QUASIFISSION

A new phenomenon of nuclear matter?

by Dietrick E. Thomsen

Scientists opening a new branch of research often discover not quite what they confidently expected. Take the heavy-ion physicists for example. Heavy-ion accelerators were planned as a way to add a new dimension to the study of nuclear physics. In them accelerated atomic nuclei are driven against other nuclei in a target. What was expected was that projectile and target would fuse into a new nuclear species, and this product, if it were unstable—and it was mostly expected to be—would then fission into two daughter nuclei.

Study of this fusion and fission reaction would yield information about the structure and dynamics of nuclei that bombarding nuclei with single-particle probes cannot. Nuclei, heavy nuclei especially, are aggregates of large numbers of neutrons and protons, but their structure and dynamics cannot be determined by simply adding up individual contributions. The whole is different from the sum of its parts, and the way the whole reacts to another whole is different from the way it reacts to a single neutron or proton. One such difference is fusion. But there's where a funny thing happened. It's called quasifission.

A true fusion plus fission reaction requires that target and projectile nuclei lose their identities in a new composite nucleus, and that this nucleus then split into two more or less equal pieces. This happens, but not as often as expected. For heavy projectiles, say krypton, it seems in fact rather rare. Instead mostly quasifission occurs. It's called quasifission, but what seems incomplete about it is the fusion.

Instead of recording two more-or-less equal fission products different from the projectile and the target, the quasifission reactions yield products that are near the mass of the projectile or the target, yet their kinetic energy is what would be caused by the mutual electric repulsion of two normal fission products. Thus it seems that though target and projectile are apparently conjoined for a fleeting bit of time, true fusion does not occur: Either target and projectile do not completely lose their identities or the system somehow remembers the identities and reproduces them more or less.

It is not clear whether all quasifission events are due to the same mechanism or not, remark F. Hanappe and four colleagues working at the Institute of Nuclear Physics at Orsay, France, but it seems that they are related to the viscosity of nuclear matter and to the friction between the two nuclei that comes into play as they come against each other. There are three main questions to answer experimentally: How do the cross sections vary with the bombarding energy? What is the angular distribution of the fragments that come off? What happens for bombarding species with weights between argon and krypton, which have not yet been studied.

In the April 1 Physical Review Letters Hanappe and colleagues report an experiment designed to shed some light on the first two questions. It used krypton 84 atoms with 525 million electron-volts (MeV) energy to bombard a bismuth 209 target.

First off the Orsay experimenters found no events that could correspond to complete fusion. There was only evidence for quasifission and for various kinds of collision in which the projectile bounced off the target without uniting with it. The cross sections for quasifission were slightly higher for bombardment with 525-MeV krypton than they were for a previous experiment that used 500-MeV krypton. The distribution of angles at which the quasifission products came off is quite different from the angular distribution for the products of symmetric fission of truly fused nuclei.

Thus it appears that this and other experiments, which form the beginnings of a systematic study of quasifission, do separate it from both true fusion followed by fission and simple scattering. It seems to be a new phenomenon of nuclear matter. Say Hanappe and his associates: "More work—with more intense beams if possible—has to be done in order to get more detailed information on the features of the quasifission reactions induced by krypton ions. Nevertheless we hope the indications we have obtained will stimulate theoretical work which is now underway for understanding the reaction mechanism."

Indeed, stimulated by this and other new experimental results, theorists are taking a new look at the details of the behavior of nuclear matter. If the reader thinks that such concepts as "viscosity of nuclear matter" or "friction of nuclear matter on nuclear matter" represent new ways of looking at nuclear physics, let him think about "compression of nuclear matter," "sound in nuclear matter," or "shock waves in nuclear matter." All these are contained in a paper, also in the April 1 Physical Review Letters, by Werner Scheid, Hans Müller and Walter Greiner of the Institute for Theoretical Physics at the University of Frankfurt am Main in West Germany.

The basic finding of Scheid, Müller and Greiner is that nuclear matter is condensed during heavy-ion collisions. Sound (the kind physicists call "first" sound—solid-state physicists recognize other kinds) in nuclear matter is not an audible bang or clang but a particular kind of compression wave that travels through it. If the relative velocity of the projectile and target nuclei is greater than the velocity of first sound in nuclear matter, the three Frankfurt theorists deduce that nuclear shock waves will occur. These ought to compress the nuclear matter to a density from three to five times its equilibrium density.

Nuclear matter is thus in theory somewhat squooshy. The theoretical derivation also finds that as two nuclei collide, nuclear matter is squeezed off to the sides. Furthermore, the highly condensed nuclear matter becomes "overcritical" for the production of pionic matter. Pionic matter is what makes up pi mesons, particles different from but closely connected to the particles of the nucleus. Pi mesons are supposed to be the nuclear glue, the material embodiment of the forces that hold nuclei together.

It appears that much of the energy of the compressed nuclear matter in heavy-ion collisions may go to the production of pionic matter. If such a mixture of nuclear and pionic matter is stable, it may represent a new state for hadronic matter (the term that covers both nuclear and pionic matter). If the mixture is unstable, it may articulate itself into gangs or showers of individual pi mesons. In either case important things can be learned about the relationship of neutrons and protons to the force that holds them together, and ". . . fundamental properties of hadronic matter can eventually be tested," to use the words with which Scheid, Müller and Greiner close their report.

Or to put it another way, a new branch of nuclear physics is off and running. Heavy-ion accelerators look like better investments than some people have thought them to be. ☐