PHYSICS

Shattered Glass

SEEKING THE DENSEST MATTER: THE COLOR GLASS CONDENSATE **BY DAVID APPELL**

Physicists investigating heavy-particle collisions believe they are on the track of a universal form of matter, one common to very high energy particles ranging from protons to heavy nuclei such as uranium. Some think that this matter, called a color glass condensate, may explain new nuclear properties and the process of particle formation during collisions. Experimentalists have recently reported intriguing data that suggest a color glass condensate has actually formed in past work.

Particles such as protons and neutrons consist of smaller particles called quarks and gluons. Just as electrons have an electrical charge and transmit their force via photons, quarks have a "color" charge and transmit their force via gluons. But one major difference is that gluons, unlike photons, interact strongly with one another. As protons or heavy nuclei, such as gold, are accelerated to nearly the speed of light, the quarks and gluons inside flatten into a pancakelike structure, a relativistic effect called Lorentz contraction. The energy of acceleration also produces more gluons. The flattened multitude of gluons then begins to overlap, falling into the same quantum state, similar to the way atoms in a low-temperature Bose-Einstein condensate overlap and behave collectively as one gigantic atom.

Besides being similar to Bose condensates, the squashed matter "bears some resemblance to ordinary glasses," says Larry McLerran, a theorist at Brookhaven National Laboratory who first formulated the concept of a color glass condensate. For instance, the color fields produced by the gluons point in random directions, like the small, diffuse electrical fields generated by the orientation of atoms in glass. Just as regular glass is an amorphous solid for short periods (years) but flows over long intervals (centuries), these high-energy gluons are in a glassy planar state that changes very slowly compared with timescales typical of nuclear systems. This state is common to all extremely high energy particles and should enable physicists to describe the distributions and scattering probabilities of particles produced during collisions.

The color glass condensate can "shatter" in a collision. The shattering

PARTICLE SWARM resulting from a collision between deuterons and gold ions might indicate that a color glass condensate formed and then shattered.

BROOKHAVEN NATIONAL LABORATORY

can produce a quark-gluon plasma, a bulk form of quarks and gluons. Although a discovery has not yet been announced, many physicists believe that a quark-gluon plasma, which would provide clues about the early universe, has been created in heavy-ion collisions in the Relativistic Heavy Ion Collider (RHIC) at the Brookhaven lab.

As a precursor to the quark-gluon plasma, the color glass condensate should have been created if the plasma formed, as McLerran and some experimentalists believe it has. Electron-proton scattering in the HERA accelerator in Hamburg, Germany, provided indications of a color glass condensate. But perhaps the clearest signals have taken place in collisions in the RHIC: both in gold-gold and in deuteron-gold collisions. (Deuterons consist of one proton and one neutron.)

To detect a quark-gluon plasma, physicists examine the spray of particles emitted perpendicularly to the beam axis. But to tease out signs of a color glass condensate, detectors look at very small angles (about four degrees) relative to the beam axis. There the effects of a large number of very low momentum gluons dominate. Both deuteron-gold and gold-gold collisions produce fewer particles (relative to other proton-proton collisions) at these small forward angles, a sign that the gold nuclei was in a color glass condensate state. The effect was first seen by the multi-institutional group referred to as the BRAHMS collaboration (for Broad RAnge Hadron Magnetic Spectrometer); two other collabo-

CONDENSATES OF ANOTHER TYPE

Another kind of condensate made headlines in January, when physicists at JILA and the University of Colorado said they had made a "fermionic condensate." It consists of atoms that ordinarily remain single but are induced to pair up near absolute zero. The fermionic condensate provides a framework to understand superconductors and may lead to ones that work at room temperature. See "The Next Big Chill," by Graham P. Collins, News Scan; SCIENTIFIC AMERICAN, October 2003, and www.sciam.com/news_directory.cfm

rations—the PHOBOS and PHENIX—confirmed the BRAHMS data.

"I think this is a very interesting hint that something is happening here," comments Gunther Roland of PHOBOS. "But I think there's still a lot of work on the theoretical side that is needed to confirm the color glass condensate as the reason for the effect we're seeing experimentally."

Theorist Miklos Gyulassy of Columbia University believes, however, that the experimental evidence for a color glass condensate is too indirect: "What has been presented so far is not enough, for me." He says that the condensate should in fact appear for gluons moving with even lower momenta than have been measured. Direct evidence for the condensate might not happen until the more energetic proton collisions occur in the Large Hadron Collider at CERN near Geneva in about three years or until there is an upgrade at Brookhaven, probably a decade away.

David Appell is based in Lee, N.H.

ECOLOGY

Double Distress

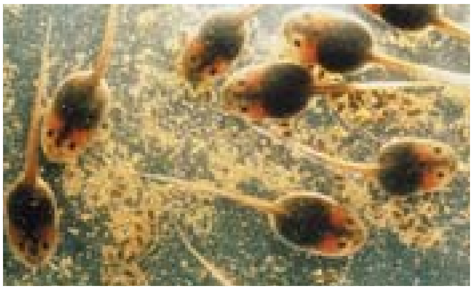
PESTICIDE KILLS FROGS ONLY IF PREDATORS ARE AROUND BY REBECCA RENNER

Amphibians are in decline, and the causes remain controversial. Among the earliest suspected culprits were pesticides, but the role of those toxic substances is not so obvious. Only a few reports have linked amphibian declines to pesticides. And even in those few studies, the pesticide concentrations appear to be too low to kill amphibians.

But University of Pittsburgh biologist Rick A. Relyea suggests that standard toxicology may greatly underestimate the power of pesticides on frogs in the wild. In the December 2003 *Ecological Applications,* he shows that carbaryl, a common pesticide sold as Sevin, is much more lethal to tadpoles—up to 46 times—when the pesticide is combined with another stressor: the presence of a predator.

Relyea kept tadpoles in water tanks that contained various amounts of carbaryl. Concentrations considered harmless on standard toxicity testing had little consequence, as expected. But many tadpoles died when the water contained tadpole-eating red-spotted newts, which were kept separate with netting.

Tadpoles are exquisitely sensitive to the smell of danger—for example, they react to just one dragonfly larva (another tadpole predator) in 1,000 liters of water, Relyea says. The carbaryl-newt data build on other findings by Relyea, who has now documented synergistic results in seven experiments with a total of six species of frog exposed to carbaryl. In an upcoming paper, he will also describe the same double-whammy effect of a predator and a common herbicide. His work "shows that the kinds of stressors prevalent in nature may be a key to understanding the real effects of pesticides on wildlife," says Yale University biologist David Skelly.



STRESSED: A toxic substance sickens tadpoles (seen here at about six weeks old) only when a predator lurks.

ADAM HART-DAVIS *Science Photo Library/Photo Researchers, Inc.*

The U.S. Environmental Protection Agency has reviewed Relyea's previous findings but believes that its regulations protect amphibians, because it bases its toxicity standards on Atlantic salmon, which are more sensitive to carbaryl than amphibians are. Still, the EPA remains interested in Relyea's synergistic effects, as are other herpetologists. "It's very difficult to prove that modern pesticides are a major cause" of amphibian declines, says biologist Donald W. Sparling of Southern Illinois University. Even DDT's role in wildlife problems took years to decipher, he notes: "We're going to have to rely on weight of evidence, and Relyea's study adds a very significant weight."

Rebecca Renner is based in Williamsport, Pa.

STILL MYSTERIOUS VANISHING ACT

The most important reason for amphibian decline is habitat loss, resulting mostly from human activities such as harvesting timber, draining wetlands and introducing nonnative species by, for example, stocking ponds and streams with trout. But amphibians are declining in "pristine" areas as well. Besides contamination from pesticides and other chemicals, these declines have been attributed to climate change, new diseases, parasites and higher levels of ultraviolet radiation. The emerging consensus is that no single overarching cause lies behind the global decline; instead several factors threaten amphibians to varying degrees.