Lab of the Rising Microsuns

After fielding a round of criticism, Brookhaven chemists are more convinced than ever that they are blazing a new path to fusion in impacting clusters of heavy water

IN SEPTEMBER 1989, MOST OF THE SCIENTIFIC community was in no mood to hear from yet another group of chemists claiming to have found a radically new route to nuclear fusion. The cold fusion drama had begun just 6 months earlier, and no one was eager for another controversial, ad hominem, scientific brawl. Yet it was in that troublesome context, and with considerable unease, that chemists Robert Beuhler and Lewis Friedman and nuclear chemist Gerhart Friedlander, all of Brookhaven National Laboratory, went public with a discovery they called "cluster impact fusion."

Unlike the cold fusion serial, which unfolded like a soap opera on the pages of newspapers and popular magazines, cluster impact fusion made its debut the old-fashioned way, on the pages of the austere, peer-reviewed journal *Physical Review Letters*. Even so, the claim that nuclear fusion was somehow being sparked when nanometer-sized clusters of molecules slammed into a target strained credibility for many physicists (see *Science,* 29 September 1989, p. 1448). But now, after 2 years of further experiments by the Brookhaven workers and a few other laboratories, the case for cluster impact fusion has strengthened, by most assessments.

If continuing research supports the Brookhaven results, the workers will be able to lay claim to a new means of pumping atoms to fusion-triggering levels of energy. So far, fusion research has been the domain of huge lasers and massive magnets, needed to generate the extreme conditions of temperature and pressure that trigger fusion. But the Brookhaven results suggest that equivalent conditions can be created when a small accelerator drives clusters of a few hundred molecules into targets loaded with fusion fuel. Just how the modest energies to which the clusters are boosted could get funneled into a few atoms in the collision zone, spurring them to fuse, is a question that is captivating and perplexing some theorists. Already a few optimists are saying that the phenomenon—if it's real—may open a back door to fusion power. But since the detailed physics of the phenomenon remain a mystery, no one can speculate confidently about what would be needed to scale the reactions up to useful levels.

Beuhler and Friedman first stumbled onto the fusion trail by accident, in the course of basic studies of what happens when clusters of atoms slam into materials. To make the clusters, they allowed water-spiked helium vapor to expand rapidly into a vacuum. There an electric discharge ionized some of the water molecules, which served as seeds around which water clusters accreted. The charged clusters, containing anywhere from tens of water molecules to a few thousand, were then fed into an accelerator that propelled them into the targets at great speeds.

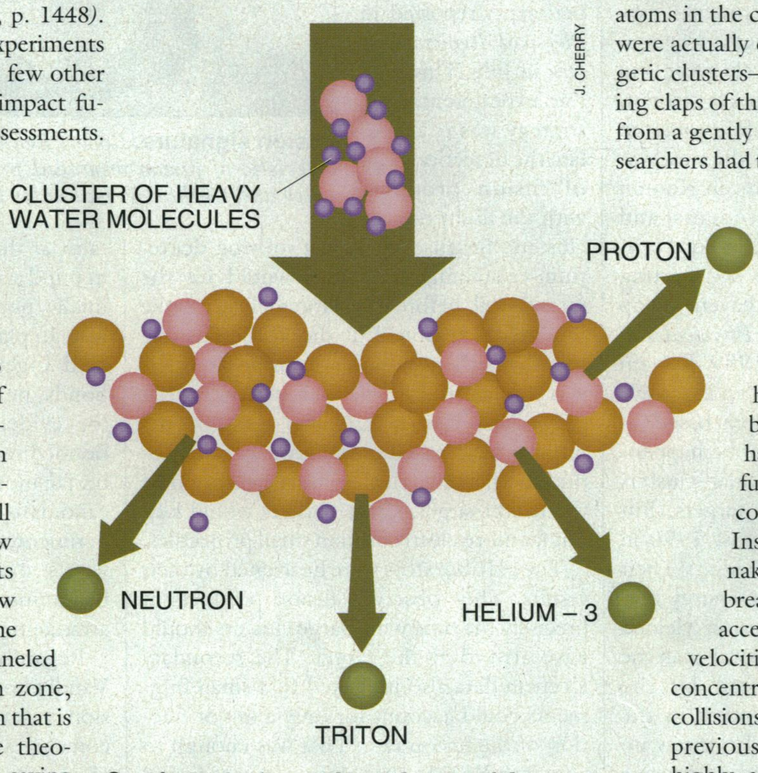
When the Brookhaven duo examined the targets with an electron microscope, they spied a rugged microscape of holes and craters. "We began to realize that the actual amount of energy deposited on the target was highly concentrated," Friedman recalls. Indeed, it appeared so concentrated that the researchers began to think of the possibility of harnessing it to trigger fusion.

At about that point, Friedman and Beuhler invited Friedlander onto the team, in part for his particle detection expertise. They began using targets of metal loaded with deuterium—a heavy isotope of hydrogen used in fusion experiments. For projectiles they turned to clusters made of heavy water, in which deuterium atoms take the place of the hydrogen atoms in normal water. Thus equipped, the group soon began detecting the signatures of fusion between deuterium atoms: protons carrying 3 mega-electron volts (MeV) of energy, tritons (nuclei made up of a proton with two neutrons) carrying a third as much energy, and helium-3. The signature was surprisingly bold, indicating that fusion was taking place in one or a few out of every 100 million collisions.

That rate may sound paltry, but it is astronomically higher—about 10^{25} times—than the researchers would have expected from the average energy of the deuterium atoms in the clusters. If the fusion products were actually coming from the mildly energetic clusters—a phenomenon akin to hearing claps of thunder bursting here and there from a gently applauding audience—the researchers had to assume that, by some exotic means, the energy had been focused into just a few deuterium atoms in the cluster and target. "Our initial reaction was that this just couldn't be," Friedman recalls.

That incredulity led him and his colleagues to consider the bubble-bursting possibility that has dogged them ever since: The fusion products might not be coming from the clusters at all. Instead, small fragments or even naked deuterium nuclei might be breaking off the clusters during acceleration, reaching much higher velocities, and delivering a far more concentrated cargo of energy into the collisions. Indeed, other researchers had previously observed fusion in such highly accelerated nuclei—though at unpromisingly low rates.

The Brookhaven team quickly be-



Crash test. *A speeding cluster of heavy water molecules smashes into a deuterium-laden target, spewing out fusion products.*

came convinced that this fast-fragment idea could not explain their results, however, and they argued against it even in the *Physical Review Letters* paper reporting their first observations. For one thing, the observed fusion yield rose more steeply as the clusters were boosted to higher energies than it would have if fragments were responsible. What's more, the workers had noticed that the fusion rate plummeted when the clusters contained fewer than 25 or more than 1300 water molecules. The observation of fusion only in a specific, albeit broad, range of cluster sizes suggested that some phenomenon involving entire clusters was triggering fusion: If fragments were responsible, cluster size shouldn't matter.

Soon after publication, the group tried to clinch their case by running permutations of the original experiment. In one test, they exchanged their heavy water clusters for regular, light water—which doesn't contain deuterium—but kept using deuterium-rich targets. The detectors still recorded signs of fusion, though at only 5% of the earlier rate. Since the light water clusters couldn't be shedding deuterium-containing fragments, the researchers argued, the cluster impacts had to be responsible. "We have thousands of experiments now confirming that this is real," Friedlander says.

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But his group was not entirely successful in putting the fast-fragment specter to rest, in part because theorists couldn't come up with any other way to explain the observations. Theoretical physicist Steven Koonin and a team of graduate students and postdocs at the California Institute of Technology certainly tried to do so, starting immediately after the Brookhaven group sent them a preprint of their *Physical Review Letters* paper in August 1989. Koonin and his colleagues carried out an extensive set of supercomputer calculations based on different models of what might be happening when heavy water molecular clusters smash into deuterium-loaded targets. But their results, published in August 1990 in *Physical Review A*, were sobering: Their best scenarios for focusing the energy of a cluster in order to trigger fusion yielded rates at least millions of times lower than the experimental values measured by the Brookhaven team. Other theorists in the United States and elsewhere also threw up their hands at finding any focusing process that could explain the Brookhaven findings.

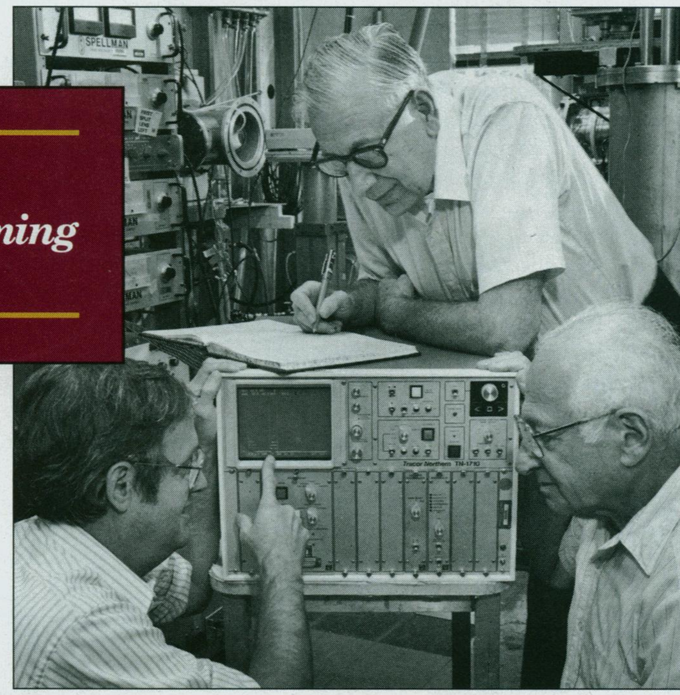
And while the theorists were at a loss, some experimentalists appeared to be having trouble confirming the results. The Brookhaven group continued to harvest data that bolstered their position, and Y. Bae (a member of the Brookhaven team since July) and his colleagues at SRI International in Menlo Park reproduced many of the initial findings. But a group of French scientists in Lyons, using clusters made of deuterium atoms rather than heavy water molecules, detected no signs of fusion at all.

Koonin, for one, saw no reason to grant that the Brookhaven group had stumbled on a mysterious new phenomenon. "We attributed their results to contamination [fragments] in the cluster beam," Koonin says. Another fusion dream dashed, it seemed.

But the Brookhaven crew, enlisting the help of several other colleagues, was ready to up the ante with experiments reported in *Physical Review Letters* in July. This time the experimentalists' strategy was to correlate the detection time of fusion products with the flight time of clusters. Because small, fast-moving deuterium-containing fragments would hit the target well before the larger clusters, the researchers reasoned, it should be possible to tell whether the pulse of fusion products was coming from fragments or clusters. The researchers also planned to monitor the number of so-called secondary electrons produced when the clusters hit detectors near the fusion target. Large clusters would kick out far more electrons than small projectiles.

The collaborators were heartened by their results. They observed fusion products at precisely the time when large clusters should have arrived at the target. The secondary electron data also indicated that small fragments could account for only a minor fraction of the fusion rate. That was enough to convince Koonin that cluster impact fusion might indeed be real. "The experiment pretty much showed that contamination is not an issue," he admits.

Not so for Tom Tombrello, an experimentalist at Caltech who stresses the inconsistencies in the experimental record. He still places his bets on some kind of "subtle dirt" as the source of the fusion signal. Even if Brookhaven's latest round of experiments have ruled out fragments produced early in the acceleration process as the fusion source, he says, the signal might still be coming from fragments produced at the moment of collision. Splashed backward into the accelerator, the fragments might then greatly reaccelerate into fusion-causing collisions.



BROOKHAVEN NATIONAL LAB

Fusion signature. *Robert Beuhler* (left) *points to a signal characteristic of fusion-produced protons as Lewis Friedman takes notes and Gerhart Friedlander looks on.*

But Robert Vandenbosch, an experimentalist at the University of Washington, has in mind an experiment that he thinks might finally put the fast-fragment objection to rest. In place of fragile heavy water clusters, held together only by tenuous hydrogen bonds, he and his colleagues plan to search for evidence of fusion from covalently bonded molecular structures, which should be far more resistant to breaking up. As a candidate projectile, the Washington experimenters already have their eyes on this year's darling of the chemistry world, buckminsterfullerene, a covalently linked arrangement of 60 carbon atoms.

Regardless of the experimental loose ends, Vandenbosch and other cluster impact fusion researchers are already straining to come up with a mechanism for the phenomenon. One conjecture, favored by Vandenbosch, relies on rapid and repeated collisions between deuterium atoms and the heavier atoms of oxygen in the impacting cluster. During the impact of a cluster, Vandenbosch suggests, deuterium atoms might backscatter only to be hit like a baseball by relatively massive oxygen atoms still careening forward. Several whaps like that might boost the deuterium's energy enough to cause fusion with another nearby deuterium nucleus, he adds. That mechanism, Friedman notes, could explain why the all-deuterium clusters in the Lyons experiments, which lacked heavier atoms such as oxygen, yielded no evidence of fusion.

Bae, Yeong Kim of Purdue University, and colleagues at SRI and the Electric Power Research Institute have developed a different scenario, which relies on shock waves to concentrate the collision's energy. They propose that the shock waves heat nanometer-sized regions of the target to temperatures of stellar interiors—hundreds of millions of degrees. Fusion would occur in the tiny compressed pockets of plasma that result, Kim says. "It's like having lots of tiny microsuns," he muses.

Beuhler, Friedman, and Friedlander conjure up another analogy, proposing that the process might be more like the one at work in an ore-blasting explosive charge or an armor-piercing shell. Such "shaped charges" can channel energy so that particles emerge from the explosions in jets traveling many times faster than the detonation wave. Likewise, the tiny cavities chiseled into the target by the impacting clusters might serve to confine atoms under huge compressions while amplifying their energies to fusion-triggering levels.

The Brookhaven trio and their growing ranks of allies freely admit that they're speculating, but they think it won't be long before experiment catches up with them. The ingredients of a bona fide area of fusion research are now in place, after all. Experiments continue at Brookhaven. More are under way, or in the works, at other labs in the United States, France, the Netherlands, and perhaps Japan. Theorists are theorizing. And skeptics are keeping everyone on their toes.

At the moment, most people in the field are pursuing little more than the thrill of basic scientific discovery. But press them a little, and they will admit that somewhere in the back of their minds lurks the possibility that their research could someday harbor payoff to people who have never heard of accelerators, deuterium, and fusion.

In that vein, Friedlander, Beuhler, and Friedman closed their first *Physical Review Letters* paper with a remark as gingerly articulated as it was bold: "The high fusion rates and the sensitivity to projectile energy suggest the possibility of a possible new path to fusion power." ■ IVAN AMATO

Genetic Survey Gains Momentum

Last summer population geneticist Luca Cavalli-Sforza of Stanford University, molecular anthropologist Allan Wilson of the University of California, Berkeley, and others issued a call to action: an urgent plea for help—and money—to collect DNA samples from aboriginal populations around the world before those groups vanish. Now, just a few months later, even the proponents of this bold new plan seem amazed at the response.

As word gets out, numerous anthropologists are offering to help collect samples from the isolated tribes they study. And in an unexpected twist, several federal agencies have approached the scientists—unsolicited—to see how they can help. Indeed, the agencies are already talking about picking up at least part of the tab, which could run to $20 million or more over the next 5 years.

The basic plan is to collect blood samples from members of at least 100 indigenous populations, such as the Bushmen of southern Africa and the Hill People of New Guinea. Such populations, isolated for hundreds or thousands of years, contain in their genes clues to human evolution, migration, and diversity. But the opportunity to analyze those genes is rapidly vanishing as society encroaches upon these once-distinct peoples. Once the samples are collected—probably from about 50 individuals in each group—the researchers would establish permanent cell lines to preserve the DNA in perpetuity, allowing it to be studied even after the tribes have disappeared (*Science*, 21 June, p. 1614).

Walter Bodmer, president of the Human Genome Organization (HUGO), was keen on the idea as soon as he learned of it, setting up a committee headed by Cavalli-Sforza and Marcello Siniscalco of the University of Sassari, Italy, to firm up the scientific strategy and the budget. The group was dealt a tragic blow last July, when Wilson died of leukemia following a bone marrow transplant. Shortly thereafter, Cavalli-Sforza was taken ill. As he recuperates, the dispersed committee has been doing its best to cobble together a proposal for both national and international funding agencies.

But with the proposal still incomplete, Cavalli-Sforza received a letter from Mark Weiss, who runs the physical anthropology program at the National Science Foundation (NSF). Weiss, who had read about the plan in *Science,* said that although his own research budget is too small to make much of a dent in the total cost, he thought his and other NSF programs could provide at least partial support. In late September Weiss brought together representatives from other potential funding sources as well: the genome projects at both the National Institutes of Health and the Department of Energy, and the National Institute of General Medical Sciences. "Everyone is excited," says Weiss. "No one said in stone that they would fund the project, but the general consensus is we are looking forward to receiving a formal proposal."

In response, Cavalli-Sforza and the HUGO committee are furiously revising and fleshing out their proposal into what they call a "grand vision" of the project. As they do so, both scope and cost are growing. The group is now talking about collecting DNA from 200 to 500 populations at a cost of several million dollars a year, double what they were thinking just last summer.

Before they start sampling, though, they'll have to resolve some strategic questions. Cavalli-Sforza and Wilson were deeply divided on the sampling strategy, with Cavalli-Sforza advocating sampling populations that have been isolated in geographic pockets, and Wilson proposing instead setting up a grid and sampling every 50 or 100 miles (*Science,* 21 June, p. 1615). "What is the best way to sample the world? Allan and I had different views," says Cavalli-Sforza. "I have been thinking a lot about a compromise, but I want to hear opinions of theoreticians."

He plans to bring together statisticians, mathematicians, geneticists, and anthropologists to tackle that issue in a workshop, perhaps as early as this winter. A second workshop will bring in physical and cultural anthropologists to help identify which populations to study, and which ones should come first. That's an urgent question, because for some groups, it is almost too late already.

Weiss thinks funding for those workshops is likely to be forthcoming from U.S. agencies. If enough money for the rest of the project materializes from U.S. and international sources, Cavalli-Sforza and his colleagues think they can collect all the samples within 2 to 3 years and establish the cell lines within 5. Then would begin the long-term analysis to tease out the DNA's secrets. ■ LESLIE ROBERTS