Another New Particle: Charmed Quarks Look Better Than Ever

The most talked about explanation for the J/ψ particle, whose discovery so shook up the world of elementary particle physics 18 months ago, has been that it is a meson comprising hypothetical entities called a charmed quark and a charmed antiquark. In succeeding months, experiments gratifyingly verified features of this model qualitatively, if not always quantitatively. The major stumbling block to acceptance of this picture has been researchers' failure to see a new particle consisting of only one charmed quark in combination with one uncharmed quark produced in electron-positron collision experiments.

At last, after an intense search lasting more than a year, this long-sought charmed particle—or at least a particle that bears every indication of being a charmed meson—has been found.

A group of 40 researchers from the University of California's Lawrence Berkeley Laboratory (LBL) and the Stanford Linear Accelerator Center (SLAC) announced the discovery last week. From their study of electron-positron collisions in the SPEAR storage ring at SLAC, the investigators concluded the new particle has a mass of 1.865 giga-electron-volts (Gev), a lifetime which may be longer than that of the J/ψ particle (10^{-20} second), no electrical charge, and a new physical property (quantum number).

Particle Matches Expectations

The experimenters themselves are stopping short of claiming that the new property is charm. But physicists around the world have been in a state of high excitement for the last month (rumors of the discovery have been circulating for that long) because the new particle has the same mass and decay products as predicted by the charmed quark theory.

If the charmed quark picture of the J/ψ is correct, then it is analogous to the ground state of a hydrogen-like atom. This subnuclear "atom" is sometimes referred to as charmonium. Various other particles that correspond to expected excited states of charmonium have in fact been found in SPEAR and in the DORIS storage rings at the DESY Laboratory in Hamburg, West Germany (*Science*, 8 August 1975, p. 443).

In the same analogy, when oppositely orbiting electrons and positrons collide and annihilate in the storage ring at sufficiently high energies, it ought to be possible to make the analog of an ionized atom, in which the charmed and anticharmed quarks are no longer bound together. It is a quirk of the quark theory, however, that free quarks, charmed or not, cannot be observed. Only combinations of quarks in the form of the various elementary particles of the hadron family (mesons and baryons) are observable. (Before the J/ψ all known hadrons had only uncharmed quarks as constituents.)

Thus, the free charmed and anticharmed quarks combine with uncharmed quarks to produce hadrons with a charm quantum number of plus or minus one (charmonium itself has a net charm of zero). Particles of this type had never before been observed in electron-positron collision experiments, although experiments involving collisions of neutrinos with nuclei at the Brookhaven National Laboratory, the European Organization for Nuclear Research (CERN), and the Fermi National Accelerator Laboratory strongly pointed to their existence (*Science*, 6 February, p. 452).

The LBL-SLAC group has long had indirect evidence that this process might be occurring in the range of collision energies from about 4 to 4.5 Gev. Putative resonances sometimes called ψ'' at 4.1 Gev and ψ''' at 4.4 Gev are broad structures, indicating a short lifetime and rapid decay via the strong nuclear interaction. This is exactly what is expected, if, for example, one of these particles were breaking up into two charmed mesons. In contrast, lower mass states, such as the J/ψ (3.1 Gev) and ψ' (3.7 Gev), researchers argued, had insufficient mass to break up into two charmed mesons and thus had to decay slowly, although via the strong interaction. Since the strong interaction conserves charm, decay via the weak interaction, which does not, is the only route available to a charmed meson and thus could account for its expected long life.

From various theoretical considerations, from the neutrino experiments, and from the ψ'' and ψ''' resonances, researchers had concluded that a charmed meson probably would have a mass near 2 Gev. Last year, for example, Sheldon Glashow, Howard Georgi, and Alvaro De Rújula at Harvard University predicted that a charmed meson with no electrical charge should exist with a mass of 1.83 ± 0.03 Gev.

To observe the particles produced when the collision energy is above the presumed threshold for creation of charmed meson pairs, the LBL-SLAC team measured what is termed an invariant mass distribution. With their detector, called a magnetic spectrometer, the investigators traced the paths in a magnetic field of charged particles produced in a decay event and deduced their momenta. From this information, they could determine the mass of a particle from which the decay products could have emerged. They then plotted the number of events as a function of apparent mass and looked for a resonance-like increase in the number of events at a well-defined mass. A peak in the number of events at a particular mass was a signal of a real particle existing with that mass, whereas events at other masses constituted a background.

Reexamining Old Data

Successful searches for new particles depend critically on where one looks and what one looks for. In their hunt for the charmed meson, the LBL-SLAC investigators concentrated on what are called hadronic decays in which the charmed meson should decay into K mesons and π mesons. Only last summer, the group published the results of an unsuccessful search. As it happened, however, the negative results were obtained when the collision energy of the electrons and positrons in the storage ring was 4.8 Gev. The new particles are efficiently produced, it turns out, only when the collision energy is in the range 3.9 to 4.6 Gev.

A second crucial factor was an improved ability to distinguish between K mesons and π mesons in the decay products. The researchers are now able to distinguish between these particles by measuring the time it takes each of them to reach a set of plastic scintillation counters in the detector from the collision region. This ability greatly enhances the sensitivity of the experiment to the putative charmed meson.

The discovery came early in May, according to Gerson Goldhaber of LBL, shortly after a particle physics meeting at which such strong pro-charm sentiments were expressed that Goldhaber felt compelled to reexamine with special care data collected over the past year. At the same time, a visiting scientist in the group, François Pierre, who is on leave from the elementary particle physics department at Saclay, in France, was going over data himself. Within a few days, both had independently found evidence for the new particle. (One day on the way to lunch, each said to the other, "By the way, I have something to show you!")

Since then, the entire LBL-SLAC team has collected about 200 events, half with a decay into a K meson and a π meson and half into a K meson and three π mesons. According to Roy Schwitters at SLAC, a multihadronic decay event is detected about once a minute, and, in about 1 percent of these, researchers find the new particle.

Evidence for a second charmed meson produced in association with the first has also been obtained. Lack of such evidence would have been highly damaging to the charm model, since the mesons must be produced in pairs to conserve charm. The evidence rests on what is called a recoil mass spectrum. Knowing the energy and momentum that went into the collision and subtracting the energy and momentum of one of the products, the researchers can determine the energy and momentum of the "rest." It turns out that the mass of the "rest" is centered in a region between 2 and 2.2 Gev, indicating that the second particle has a mass different from the first. More data has to be accumulated, however, before the LBL-SLAC investigators will estimate the energy more precisely.

Less cautious in their interpretation are others who have seen the recoil data, which appears to show two peaks at 2 and 2.15 Gev. Glashow and his associates at Harvard say the apparent structure is consistent with the simultaneous production of a charmed meson in either a 1.865-Gev ground state or a 2-Gev excited state and a second charmed meson in the excited state. Rapid decay of an excited charmed particle into its ground state could give rise to the particle observed in the invariant mass distribution.

The particles that the investigators found are electrically neutral. There should also be a charged meson with charm at about the same mass as the neutral meson and a second charged meson at a mass (in the ground state) of about 2 Gev. Neither of these particles has been observed as yet. Theorist Michael Chanowitz at LBL points out that they could be detected by their characteristic decays, but because the charged particles should be produced much less frequently than the neutral ones, much more data must be accumulated before a statistically valid identification could be made.

Checking Charm's Consequences

Glashow, who is coinventor of the charm model, is obviously happy with the particle discovery, as well he might be. Charm was first postulated more than 10 years ago on what can fairly be described as esthetic grounds. Later on, the model was extended to explain certain discrepancies in the decay by weak interactions of strange particles, such as the K meson. It has to be regarded as deeply satisfying, argues Chanowitz, if a concept proposed years before for altogether different reasons should now be the key to understanding the surprises in elementary particles that have occurred in the last 2 years.

The task now is to verify the several predictions of the charm model that have not as yet been observed. If, as SLAC's Sidney Drell points out, the LBL-SLAC group's experiment is by far the most convincing piece of evidence for charm up to now, until all its consequences are checked out, scientists must retain an open-minded skepticism.

For one thing, other decay routes of the neutral particle besides K-π and K-3π ought to be seen, observers agree. One important example of these, according to theorist Fred Gilman of SLAC, is called a semileptonic decay via the weak interaction in which charm is not conserved (none of the decay products have charm). In the semileptonic decay mode, the putative charmed meson should often decay into hadrons (including a K meson), a charged lepton (an electron, a positron, a muon, or a antimuon), and a neutrino.

The only other laboratory in the world able to duplicate the SPEAR experiment is DESY. In particular, the scientists there have a particle detector that is particularly suited for picking out electrons and positrons from other charged particles. Verification of the semileptonic decay might therefore come from DESY. Bjorn Wiik, a group leader at DESY, has reported that his group has seen electrons under the expected conditions. But, he cautions, it will be a few more weeks before enough data is in hand to ascertain whether the electrons are coming from the decay of the particle seen at SPEAR or from some other source.—ARTHUR L. ROBINSON

Water Structure and Ion Binding: A Role in Cell Physiology?

A major difference between living and dead cells is that living cells selectively retain certain ions, such as potassium, and exclude others, such as sodium. Ion concentrations in dead cells reflect those in the solutions surrounding them. For more than 15 years, a small group of researchers has challenged the conventional explanation of this effect. Most physiologists believe that it is due to ion "pumps" in membranes. The pumps are said to use cell energy to transport some ions into and others out of the cell. The dissident group, however, contends that the pumps do not exist and that, instead, ions are excluded from cells on the basis of their low solubilities in cellular water, except when specific charged sites with which the ions can associate are available. Cell water, they maintain, has a different structure than either liquid water or ice, and this special structure affects the solubility of various ions in it.

Dialogue between advocates of pumps and of structured water and ion binding has been strained (see box). Each side believes it has steadily accumulated evidence that the other side is wrong. Recently, however, some crucial experiments and calculations have been performed that provide strong evidence for the existence of pumps. These results do not rule out the possibility that structured water still plays a role in cell physiology, but the details of such a role remain to be determined.

The structured water and ion binding theory is based on the following argument. First, its advocates believe they have evidence that ion pumps are thermodynamically impossible—they would require more energy than is available to the cell. This means that there must be some other explanation for selective ion retention and exclusion. Next, its advocates point to their use of nuclear magnetic resonance (NMR) to probe the structure of cell water. Results of NMR