biological homochirality is linked to the fact that "fundamental forces in nature are chiral." For example, the electrons and positrons that are produced by a form of radioactive decay called β decay, which is governed by the so-called weak force, can exhibit a chirality themselves by spinning either to the left or the right, respectively; several theoreticians and experimentalists have asked whether a bombardment by such rays could have induced homochiral biomolecules. But none of this work, said Bonner, has yielded convincing conclusions.

That failure leads Bonner to speculate that homochiral molecules came to Earth from an extraterrestrial source. Perhaps, he suggested, a remnant of a supernova known as a neutron star emitted radiation that included circularly polarized light (CPL), an electromagnetic wave that spirals clockwise or counterclockwise. These CPL waves, in turn, might have led to an enantiomeric excess of organic molecules in space.

This idea was most fervently promoted at the meeting by Mayo Greenberg from the University of Leiden in the Netherlands. Greenberg theorized more than a decade ago that comets are composed of interstellar dust containing organic material. Building on Bonner's hypothesis, Greenberg presented evidence that he could get enantiomeric excesses of the amino acid tryptophan in a laboratory experiment that mimicked CPL from a neutron star. "If a comet could have provided a local concentration [of homochiral biomolecules], you could have a head start" for the origin of life, said Greenberg.

Although many of the theories about the origin of homochirality can never satisfactorily be proved or disproved, the comet theory may be put to the test. In 2003, the National Aeronautics and Space Administration will launch its Rosetta mission, a spacecraft that will orbit the comet Wirtanen and send two smaller spacecraft to land on it and perform experiments. Walter Huebner, a visiting NASA scientist who attended the meeting, is working to include a device on one of the crafts to assess whether homochiral molecules are present on the comet.

Although Scripps's Bada is designing a device that could measure homochirality in extraterrestrial settings—he's particularly interested in Mars—he strongly doubts that they'll find homochiral molecules in a comet. "If the Earth was seeded with homochirals, we should see it happening today," said Bada, who has analyzed amino acids in meteorites and found them to be racemic.

Greenberg took the counterarguments in stride. "It's a continuing story," he said of the search for homochirality's origin. And, like a racemized mix of molecules, scientists will surely have opposite spins on the story for years to come.

–Jon Cohen

PHYSICS

A New Accelerator Explores The Social Life of Quarks

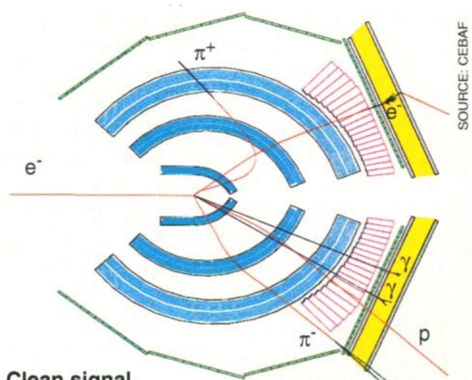
On a large scale, matter may seem inert, but zooming in on a single atom reveals a beehive of activity. The quarks that inhabit the nucleus cluster in small groups to form protons and neutrons, but they don't stay put—hopping restlessly from one group to another and sometimes summoning up companions from the vacuum. This picture of ceaseless motion, however, is just a rough interpretation, based on tantalizing observations and on the formidable mathematics describing quark behavior. "The situation today in the study of the nucleus is similar to what scientists faced in the 1920s with the study of the atom," says physicist Nathan Isgur.

"We don't get to see quarks as they live, inside the nucleus," adds Jack Lightbody, a physicist at the National Science Foundation. Part of the problem is that Lightbody and his colleagues just haven't had the right tools. The traditional way to observe the smallest units of matter is to smash protons or smaller particles together in a mammoth machine. This brute-force approach can flush out individual quarks and gluons, particles that carry the "strong" force that binds quarks together. But high energies and showers of debris can obliterate the subtle patterns that reveal the society of quarks in their natural habitat, the atomic nucleus. Probing the nucleus with a lighter touch is the goal of the Continuous Electron Beam Accelerator Facility (CEBAF), a new particle accelerator in Newport News, Virginia. Built by the Southeastern Universities Research Association with funding from the Department of Energy, CEBAF was completed last summer—on time and on budget, its managers boast—and is set to begin taking data this spring.

Rather than colliding bursts of high-energy particles, the $515 million accelerator probes nuclei in fixed targets with a steady stream of electrons. The subtler approach, says physicist Elizabeth Beise of the University of Maryland, should allow her and her colleagues to observe the strong force as it normally behaves in the nucleus. At CEBAF, they hope to study the paradoxical tendency of the strong force to increase as quarks are separated; they would also like to observe it conjure up new quarks from apparently empty space and find out how it seeps out of individual protons and neutrons to form the glue that holds the nucleus together.

To be sure, descriptions of all these behaviors are to be found in the theory of the strong force, called quantum chromodynamics (QCD). Yet under the conditions of ordinary matter, the equations of QCD become an impenetrable thicket. CEBAF, says Isgur, head of the theory group there, is designed to probe that thicket.

To do so, CEBAF uses chains of superconducting accelerating cavities to hurl electrons around an oblong racetrack with a long axis of 500 meters. After five circuits, the beam smashes into a fixed target, where the electrons collide with nuclei in a variety of materials. Using a fixed target rather than colliding two oppositely directed beams, as many accelerators do, sacrifices collision energy. Indeed, CEBAF's 4 billion electron volts is several hundred times lower than the energy of colliders such as HERA, in Hamburg, or the Fermi National Accelerator Laboratory's Tevatron. But high collision energy isn't critical for subtle exploration of the nucleus. CEBAF's design allows experimenters to vary the target to study nuclei of various types, and it generates far more collisions than can be achieved by aiming two hairsbreadth beams of particles at each other.



Clean signal. A simulation shows a collision within CEBAF's Large Acceptance Spectrometer, a detector scheduled for completion in late 1996. An electron (e^-) collides with a proton (p), snapping a quark-quark bond and generating a quark-antiquark pair that decays into a sprinkle of pions (π) and a pair of gamma rays (γ).

What's more, unlike other accelerators, CEBAF produces these collisions continuously. Existing accelerators generate their high-energy particles in bursts, resulting in a boom-and-bust cycle of collisions. During a spate of collisions, says Isgur, "you are blinded by a burst of particles," making it impossible to sort out isolated collisions. In CEBAF, the electrons strike the target in smaller bunches, at a much higher rate.

Until a few years ago, this strategy was out of the question, says John Domingo, CEBAF's associate director for physics, because accelerating a steady stream of electrons to high energies would have consumed impractical amounts of power. But the development of superconducting cavities lowered the power needs to a practical level. The resulting persistent bombardment offers physicists a good chance of observing isolated collisions, marked by a single ricocheting electron and a shower of secondary particles.

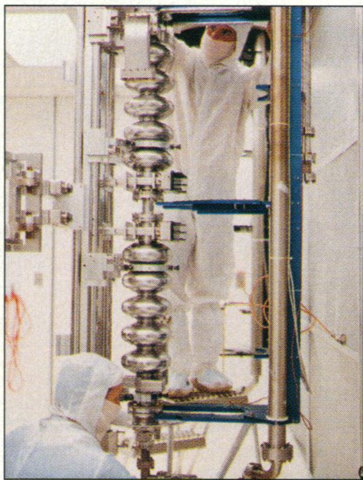
Bonds, shaken and stirred. Providing CEBAF's $70 million annual operating costs survive the budget-cutting fervor in Congress, these clean, easily sorted collisions should become a resource for physicists trying to peer into the nucleus. Already, CEBAF's Program Advisory Committee has approved some 75 experiments designed to sift the debris from these collisions for clues to some of the wilder predictions of QCD. Rather than shattering quark-quark bonds, as high-energy collisions do, the nuclear encounters in CEBAF should gently stretch these bonds, allowing a clearer view of the bonds—and of what happens when they finally snap.

Because the strong force seems to forbid quarks from existing alone, pulling apart bound quarks is a little like trying to cut a magnet in half. Just as new north and south poles immediately appear on the magnet halves, new quarks instantly appear to join the original ones. Observing this process in action may help physicists choose from among a welter of competing pictures of how the strong force regulates the microcosm inside the nucleus.

In one model, says Isgur, the strong force, unlike an electric field, isn't spread through space but is confined in narrow tubes that stretch like rubber bands. If a quark is dislodged from the nucleus, the tube holding it stretches until it breaks, spilling out new quarks that immediately bind to the free ones. Some of CEBAF's collisions, however, should transfer energy to the tubes rather than breaking them, exciting certain vibrational modes in a process somewhat like plucking one of a guitar's strings. The twanging should generate a specific pattern of new particles, which would register in CEBAF's detector.

An alternative model pictures the strong force as a kind of sack that allows the quarks to move freely, within limits, but prevents them from straying farther. In yet another model, the strong force resembles a uniform sea of glue in which quarks are embedded. Each model—and there are many others—offers different predictions about the patterns of new particles that will materialize as CEBAF stretches quark-quark bonds.

Other CEBAF researchers plan to probe a different set of inhabitants of the nucleus: virtual quarks. Protons and neutrons own just three quarks each, according to theory, but they have a special sort of credit system that lets them constantly borrow energy from the vacuum and use it to create pairs of virtual quarks that pop into and out of existence. Experiments at other accelerators have already revealed these shadowy particles—but at such high energies that the quarks' behavior is altered. At HERA, for example, both virtual and real quarks roll around within protons and neutrons like stray marbles, as if they didn't feel the effects of their companions (*Science*, 24 June 1994, p. 1843). CEBAF, says Isgur, should help researchers study the virtual quarks' social behavior to answer such questions as "How are the virtual quarks arranged in there? How do these relate to the way nucleons [protons and neutrons] bind to one another to form nuclear matter?"



LYNN FREENEY / U.S. DEPARTMENT OF ENERGY

Hidden advantage. CEBAF's tunnel follows the racetrack outline visible in the photograph. Niobium superconducting cavities *(top)* accelerate the continuous electron beam.

The confederacy of quarks. CEBAF won't be confined to exploring the interiors of protons and neutrons. Researchers there also plan to study how the strong force unites these smaller quark groups in the larger society of the nucleus. One source of clues may be a phenomenon known as transparency. QCD predicts that, when struck just right, a proton can pass through a nucleus like sunlight through glass. "You squeeze the proton to a tiny quark ball," says Isgur, compressing it so that it can sail through the nucleus. "When you have such a spectacular prediction from a theory," he says, "you want to test it," because it may be a good place to look for holes in the theory.

Groups led by Brad Filippone of the California Institute of Technology and Richard Milner of the Massachusetts Institute of Technology plan to do just that. If an impinging electron really can compress a proton so that it can slip past its neighbors, the effect should be evident in CEBAF's detector: The path of the dislodged proton will imply that the target nucleus has fewer than its actual number of nucleons. By comparing the predictions of transparency to the effect as it is actually observed, Filippone and Milner hope to gain insights into the forces that normally hold nucleons in place.

Beise, meanwhile, hopes to study how protons and neutrons interact under less extreme conditions. She plans to study the workings of the nuclear binding force by examining one of the very simplest atoms, deuterium, which has one proton and one neutron. "By looking at the way the electron [from CEBAF's beam] is scattered off the deuterium, you can learn about the way [protons and neutrons] are held together," she explains. One possibility, say some physicists, is that the nuclear binding force resembles chemical bonding. Just as atoms stick together when they share electrons, so protons and neutrons might also form bonds by sharing quarks.

Finding such a parallel would be reductionism at its best, revealing common principles governing matter at different levels. It would also illustrate CEBAF's ability to reunite two long-divergent fields—nuclear and high-energy physics. Back in the 1950s, recalls Domingo, both fields were asking the same questions about the constituents of the nucleus. But as high-energy physicists continued their search for smaller and smaller building blocks of matter in the 1960s and '70s, they turned their backs on the nucleus.

"Now the distinction is disappearing again," Domingo says. To really understand quarks, high-energy physicists are realizing, these elementary particles cannot be considered in isolation. They are, it would seem, social organisms, and their true natures emerge only in society. And that brings the spotlight back to protons, neutrons, and the atomic nucleus—the domain CEBAF is designed to explore. Says Domingo: "We're finally back together, and that's great."

–Faye Flam