on the question of direct contact with experiment that superstring theory has been criticized for, as Weinberg puts it, a lack of phenomenological success. Experiment cannot hope to reach the energy levels where gravity, the weakest of the four forces at ordinary energy levels, gets strong enough to meld with the other three. Nor can experiment reach the energy levels at which such things as shadow matter might become evident. At reachable energy levels, superstring theory seems compatible with everything we know, but it doesn't seem to predict anything unique that, if found by physicists, would prompt them to say: "Aha! We know that superstring theory is real."

The ethereal quality of the theory has led one critic, Noburu Nakanishi of the Research Institute for Mathematical Sciences in Kyoto, Japan, to compare it to a disease in which victims have taken leave of their senses. Writing in the journal Soryushiron Kenkyu, as quoted in Cern Courier, he refers to "Kaluza-Klein symptoms" — that is, belief in more than four dimensions. "Cases . . . believe in a miracle," Nakanishi writes. "Not a comparatively minor miracle like the parting of the Red Sea in the story of the Exodus, but a Great Miracle in which a 10-dimensional space-time is divided into four-dimensional space-time and a six-dimensional space. . . . [P]atients do not recognize their own abnormality, regarding the Kaluza-Klein symptoms [as] normal and disregarding the fourfold dimensionality of the real world."

Weinberg brushes aside the criticisms. "Superstring theory is our only hope of understanding physics at the scale where gravity is important. Furthermore, it is beautiful. I have the same reaction to it that Einstein and Eddington had to general relativity." □