PHYSICS

New Exotic Particle Points to Double Life for Gluons

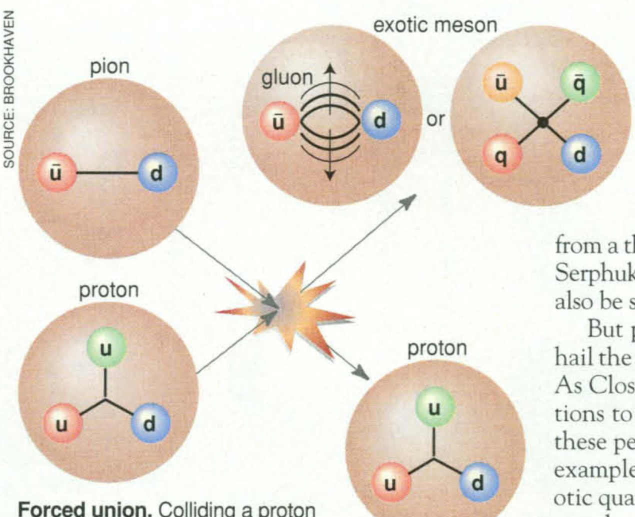
As elementary particles go, the gluon is looking inordinately multitalented. It has long been known as an insubstantial "force particle" that flits between quarks, conveying the strong force that binds them together into protons, neutrons, and other composite particles. Now there's evidence that gluons can act as constituents of matter as well, contributing mass just as quarks and electrons do. Two experiments, one at Brookhaven National Laboratory in Upton, New York, and the other at CERN, the European laboratory for particle physics, have just weighed in with glimpses of a short-lived hybrid particle consisting of a quark, an antimatter quark, and a gluon.

"If they've really done it, it's a confirmation that the gluon is a constituent of matter with the same degree of respectability as a quark," says University of Chicago physicist Jonathan Rosner. The particle, which the Brookhaven physicists call an exotic meson, wouldn't be the first clue that gluons can step into a more substantive role: For the last 2 years, researchers have been tantalized by evidence of glueballs, particles made up of nothing but gluons (*Science*, 15 December 1995, p. 1756). But the exotic meson, reported by the Brookhaven group in the 1 September *Physical Review Letters* and confirmed by the CERN group, would put gluons on an equal footing with quarks in a single particle. It would also vindicate theoretical predictions based on quantum chromodynamics (QCD), the theory that describes the behavior of quarks and gluons.

Because QCD's complex equations break down at energies typical of ordinary matter, a reliable understanding of the interactions between quarks and gluons is hard to come by. In the early 1980s, however, theorists, including Frank Close, a physicist at Britain's Rutherford Appleton Laboratory, and Ted Barnes of the University of Tennessee and the Oak Ridge National Laboratory, recognized that QCD allowed for the existence of a hybrid quark-gluon particle.

"However you modeled this thing," Close explains, "it suggested such a state should exist—whether as a quark, an antiquark, and single gluon trapped together in a sort of bag ... or as a quark and antiquark linked by a tube of flux, which would be a collection of gluons working together. If you excited the flux, like plucking a violin string, you would find such exotic states," because the gluons would gain energy, the equivalent of taking on mass.

The constituent gluon or gluons would also endow the hybrid with a set of quantum numbers—parameters such as spin and charge—that the equations forbid for more mundane mesons, consisting only of a quark and an antiquark. Because these exotic quantum numbers would manifest themselves in how the short-lived particles decayed, physicists could look for these signatures in the shower



Forced union. Colliding a proton containing two up quarks and a down with a pion (an anti-up and a down quark) spawns an "exotic meson" containing either two quarks and a gluon or four quarks.

of debris created by slamming particles together in accelerators. They have been doing that, unsuccessfully, for 15 years. Because its signature is excruciatingly subtle and buried beneath a background of ordinary mesons, says Rosner, "the quark-antiquark-gluon hybrid is not the easiest thing in the world to identify."

In 1994, the Brookhaven physicists, a group some 51 strong from seven institutions, began a new search, using a newly refurbished 2-decade-old detector, known as the multiparticle spectrometer. Brookhaven's Alternating Gradient Synchrotron sent a beam of pions, a kind of ordinary meson, crashing into a liquid hydrogen target. The multiparticle spectrometer captured the resulting spray of secondary particles.

In some 200 million collisions between pions and protons in the target, says Suh-Urk Chung, a spokesperson for the experiment, 40,000 yielded debris, suggesting that a new particle had formed in the collision and survived for all of 10^{-23} seconds. The charge, energy, and direction of the decay products, says Chung, imply that it has a mass of 1.4 gigaelectron volts and a set of quantum numbers that cannot be carried by a typical quark-antiquark meson.

The physicists say they are heartened by the nearly immediate confirmation that came from the Crystal Barrel collaboration at CERN, which was looking in an entirely different system of particles. According to University of Bonn physicist Eberhard Klempt, a member of the collaboration, the CERN experiment studied collisions between antiprotons from CERN's Low Energy Antiproton Ring and a heavy hydrogen target. Among the collisions captured in the Crystal Barrel detector were ones in which an antiproton encountered a neutron in the heavy hydrogen. The meeting of antimatter and matter generated a flash of energy, briefly creating "a subsystem with exotic quantum numbers which fully agree with the Brookhaven numbers," says Klempt. Researchers from a third experiment, this one at the Serphukov Laboratory in Russia, may also be seeing a similar phenomenon.

But physicists aren't quite ready to hail the definitive arrival of the hybrid. As Close puts it, "There are two questions to be answered: First of all, have these people really discovered the first example of something with these exotic quantum numbers? And second, if so, what does it tell us about the deep structure of the object?"

For starters, he says, the three groups measure subtly different masses, suggesting either the existence of three subtly different exotic mesons, or that one, two, or all three of the collaborations are somehow being fooled. The third possibility, says Close, "which I think is probably the likely one, is that there is a single object, and some complicated dynamics are causing it to give the impression of being at different masses."

But even if the particle is real and the quantum numbers truly exotic, the groups might be seeing not a quark-antiquark-gluon hybrid, but a particle made of two quarks and two antiquarks. That would make the exotic meson the first four-quark particle to be identified—an interesting finding, but not as interesting as a quark-gluon hybrid. Barnes notes, however, that "QCD predicts so many [four-quark particles] that if you take them seriously, you have to expect to see hundreds of them," contrary to the results so far.

If the experiments really have corralled a hybrid, physicists will have a new test bed for QCD: a system in which to isolate and study the behavior of gluons. "The way they'll behave should be different than the way quarks behave," says Close. "The challenge will now be showing exactly what that difference is."

–Gary Taubes