Steps to a grand unified superstring theory

Theoretical physicists have long sought a simple, unified description of how the universe works, from the long-range effects of gravity to the interactions of quarks and other fundamental particles of matter. Many are convinced that string theory — in which particles exist not as points but as tiny, wiggling loops — furnishes an appropriate framework for such a description. However, string theory resides in an abstract realm far removed from the real world, and there's no consensus on how to bridge the seemingly vast chasm between theory and experiment.

A group of theorists has now, for the first time, uncovered a route originating in string theory that apparently leads to testable predictions about the behavior of matter. Their model allows them to calculate from the basic equations such quantities as the masses of quarks, and to predict the existence of exotic particles not yet discovered.

"We have derived a set of rules that allows us to calculate [physical quantities] directly from the string," says Dimitri V. Nanopoulos of Texas A&M University in College Station. "That makes it very exciting because we can now calculate properties that we can test directly. We have cleared the way for comparing string theory with experiment."

Nanopoulos, John Ellis of the European Laboratory for Particle Physics in Geneva and their collaborators describe some of the consequences of their new model in a continuing series of papers that began in the Aug. 16 PHYSICS LETTERS B. Additional articles are scheduled to appear later this year.

The new theory incorporates a so-called "grand unified theory," which attempts to bring together all the different ways in which elementary particles can interact — expressing these relationships in a compact, shorthand form describable by a mathematical structure called a group. The mathematical group describing the particular variety of grand unified theory used in the new model carries the label "flipped SU(5)."

By successfully embedding this grand unified theory in a superstring framework, which includes gravity, the researchers now have what they call the leading candidate for a truly unified theory. "In the couple of years since we first devised this theory from strings, we've been exploring its consequences in increasing detail," Ellis says. "It has worked surprisingly well."

Nanopoulos and his colleagues are using their model to calculate the masses of quarks, electrons and other elementary particles. Although the calculations are lengthy and tedious, no fundamental barriers appear to stand in the way, the researchers say.

Their result for the mass of the bottom quark is only a few percent away from the experimentally determined value. Furthermore, preliminary calculations reveal that the as-yet-undiscovered top quark should have a mass (expressed in energy units) somewhere between 130 gigaelectron-volts and 150 gigaelectron-volts. This result is consistent with estimates based on experimental data.

Like other, previously studied grand unified theories, the new model predicts that matter is unstable and that protons eventually decay. However, the flipped SU(5) model predicts somewhat longer lifetimes for protons than other, now-rejected theories suggested.

"There are now proposals for a new round of proton-decay experiments, which might get up to this [predicted] lifetime," Ellis says. "We would be very interested in having [those proton-decay experiments] pursued."

The new model also suggests that the universe contains a hitherto unsuspected form of invisible matter. Dubbed cryptons, these new particles — if they exist — could account for a portion of the dark matter in the universe, which exerts a gravitational force but issues no detectable radiation.

"All the available cosmological and astrophysical constraints allow that possibility," Ellis says. "We've shown that these cryptons survive long enough [at least 10^{18} years] to be the dark matter in the universe."

"The cryptons are a completely new kind of matter," Nanopoulos adds. "Nobody has ever dreamed that something like that could exist."

The model also predicts that neutrinos would have a mass, but that mass is probably very small compared with the quark and electron masses. Nanopoulos and his colleagues are now attempting to calculate whether neutrinos in addition have a significant magnetic moment. This could have a bearing on explanations for the dearth of solar neutrinos.

How well the new theory fares will depend on how successfully its predictions meet the test of experiment. Moreover, other theorists have alternative models and approaches that may yet lead to testable predictions.

"It could very well be that there are other models that one could derive from strings," Ellis says. "But even if our particular model turns out not to be right, I still feel that the sort of things that we're learning in our model could be very useful in unraveling the details of [any better] model." — *I. Peterson*

Hot fusion research reaches a milestone

Though generating power from atomic fusion remains many, many moons away, physicists have reached a milestone in this effort to harness the energy source of the stars. Last week, two independent groups of researchers reported that deuterium atoms fusing within experimental reactors can now return enough of the reaction-priming power pumped into them to warrant their labs proceeding with the next step towards taming star-power.

That step would involve substituting a "higher-octane" blend of deuterium and radioactive tritium atoms for the all-deuterium fusion fuel now used in these reactors. Physicist Dale M. Meade of the Tokamak Fusion Test Reactor (TFTR) at Princeton University and Paul-Henri Rebut, director of the Joint European Torus (JET) in England, say that deuterium-tritium fuel would give back more than half the power consumed in initiating fusion reactions. They announced their findings at an International Atomic Energy Agency fusion conference in Crystal City, Va.

Presently, JET and TFTR operate by heating atoms of deuterium (a heavy isotope of hydrogen) to many millions of degrees, while using strong magnetic fields to compress the resulting plasma of free electrons and nuclei to enormous densities within a hollow, doughnut-shaped vacuum vessel. Rebut and Meade report that fusion bursts within JET and TFTR can now produce a few thousandths of the power consumed to heat the deuterium plasma.

By itself, that's a losing balance. But when the physicists project power outputs from deuterium-tritium plasmas — which yield about 300 times the power of all-deuterium plasmas — the balance presumably would reach about 60% in TFTR and 80% in JET. Tritium is a radioactive hydrogen isotope.

Scientists call the ratio of fusion-power output to heating-power input the "Q-value," and have generally agreed that the time to switch fusion fuels is when all-deuterium fusion power reaches a point that corresponds to projected deuterium-tritium Q-values above 0.5. These calculations ignore power used for non-heating roles.

For practical fusion power, a reactor would have to perform at a Q-value of 25 to 30, or it would have to host self-sustaining fusion reactions, which require no further power input once ignited. But first things first. Provided funds and necessary equipment come through, TFTR could gets its first deuterium-tritium fuel by 1993 or 1994, and JET probably by 1995. — *I. Amato*