Proton puzzle puts physicists in a whirl

The more deeply particle physicists probe the proton's structure, the more complicated it seems to get. The latest experimental result to spur theorists into a flurry of speculation concerns the proton's spin, which is the source of its magnetism. This experiment suggests that very little — perhaps none — of the proton's spin comes from the spins of the quarks that are thought to make up a proton. The result raises serious questions about how the proton is put together.

"This is not an experiment telling us about esoteric things that happened in the first microsecond of the Big Bang or in some remote part of the universe," says Francis E. Close of the University of Tennessee in Knoxville. "This is the stuff we're made of, and it's showing that maybe we don't understand it as well as we thought."

Although scientists have raised questions about the validity of the experimental results, reported last year in PHYSICS LETTERS B, dozens of theoretical papers have addressed the puzzle in recent months. "There is no denying . . . that something new and unexpected is there to be investigated," Close says. "A great deal of work is now being done to examine possible explanations."

Over the years, theorists have developed a number of models for picturing a proton's internal structure. One of the more sophisticated models suggests that each proton contains three principal, or "valence," quarks (two "up" quarks and one "down" quark), tightly bound together by the strong nuclear force, which is carried by electrically neutral particles called gluons. The proton also contains an unruly "sea" of pairs of quarks and antiquarks. All of a proton's constituents are in continual motion.

"The proton has a very well-defined value for spin, but it's got a lot of internal structure," Close says. "The question is how the individual bits and pieces of that structure add up to the proton's spin."

In their experiment at CERN, near Geneva, Switzerland, researchers belonging to the European Muon Collaboration fired muons (particles with the same properties as electrons but with masses about 200 times larger) at protons in the nuclei of ammonia molecules held in a magnetic field. Their surprising results indicate that the spins from all the quarks in the proton — both the valence and "sea" quarks — cancel out. Moreover, in addition to the "up" and "down" valence quarks, "strange" quark and antiquark pairs seem to play an important role within the proton.

So far, no clear consensus has emerged to explain the findings. One possibility is that a proton's quark constituents are not only spinning but also orbiting one another. Another is that the gluons themselves are spinning uniformly in a particular direction. Other experimental data already indicate that gluons carry most of the proton's mass and about 50 percent of a proton's momentum. But the same data also show that "strange" quarks make only a small contribution to a proton's momentum.

"The interesting question is how do you make a picture of the proton in which strange quarks enter in an intelligent way, and how does that dynamics manifest itself in spin and certain other quantities but not in momentum and energy," says Robert L. Jaffe of the Massachusetts Institute of Technology. "Simple rules are not going to work." Jaffe and MIT colleague Aneesh V. Manohar have prepared a lengthy, soon-to-be-published paper on the whole question of proton structure and spin.

"What's being discovered here is the intrinsic complexity of the proton," Jaffe says. "We had hoped to get by without having to deal with this complexity, but we're finding we can't get by without it." In other words, simple models don't work very well for explaining all of a proton's properties.

"In some ways, we're in a very peculiar situation," says Ta-Pei Cheng of the University of Missouri in St. Louis. "We have a theory [quantum chromodynamics and the quark-gluon picture] that most of us believe very strongly to be the correct theory, but we don't know how to derive many basic properties [of particles such as protons]." *— I. Peterson*

Methane key to Arctic mystery mounds

Explanations in science often must await the right time. Since 1974, geologists have puzzled over mounds of marine fossils found on some bleak Arctic islands. But seemingly unrelated discoveries in the last five years in other parts of the world have paved the way for a crew of Canadian scientists to decipher the ancient mounds.

The Arctic deposits are roughly circular and stand up to 8 meters high, shaped sometimes like a wide hill and other times in pillar forms. Researchers found them first on Ellef Ringnes Island and more recently on Prince Patrick Island, both along the rim of the Arctic Ocean. Within the carbonate rock of the mounds are thousands of fossilized mussels, worm parts, fish teeth and other evidence of undersea oases. When these animals lived, the islands were located at the bottom of the sea, covered by at least 400 meters of water.

Benoit Beauchamp of the Geological Survey of Canada in Calgary says he and his colleagues were able to explain the mounds only when they became aware of recent work in the Gulf of Mexico and other spots. In these areas, scientists have discovered dense communities of mussels and worms clustered around cracks where natural gas (methane) and oil bubble to the surface. Bacteria living on these hydrocarbons and on hydrogen sulfide provide food for the more complex creatures.

The Arctic mounds are the first proof that these hydrocarbon communities existed in the distant past, according to a report in the April 7 SCIENCE by Beauchamp, J. Christopher Harrison and Walter W. Nassichuk of the Survey along with H. Roy Krouse of the University of Calgary and Leslie S. Eliuk of Shell Canada.

Evidence for a methane seep comes from analysis of carbon isotope ratios in the carbonate rock around the fossils. Beauchamp's group found the carbonate had extremely low ratios of carbon-13 to carbon-12 in comparison to normal seawater. Methane, which is depleted in carbon-13, must have provided the source for the carbon in the rock, say the researchers.

Formed by the decay of ocean organisms buried under sediments, methane and other hydrocarbons become trapped in porous layers of rock under the ground. Fractures in the crust provide a plumbing system that allows the light hydrocarbons to seep upward. The Arctic mounds sit along known faults that would have tapped methane deposits in the crust, according to the geologists.

In this area of the Arctic, the geologic setting is quite similar to regions off the Louisiana coast that hold significant oil and methane deposits, says Beauchamp. The discovery of ancient seeps, he says, "has some economic implications. It might tell us that hydrocarbons are still present below the surface." The mounds may also help reveal how these seep communities evolve.

James Brooks, who has worked on hydrocarbon seeps in the Gulf of Mexico, says the Arctic deposits call to question whether geologists have found any fossil hydrocarbon seeps before. "They could have been identified as shallow-water deposits when they were actually deep-water cold-seep deposits, which would change the geologic interpretation considerably," says Brooks, a geochemist at Texas A&M University in College Station.

The methane vents are called cold seeps to distinguish them from another kind of seafloor oasis where jets of superhot water support lavish communities of tubeworms, shrimp and other animals. In the past several years, geologists have found fossil examples of these hot-vent communities from tens of millions of years ago. *— R. Monastersky*