Theoretical Physics: Speculations on Abnormal Nuclear Matter

As high energy physicists have sought to elucidate the properties of ever smaller constituents of matter, their interests and those of nuclear physicists have increasingly diverged, and the two fields are in practice quite separate. But a speculative result now being widely discussed among both high energy and nuclear physicists seems to have bridged the gap at least temporarily, and the resulting dialogue may well convince practitioners of both specialties that the two fields are by no means so far apart. The topic of discussion is some theoretical work by T. D. Lee and G. C. Wick of Columbia University that suggests the existence, under certain conditions, of abnormal nuclear states—states that may manifest themselves as stable, superheavy nuclei and that would constitute a new form of matter. Some theoreticians are characterizing the work as "very speculative, but very interesting," while others, especially nuclear physicists, are less enthusiastic. There is no experimental evidence that what Lee and Wick propose is correct, but their theory does suggest some new lines of investigation for heavy ion accelerators of the type now being built.

That the research should have implications for nuclear physics is all the more remarkable since it began as an effort to unravel one of the major puzzles of high energy particle physics—the violation in some elementary particle interactions of fundamental symmetries in nature, such as the symmetry of the nuclear force. In recent years theoretical physicists have begun to explore the possibility that what causes these symmetry violations or breakdowns is not the particle interaction per se or the field theory used to describe the interaction but rather the properties of the vacuum, of empty space. "It's as though," one physicist put it, "the vacuum does not respect the symmetry of the strong nuclear force" which leads to spontaneous (as opposed to systematic) violations. The gauge theories that have been proposed by S. Weinberg of Harvard University and others to unify the weak nuclear and electromagnetic force, for example, also rely on the spontaneous character of symmetry breakdown.

Vacuum, it would seem, is not as absolute a concept as might first appear. The 19th century belief in a pervading aether through which light waves propagated was challenged by the Michelson-Morley experiment, and the resulting debate was nominally settled in favor of empty space with the acceptance of Einstein's theory of special relativity. But later developments, such as Dirac's quantum mechanical theory of the electron, showed that the vacuum has complicated properties, so that current theoretical attempts to ascribe still more complicated properties to the vacuum are not unprecedented. An additional motivation to consider such an approach is the growing conviction among many theoretical physicists that efforts to construct an acceptable model of nucleons (protons or neutrons) are not leading anywhere and that a new tack is necessary.

Properties of the Vacuum

Lee and Wick took on a somewhat different problem, one for which subnuclear particles do not enter in and for which results could therefore be more easily calculated, but one for which the properties of the vacuum are equally central. They considered field theory equations which describe what is believed to be one of the elements of the nuclear binding force. The equations are not new and have been a constituent of many elementary particle theories for a decade. Lee and Wick discovered, however, that these equations have a new and hitherto unsuspected solution corresponding to an abnormal (excited) state of the vacuum or to abnormal nuclear states. An excited vacuum state, according to Lee, is a region of space in which the properties differ from those of a normal vacuum. When the region of space is not a vacuum but a large nucleus, the theory predicts an abnormal form of nuclear matter in which the effective mass of nucleons is markedly reduced and from which a stable, superheavy nucleus may result. The conditions for forming this abnormal nuclear matter, according to Lee and Wick, are that the nucleus be large enough for surface effects to be unimportant and that the density of nucleons be increased beyond that of a normal nucleus.

Not everyone has been impressed by the novelty of the result or convinced that abnormal nuclear matter is very probable. While conceding that Lee and Wick have linked the notion of symmetry breakdown with what amounts to a new phase of nuclear matter, some physicists point out that the concept of a phase change is not new in nuclear physics. And several theorists believe the result contradicts what is empirically known about the nuclear force. Nonetheless, few physicists are discounting the possibility of abnormal nuclear matter entirely.

How these abnormal states might be produced, if they exist, and what their properties will turn out to be are open questions. Lee speculates that such states might consist of clumps of nuclear matter of 400 nucleons or more. The resulting superheavy nuclei would thus be quite different from the heavy nuclei that, on the basis of conventional nuclear theory, are expected to exist in the "island of stability" around atomic weight 300. Consequently, high energy collisions between heavy ions (such as lead colliding with lead) offer the best chance of producing abnormal nuclear matter, according to Lee.

Research with heavy ion accelerators is a rapidly expanding area of nuclear physics, but most of the current facilities are limited in the size of the ions that can be accelerated. The Bevalac facility now under development at the University of California at Berkeley, for example, is restricted to ions no heavier than krypton (atomic weight 83.8) with present equipment. With improved equipment—essentially a matter of a new liner to reduce the presence of stray atoms in the accelerator or a higher energy injector, according to Bevalac project leader Herman Grunder—it should be possible to accelerate much heavier ions.

Lee and Wick's proposals seem to have struck a core of interest among heavy ion experimenters. As a result, the whole area of very heavy ion collisions is likely to receive new attention, even if the theoretical speculations about abnormal nuclear matter turn out to be wrong. And in the meantime, the work of the Columbia physicists will surely encourage other theoreticians to continue to probe the properties of the vacuum in contexts such as nucleon models, neutron stars, and heavy nuclei.

—Allen L. Hammond