Quarks take wrong turns

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Physicists peering inside the neutron are seeing glimmers of what appears to be an impossible situation. The vexing findings pertain to quarks, which are the main components of neutrons and protons. The quarks, in essence, spin like tops, as do the neutrons and protons themselves.
Now, experimenters at the Thomas Jefferson National Accelerator Facility in Newport News, Va., have found hints that a single quark can briefly hog most of the energy residing in a neutron, yet spin in the direction opposite to that of the neutron itself, says Science News

"That's very disturbing," comments theoretical physicist Xiangdong Ji of the University of Maryland at College Park.

The finding suggests that scientists may have erred in calculations using fundamental theory to predict quark behavior within neutrons, he says. It might also indicate that orbital motions of particles within neutrons, in addition to those particles' spins, are more important than previously recognized. Those motions might be akin to the moon's rotation around Earth as the satellite also spins about its own axis.

Given that neutrons and protons are sister particles, called nucleons, the new findings apply to both, says Xiaochao Zheng, a member of the experimental team who's now at Argonne (Ill.) National Laboratory.

Nucleons are the building blocks of atomic nuclei. A typical nucleon includes three quarks: two down quarks and one up quark for a neutron; two up quarks and one down quark for a proton. In addition to those socalled valence quarks, each nucleon contains multitudes of gluons—particles that bind quarks—and of short-lived quark-antiquark pairs, known collectively as the quark sea.

Each of these constituents of a nucleon carries some share of the nucleon's energy, although the distribution of that energy among the constituents constantly shifts, Ji explains.

From previous experiments, scientists knew that only valence quarks can grab major portions of a nucleon's total energy content, says Jian-Ping Chen of the Jefferson lab, a coleader of the experiment. The new spin-detecting experiment is the first to measure the state of the neutron when most of its energy momentarily resides in a single quark.

Calculations based on the prevailing theory of quark behavior predict that any quark holding more than about half the energy of a nucleon should spin in the same direction as the nucleon. However, when the new experiment probed valence quarks temporarily laden with up to 60 percent of a neutron's energy, it revealed that only the up quarks behaved as expected. The down quarks somehow carried most of the energy yet rotated in a direction opposite to that of the neutron as a whole.

Electrons and entire atoms also have spins. To arrive at the new findings, the experimenters made a target of helium gas in which nearly all atoms were forced to spin in the same direction and bombarded it with a beam of high-energy electrons, whose spins were also forced to have uniform orientations.

The researchers determined the spin orientations of the quarks in the helium atoms by placing detectors in specific positions where they are more likely to make detections when the orientations of the electron's spin and the quark's spin are opposite, Zheng says. She and her colleagues present their results in the Jan. 9 Physical Review Letters.