PHYSICS

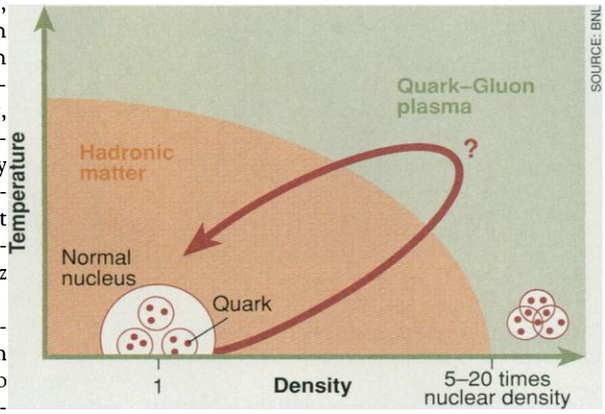
Has CERN Made the Stuff of The Newborn Universe?

To say that quark-gluon plasma is rare is a gross understatement: This state of matter was last seen when the universe was 10 microseconds old. That was the last time the place was hot enough and dense enough to allow the primary constituents of ordinary matter, quarks and gluons, to exist outside the more complex particles, such as protons and neutrons, in which they are irrevocably bundled today. For the past 10 years, however, physicists have been trying to recreate a quark-gluon plasma in their particle accelerators. And this past May, physicists at CERN, the European particle physics laboratory outside Geneva, reported evidence suggesting that they might indeed have done it. The possibility has set the community abuzz over the past few months.

No one, least of all the physicists involved, is willing to claim anything definitive. "There's no unambiguous signal, no smoking gun that says, 'This is it. We've found the quark-gluon plasma,' " says physicist Sam Aronson of Brookhaven National Laboratory. But given the clues the experimenters have spotted in debris from high-energy lead nuclei slamming into a target, says Aronson, "it's getting harder and harder to believe that everything they're seeing is just due to conventional physics processes." Brookhaven theorist Rob Pisarski adds, "There is definitely something new going on" in the CERN experiments.

If it is a quark-gluon plasma, physicists will have their first samples of the stuff of the newborn universe. They will also have grounds for optimism that future experiments at more powerful accelerators will be able to produce it in quantity, allowing them to study its behavior in detail. How it forms and decays should offer physicists a glimpse of the dynamics of the early universe and a test bed for their understanding of the strong force, carried by gluons, which ordinarily confines quarks in protons and neutrons, forbidding them from venturing forth on their own.

In the early 1980s, theoretical physicists churned through the tortuous equations of quantum chromodynamics, the theory that describes the strong force, to find out what would be needed to overcome this constraint. The calculations suggested that if nuclei could be slammed together at energies of at least 150 billion to 200 billion electron volts or squeezed together to densities 10^{20} times greater than that of normal matter, the neutrons and protons would in effect burst, spilling their quarks and gluons out into the world at large. The process, called deconfinement, is analogous to what happens in an ordinary plasma when electrons are stripped from atoms, leaving a gas of free electrons and free nuclei. But a quark-gluon plasma would be considerably harder to make and recognize.



Visit to the primordial universe? Nuclear collisions at CERN may have squeezed matter to densities high enough to create a quark-gluon plasma.

The calculations implied that accelerators such as the Super Proton Synchrotron (SPS) at CERN could create the necessary temperatures and densities by firing heavy ions such as sulfur or lead into stationary targets. But any quark-gluon plasma created would last for all of 10^{-23} seconds. Then the plasma would cool and expand sufficiently for the quarks and gluons to "freeze out" and bundle back into garden-variety subatomic particles. In 1986, however, theorists Helmut Satz of CERN and the University of Bielefeld in Germany and Tetsuo Matsui, now at the Yukawa Institute in Kyoto, Japan, pointed out that at the energies of existing accelerators, the fleeting quark-gluon plasma would leave behind at least one observable clue.

The key is a particle known as the J/psi. J/psi's, which are composed of a heavy quark known as a charm quark and its antimatter twin, materialize in the debris of high-energy collisions. But in the inferno of a quark-gluon plasma, Satz and Matsui noted, any J/psi's from the initial collision would melt. "Then these two heavy quarks out of which it was made would fly apart, and when the plasma cools off, the two quarks would be so far apart they couldn't bind with each other anymore," says Satz. The same thing would happen to particles made of lighter quarks, but because these quarks are common, the particles could easily re-form.

"The moral of the story is that if there was a plasma, the J/psi should disappear," says Satz. To search for a quark-gluon plasma, physicists only had to look for the sudden disappearance of J/psi particles in collisions of increasing violence. Of course, as J/psi's would only be created in one out of every 100,000 or so collisions, says Satz, "this makes it a tricky experiment."

In the mid-1980s CERN built a detector known as NA50 to look for the signatures of J/psi's from heavy nuclei colliding in the laboratory's SPS accelerator. Experiments started in 1986, says NA50 physicist Claudie Gerschel of the Institute for Nuclear Physics in Orsay, France, using lighter nuclei as projectiles, from single protons all the way up to sulfur, which contains 16 protons and 16 neutrons. With these lighter nuclei, the NA50 physicists were able to establish how many J/psi's they would expect to see from collisions that don't form a quark-gluon plasma, which would give them a point of comparison for identifying J/psi suppression in more violent collisions.

In 1994, CERN upgraded the SPS to allow it to use lead nuclei as projectiles, and in the late fall of 1995, NA50 and a half-dozen other experiments on the SPS collected 5 weeks of data on lead nuclei colliding with fixed targets. Last May at the 1996 Quark Matter Conference in Heidelberg, Germany, the NA50 physicists announced their results: They had seen a dramatic reduction in J/psi's in high-energy collisions. And the more energetic the collisions, says Gerschel, the more startling was the absence of J/psi's. "We don't claim we have seen a quark-gluon plasma," she says. "What we say is that we observe in lead-lead collisions a very different behavior from what we had with protons, oxygen, and sulfur."

Gerschel's cautious phrasing reflects the possibility that something more mundane may be going on. The leading candidate, says Aronson, "goes by the buzzword 'co-movers.' " Back in 1990 Brookhaven's Sean Gavin and Ramona Vogt of Lawrence Berkeley National Laboratory predicted that violent lead-lead collisions would also create an explosion of particles, in particular pions, that would ricochet through the collision site, destroying J/psi's as they went. With another year's worth of data, the two competing explanations for J/psi suppression should be distinguishable based on how quickly it sets in. As Satz says, the distinguishing feature of the phase transition to a quark-gluon plasma—or any phase transition, for that matter—is that it happens suddenly. "Water is water

between 0 and 99 degrees," he says, "and then all of a sudden at 100 degrees it evaporates." With co-movers, on the other hand, the disappearance of J/psi's with increasing collision energy should be gradual.

In the meantime, however, there are several other hints that a phase transition might be taking place in the CERN heavy-ion collisions. Theorists predict that as matter gets hotter and quarks move toward deconfinement, they should also appear to get lighter. In protons, for instance, quarks appear to have a mass of about 300 million electron volts. "This is not the bare quark mass," Satz says. "It arises from the quark binding itself with gluons all around it. In a hot enough quark-gluon plasma, the quark shakes off all the gluons and gets its naked mass back." At the Heidelberg meeting, physicists from a CERN experiment called CERES reported seeing an excess of low-mass particles in lead-gold collisions, confirming hints from both CERES and another CERN experiment known as HELIOS 3. The data, however, are far from strong enough to rule out more mundane explanations for the excess.

The ambiguity should end when Brookhaven fires up its new Relativistic Heavy-Ion Collider (RHIC) in 1999. If the CERN results really are the first evidence of a quark-gluon plasma, then RHIC, colliding nuclei at higher energies, should have little trouble establishing an iron-clad case. As Pisarski puts it, "I would assume a quark-gluon plasma has been produced for short periods of time and small volumes at CERN. You just can't pick it out definitively. Once we go to RHIC ... it should all be much clearer."

–Gary Taubes

BIOCHEMISTRY

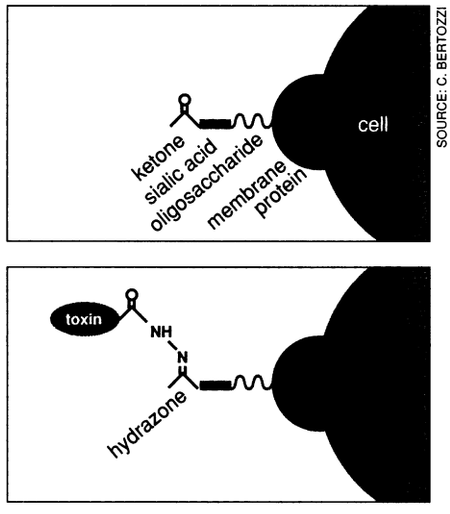
Making Cells Selectively Sticky

Living cells are coated with sticky sugars, and a group of researchers at the University of California, Berkeley, has now found a way to alter what those sugars will stick to. The sugar molecules—long chains of them called oligosaccharides—are attached to the ends of the protein receptors and other structures on the cell surface. Investigators have long pictured turning these sugars into the molecular equivalent of Velcro, by modifying them to bind specific molecular partners, such as drugs aimed at specific cells. Past sugar-altering techniques have either damaged the cells or been viable only in the test tube. But at a meeting of the American Chemical Society in Orlando, Florida, 2 weeks ago, the Berkeley group, led by organic chemist Carolyn Bertozzi, reported a scheme for harnessing cells' own machinery to alter their sugars.

"It looks like very nice work," says Steve Withers, a carbohydrate chemist at the University of British Columbia in Vancouver. If the Berkeley researchers can find a way to alter the sugars on the surface of cancer cells while leaving normal tissue untouched, for example, they might be able to turn anticancer toxins into smart weapons, says Withers. Bertozzi says that the altered sugars could also be used for fastening cells to artificial substrates to create engineered tissues.

The strategy isn't new. In the late 1970s, for instance, researchers led by Carl Gahmberg at the University of Helsinki in Finland began showing that they could oxidize cell-surface sugar groups to make compounds known as aldehydes, which could selectively interact with amines and other compounds. But the oxidants used to alter the sugars often damaged the cells they modified. Another approach has relied on specialized enzymes capable of transforming specific cell-surface sugars. "But that approach doesn't work for modifying cells in vivo," as there is no way to deliver the sugar-transforming enzymes to cells in the body, says Bertozzi.

In search of a scheme that might have a better chance at making the jump from the test tube to the clinic, Bertozzi and her colleagues Lara Mahal and Kevin Yarema looked for a means of co-opting cells' own biochemical machinery to alter their surface sugars. Enzymes in cellular organelles called the endoplasmic reticulum and the Golgi apparatus typically attach these sugars to newly synthesized protein receptors just before the proteins make their way to the cell membrane. The last chemical group on each chain of sugars is often a sugar called sialic acid, and it was this outermost sugar that the Berkeley researchers targeted for modification.



SOURCE: C. BERTOZZI

Hook and eye. A ketone group added to a cell-surface protein could provide a target for toxins or other drugs bearing a matching chemical group.

The team decided to alter these terminal sialic acids by attaching small chemical groups called ketones to them. Ketones are abundant within cells but virtually absent from cell surfaces, notes Bertozzi. So the researchers hoped that ketone-tipped sialic acids could act as a target for compounds designed to interact only with ketones.

Carrying out this plan turned out to be relatively simple. Cells normally modify a precursor sugar called N-acetylmannosamine to create the sialic acid, then attach it to the oligosaccharides decorating a protein receptor. To hijack the process, the researchers simply attached ketones to the mannosamine, creating a compound known as ManLev. They then fed the ManLev to cancerous lymphocytes in culture and waited to see if the cells would convert it to ketone-modified sialic acid and attach the acid to cell surfaces. The scheme worked. Bertozzi and her colleagues found that the ketones were expressed on cell-surface proteins, right at the end of the sugar complexes.

In addition, Bertozzi and her colleagues showed that the modified sugars can serve as hooks for other compounds—the other part of the molecular Velcro. Researchers have long known that a small chemical group known as a hydrazide selectively reacts with ketones. To see if they could exploit this affinity, the Berkeley group indirectly linked fluorescent dyes to the hydrazides, then added the combination to ketone-bearing cells. The dye-bound hydrazides promptly bound to the modified cells. The researchers are now trying to link toxins to hydrazides to see if these compounds will home in on ketone-bearing cancer cells. Because many kinds of cancer cells overexpress sialic acid—and would therefore bear more ketones—the researchers hope that hydrazide-linked drugs will selectively target cancer cells.

In addition to guiding cancer drugs to their targets, Bertozzi believes the ketone-hydrazide linkage could prove useful for anchoring cells to artificial matrixes. That would give researchers working to design complex tissues such as an artificial liver a new tool for arranging different cell types in specific regions of a scaffold. "It's a creative approach," says Joseph Gardella, a tissue engineering expert at the University of Buffalo in New York, who like most tissue engineers tries to come up with scaffold materials that normal cells will stick to. The new approach, by contrast, could anchor cells to a broader set of scaffolds. If the scheme works, sticky sugars could give researchers a whole new handle on cells.

–Robert F. Service