Brookhaven Chemists Find New Fusion Method

Firing clusters of heavy water molecules into a deuterium target produces fusion at a surprisingly high rate, but the practical applications are unclear

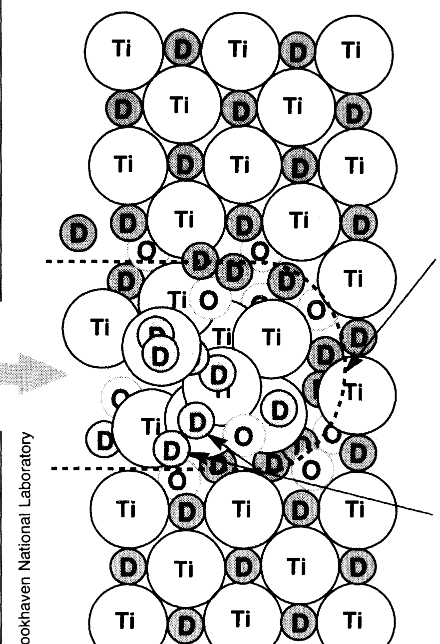
IT'S NOT COLD FUSION THIS TIME—it's actually rather hot—but once again a team of chemists has announced a new way to perform nuclear fusion. Robert Beuhler, Gerhart Friedlander, and Lewis Friedman at Brookhaven National Laboratory have created short-lived, microscopic "stars" by shooting tiny clusters of heavy water molecules into a target filled with deuterium atoms. The technique, they say, could lead to "a possible new path to fusion power."

Almost certainly, the Brookhaven scientists' work will evoke memories of the controversial "fusion in a jar" announcement earlier this year by electrochemists Stanley Pons and Martin Fleischmann. But the two pieces of work have little in common, aside from both teams being composed of chemists intruding in a field traditionally dominated by physicists and both claiming to have done fusion in a fundamentally new way. The Brookhaven method seems less likely to generate controversy than its highly publicized predecessor and more likely to generate practical fusion power sometime in the future.

The Brookhaven technique, described in the 18 September *Physical Review Letters*, depends on the ability to form clusters of dozens to hundreds of heavy water molecules and accelerate them at a target, a skill the team has developed over 15 years. (In heavy water, the two hydrogen atoms are replaced by deuterium, the isotope of hydrogen with one proton and one neutron.) When the clusters strike the target, which also contains deuterium, the heat and compression at the point of impact cause pairs of deuterium atoms to fuse, creating atoms of helium-4 and releasing energy. The helium-4 atoms quickly break down into either helium-3 and a neutron or tritium (the isotope of hydrogen with one proton and two neutrons) and a proton.

The team used a silicon solid-state detector to spot these by-products as they flew out of the target and to measure their energy. Although neutrons are invisible to the detector because they have no charge, the other three particles appeared at their expected energies. "A 3-MeV proton, a 1-MeV triton, and a slightly lower energy helium-3 together are conclusive evidence that fusion is taking place," Friedman said.

The target used for the experiments was titanium deuteride, but Friedlander said the team has also used zirconium deuteride and polydeuteroethylene. The clusters, which had from 25 to 1300 heavy water molecules, were ionized so that they had a positive charge and thus could be put in motion by an electrostatic accelerator.



Point of impact. *After a cluster strikes the titanium deuteride (TiD) target, pairs of deuterium atoms fuse.*

A big advantage of using this cluster-impact method for fusion, Friedman said, is that the clusters allow a more efficient use of the energy needed to initiate the fusion reaction. If two deuterium atoms are brought close enough together, they naturally fuse into helium-4 with a release of energy, but the problem facing all fusion methods is that deuterium atoms repel each other, so a certain amount of energy must be expended to bring them together. In traditional approaches, such as inertial confinement fusion or magnetic confinement fusion, the energy applied to the deuterium atoms first goes into the electrons circling the atoms, Friedman explains, but in the Brookhaven method the energy is applied directly to moving the atoms toward the target.

Likening the nucleus of the deuterium atom to a medicine ball and the electrons to peas, Friedman said the traditional fusion methods are like trying to get the medicine ball moving by bouncing peas off of it. "We're putting the energy directly and efficiently into the medicine ball," he said.

A second advantage of the cluster method is that it concentrates a large number of heavy water molecules into a small volume of impact, Friedman said. Other researchers have shot individual deuterium ions into a deuterium target to bring pairs of deuterium atoms close enough to fuse, but the fusion rate is very low. The problem with this method is that a single atom driven into a deuterium target behaves much like a nail driven into a piece of wood—it goes deep, pushing its way through and dissipating its energy along an extended path. The single atoms are unlikely to collide directly with a deuterium atom in the target with enough energy to fuse.

But slamming a cluster into the target is more like smashing a hammer into wood—the force of the impact is concentrated in a small volume near the surface. When such a cluster strikes the target, the impact volume is compressed and heated tremendously, creating the conditions necessary for fusion.

The clusters are created by first bubbling helium gas through heavy water to create a helium/heavy water vapor, Beuhler said, then ionizing some of the heavy water molecules by firing an electric arc through the vapor, and finally spraying the vapor through a tiny nozzle into a vacuum chamber. As the spray comes through the nozzle, the ions serve as seeds around which the clusters grow. By controlling the vapor pressure, the nozzle size, and the arc conditions, Beuhler said, the team can determine the size of the clusters to within 10%.

The clusters were accelerated to energies between 200 and 325 keV, which meant they were traveling at speeds of about 100 kilometers per second when they hit the target. The apparatus created about 10 billion cluster impacts each second, resulting in several fusions each second, Beuhler said. If the same number of deuterium atoms were shot into the target singly instead of in clusters, the result would be maybe one fusion per year, Friedlander estimated.

Scaling the small amount of fusion up to the point where it can be used for commercial power is still very speculative. Friedlander said the amount of fusion will have to be increased by a factor of 1 billion just to reach the breakeven point. But just to be safe, Brookhaven has filed a patent application on the process.

The next step in the team's work, Friedlander said, will be to increase the energy of the clusters up to 5 MeV. The fusion rate increased by about a factor of 10 when the energy of the clusters was increased from 225 keV to 300 keV, so the scientists are eager to see what happens at much higher energies. And with the higher energies, they will be able to accelerate larger clusters. At 300 keV, they found that the fusion rate dropped off as the cluster size was increased to more than 600 heavy water molecules. If the cluster is too large, Friedman said, each individual deuterium has too little energy to fuse when it collides with other deuterium atoms. Right now, Beuhler said, limitations in the equipment prevent making clusters much bigger than 3000 molecules, but there are no fundamental limits to how big they can make the clusters.

Since the paper was written, Friedlander said, the team has increased the fusion rate by using a polydeuteroethylene target that has a greater density of deuterium than titanium deuteride and has a greater stopping power so that the cluster's impact is concentrated in a smaller volume. With the increased rate, the team has also been able to detect fusion when it uses clusters of light water molecules on a deuterium target, although at rates only about one-twentieth of the heavy water rates.

Strangely enough, the Brookhaven team did not start out looking for fusion. Instead, the new fusion technique is a somewhat serendipitous result of 15 years of basic research studying what happens when a cluster of atoms hits the surface of a material. "We knew that these clusters generated assemblies of very energetic atoms [on the impact surface]," Friedman said, "and we wanted to know what temperature exists in the assembly after the collision." The original idea of looking for fusion came about as a way to determine just how hot the area of impact got, he said.

If the discovery leads to practical fusion power, the credit should go to funding basic research, Friedman said. "The chemical sciences people at DOE have been willing to support a few people who are way out in left field for a long time," he said, including himself and his colleagues among those out in left field. ■ ROBERT POOL

Materials Research for the 1990s

The United States must pay increasing attention to its materials science and engineering efforts if the nation's industry is to remain competitive with the rest of the world states a report released 26 September by the National Research Council. In particular, the report says the country must improve its abilities to synthesize and fabricate such materials as ceramics, plastics, and metals.

The 279-page study, "Materials Science and Engineering for the 1990s," differs from other state-of-science reports in that it was written from the point of view of American business, said Praveen Chaudhuri of International Business Machines, cochairman of the committee that prepared the study. "We asked eight industries about their wish lists for materials," he said, and these industries—aerospace, automotive, biomaterials, chemical, electronics, energy, metals, and telecommunications—all had similar concerns. They agreed that advanced materials are vital to their economic health, he said, and they pointed to inadequacies in synthesizing and processing materials as a major obstacle facing them.

James Economy, a materials scientist at the University of Illinois and a contributor to the report, offered one example of how a deficiency in synthesis and processing can hold back productivity. Xydar is a liquid crystal polymer made by Amoco that can be formed into a plastic as strong as steel, half the weight of aluminum, and able to withstand temperatures up to 350°C. It would seem ideal to replace aluminum in certain automobile engine parts. However, when it is melted, the way in which it flows into a mold makes the molecules on the surface of the mold more oriented than those in the center. This in turn, Economy said, causes the outside and the inside of the finished part to have different thermal expansion coefficients, which can lead to stress and cracking when the part is heated and cooled. "We need new concepts in processing that will permit us to use these materials," Economy said. "But very little work is being done in these directions."

Shortcomings in synthesis and processing are hurting even such an old and established industry as the steel business, said Merton Flemings of the Massachusetts Institute of Technology, the other cochairman of the panel. "We have lost a great deal of business nationally and internationally" in the steel industry, he said, because "this country has fallen seriously behind its competitors in processing science, in new process development, and in applications of those processes." U.S. companies lag foreign concerns in a range of steel processing methods, from continuous casting to innovative methods of sheet rolling and surface treatments, he said.

One of the major contributions of the report, Chaudhuri said, is that it offers a unified view of materials science and engineering that has not been present in previous studies. Although the field is quite diverse and difficult to define, it can be thought of as consisting of four areas of concern, the report says. In addition to synthesis and processing, there are structure and composition, properties, and performance. Every practitioner asks questions in at least one of these areas, and, since the four are intimately connected, most researchers end up working in several at once.

It wasn't always this way, Flemings noted, although in a sense materials science can be traced back 12,000 years or so, to when the first person baked clay to make pottery. "One hundred years ago, we couldn't have looked at this field with structure and composition included," Flemings said, because no one understood the atomic structure of matter. Learning about atoms and molecules gave a powerful tool to materials science, but "the field went too far," he said. "We began to focus so much on structure and its relation to properties that we didn't pay enough attention to the area of synthesis and processing."

The report offers a number of recommendations to strengthen materials science and engineering in the United States. Noting that federal support for materials science research fell by 11% from 1976 to 1987 and the nondefense portion fell 23%, it says funding should be restored to its level in the past. Included in this funding should be support for new instruments for analysis, synthesis, and processing of materials, the report says. It advises colleges and universities to develop integrated programs in materials science that, in particular, emphasize the importance of synthesis and processing. And since materials science is such a diverse and often fragmented field, government, industry, and universities should all work to unify it as much as possible into a single science. ■ ROBERT POOL