Elementary Particles: Neutrino Experiments Suggest Charm

News of elementary particle discoveries continues to come, as it has for the past year, at a rapid pace. Most recently, a group of researchers working at the Fermi National Accelerator Laboratory has produced what they claim is conclusive evidence for "a new particle with an entirely new physical property." Although they emphasize that proof of the connection is lacking, the researchers speculate that the new property may be none other than charm, the elusive quantum number that has been much in the news since the discovery of the J/psi particle 15 months ago (*Science*, 6 December 1974, p. 909).

Researchers at the Fermilab announced their findings at a meeting on the physics of new particles, which was held early in December. The group, comprising scientists from the University of Wisconsin, the University of California's Lawrence Berkeley Laboratory, the European Organization for Nuclear Research (CERN), and the University of Hawaii, found four events from among about 1000 that they studied that could not in any way be explained without invoking the presence of an unidentified particle with a new quantum number. Within a month, a second group of researchers, working at CERN in Geneva, made it known that they, too, had evidence for a new particle from an experiment very similar to that at the Fermilab but at much lower energies.

Earlier in the fall, a second Fermilab team, consisting of investigators from Harvard University, the University of Pennsylvania, the University of Wisconsin, and the Fermilab, had started the bandwagon rolling by also presenting experimental evidence for a new particle with a new quantum number.

These experiments, each of which involved the use of beams of neutrinos obtained from proton accelerators, should also boost somewhat the egos of physicists who use such machines. In recent months, electron-positron storage rings had become the glamor machines of high energy physics, in part because they have seemed to be ideal for studying the J/psi particle and its related family members.

The Wisconsin-California-CERN-Hawaii researchers studied the interaction of a beam of neutrinos with nuclei in the Fermilab's 15-foot (4.6 meter) bubble chamber, which was filled with a mixture containing 80 percent liquid hydrogen and 20 percent neon. They obtained the neutrinos indirectly from collisions of protons with a metal target in the 400-Gev synchrotron. What the investigators found in the four events had never before been observed—a combination of a negative muon, a positive electron (positron), and the decay products of a neutral K meson (a particle having the property of strangeness, a quantum number whose introduction dates back 25 years). It is also assumed that a neutrino was among the final products.

In the bubble chamber, an incident neutrino interacts with a neutron via the weak nuclear force (since the neutrino is a lepton), and the neutrino is transmuted into a negative muon. The researchers conjectured that the neutron is changed into the new hadron with a mass about twice that of a proton (that is about 2 Gev) and with the new quantum number. The new particle could be either a meson or a baryon. The transformation is possible because some of the usual conservation of quantum number selection rules do not apply in weak interactions. After a life too short (less than 10^{-11} second) to be observed in the bubble chamber, the new particle decays, again via the weak interaction, into the neutral K meson, the positron, and the electron neutrino. No possible decay of known particles could leave this combination of products. Says William Fry, leader of the experimental team, "This is the signature for something with a new property."

Identifying the Particles

Positive identification of this telltale combination of two leptons and a strange particle is what makes the discovery so exciting. Identification of leptons from their tracks in a bubble chamber is not a foolproof process by any means. Identification of the muon, in particular, can be a problem. For this reason, the investigators used what they term an external muon identifier (EMI). Only a muon has a high probability of passing through the 0.6 meter of zinc separating the EMI from the bubble chamber and being detected, according to Fry. Aiding in the identification of the positron was the neon in the bubble chamber, which enabled a characteristic bremstrahlung radiation to be recorded. Identification of the K meson by its decay products is regarded as more straightforward.

Investigators at CERN performed very nearly the same experiment with neutrinos produced from the 28-Gev proton synchrotron there. The experimental team, consisting of 56 scientists from seven European laboratories, used the CERN heavy liquid bubble chamber known as Gargamelle, which was filled with liquid Freon, as their detector. The first CERN event was discussed at a meeting last spring, but only recently did the researchers find the second and third of these. Although three events are considerably more convincing than one alone, because the investigators did not have an EMI, some observers consider their results as somewhat less conclusive than those from the Fermilab.

An earlier finding by researchers using the 28-Gev proton synchrotron at the Brookhaven National Laboratory is also considered inconclusive. Last April investigators under the direction of Nicholas Samios reported on one event consisting of several pi mesons and the decay products of a neutral lambda particle (a baryon with the property of strangeness). This combination points toward a new hadron (a baryon) with a mass of about 2.4 Gev, but so far the Brookhaven group has found no more such bubble chamber tracks.

The Harvard-Pennsylvania-Wisconsin-Fermilab group, under the direction of David Cline, Alfred Mann, and Carlo Rubbia, first reported what they call dimuon events last winter. At first, the experiments seemed to admit of several interpretations, although the leading one was the existence of a new hadron with a new quantum number. Since then, they have completed more experiments and, drawing upon some theoretical work of Abraham Pais of Rockefeller University and Samuel Treiman of Princeton University, these investigators have concluded that the existence of a new quantum number is the interpretation that best fits their data.

In the dimuon experiment, the experimenters observed two muons, one positive and one negative, when neutrinos struck nuclei in a liquid-filled scintillation counter. The detector consisted of several such scintillation counters alternating with spark chambers, an assembly called a calorimeter, together with a magnetic spectrometer comprising iron core magnets and spark chambers. Sixty tons of iron separated the spectrometer from the calorimeter, thus insuring that only muons would be detected in the former.

Mann believes that Fry and his colleagues recorded a process that is in a sense complementary to and implied by the results of the dimuon experiments. That is, after creation of the new hadron during the collision of a neutrino and a neutron in the scintillation counter, the new particle can decay into a strange par-

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Subcellular Localization of Inorganic Ions in Plant Cells

Van Iren and Van der Spiegel (*1*) reported that they obtained the "first direct evidence for significant amounts of ions in the endoplasmic reticulum" of plant cells. They used an in vivo precipitation technique in which barley roots were exposed to Tl^+, and then treated with I^-, leading to precipitation of TlI in the tissue. The intracellular distribution of the precipitates was examined electron microscopically. As Van Iren and Van der Spiegel stated, Tl^+ may be used as a "physiological isotope" for K^+. The administration of I^- as an analog of the nutrient ion Cl^- is questionable, however, as these two halide ions appear to be absorbed by different mechanisms (*2*).

We have independently studied the intracellular localization of Cl^- in barley roots by using an in vitro precipitation technique originally proposed by Komnick (*3*). Roots of intact barley seedlings were allowed to absorb Cl^-, after which root specimens were fixed for electron microscopy in the presence of Ag^+ to precipitate Cl^- as AgCl. The precipitates were found to be located particularly in the endoplasmic reticulum and in plasmodesmata of cells of the cortex and of the stele in these roots (*4, 5*). We were able to detect the precipitates in the endoplasmic reticulum of xylem parenchyma cells after an absorption period of only 20 minutes from 5 m*M* Cl^- (*5*). This emphasizes the efficiency of the symplasmic pathway for ion transport to the xylem of roots in which the apoplasmic pathway is blocked by the Casparian strip of the endodermis (*6*). Using the Ag^+ precipitation technique, Van Steveninck *et al.* (*7*) also succeeded in localizing Cl^- in the endoplasmic reticulum of cells of the alga *Nitella translucens*.

The Ag^+ precipitation technique has been criticized, because Cl^- ions may diffuse in the specimen during the preparation or may even be lost from it (*1*). We have tested for loss of ^{36}Cl from barley roots during specimen preparation and found that less than 4 percent was lost during the whole preparation procedure (*8*). Furthermore, the electron-dense precipitates observed with the electron microscope were shown by electron microprobe analysis to be composed of Ag and Cl (*8*). Localization of Cl^- by the Ag^+ precipitation technique has the additional advantage that the AgCl precipitates are stable under the electron beam (*4, 5, 7, 8*), whereas TlI evaporates, leading to holes at the sites of its original location (*1*). Nonetheless, possible localization artifacts arising from diffusion during the use of the Ag^+ precipitation technique must be considered critically (*9*). We have concluded that during the preparation procedure, ions may migrate within a membrane-bound cell compartment (*4, 5, 9*). Thus, localization at the level of the endoplasmic reticulum would not be affected qualitatively by a possible migration of ions in the course of the specimen preparation.

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ticle through the emission of either a positive muon or a positron, and a neutrino. Because of the detector they used, however, the researchers observing dimuons do not have direct evidence of the presence of a strange particle. Altogether, more than 80 dimuon events have been found.

Although the discovery of a new particle in itself is sufficient to generate excitement among physicists, in this case the interest is heightened by the possibility that the particle may possess the property of charm (*Science*, 8 August 1975, p. 443). Like strangeness, charm does not correspond to any physically observable property. Instead, strangeness and charm are arbitrary designations for quantum numbers whose existence is implied by the results of certain experiments.

Theorists' favorite explanation for the existence of the *J*/psi particle invokes certain hypothetical entities called charmed quarks. Quarks have been conjectured as the fundamental constituent particles that make up the hadrons (which feel the strong force) (*Science*, 17 May 1974, p. 782). Among the many varieties of quark theories extant in physics today, a model with four such particles, one of which possesses the property of charm, is the most widely discussed.

The *J*/psi particle, it has been proposed, comprises a charmed quark and its antiquark. Thus, this meson, as a whole, does not exhibit charm. Although a number of experiments at the Stanford Linear Accelerator Center (SLAC) and at the DESY Laboratory in West Germany involving apparent excited states of the *J*/psi particle are seen by scientists as being consistent with this model, the failure of experimentalists to observe charmed hadrons (containing only one charmed quark) when some of these excited states decay has been a major stumbling block to acceptance of the charm model. Hence the interest in the neutrino experiments: although there is as yet no direct connection between the proposed new particles and either the specific charm model that was first proposed in the 1960's or the *J*/psi particles, the mere existence of a new quantum number suggests charm in the general sense of there being a fourth quark. In fact, it is not inconceivable that there are even more quarks with other properties.

Because the Wisconsin-California-CERN-Hawaii experiment explicitly identified all the final state particles, it seems to some to be a little more clear-cut in its interpretation than the other experiments. Theorist Benjamin Lee of Fermilab, for example, thinks that this experiment constitutes the strongest evidence yet for charm, and SLAC's Sidney Drell says that the events seem to admit of a natural interpretation in terms of states of charm. But all observers emphasize that it is still premature to make the connection. Lee cautions that he would like to see more events so that all the consequences of the charm model can be verified. More cautious still is Sheldon Glashow, an originator of the charm concept, who maintains it is still absolutely crucial that charmed particles be seen in the electron-positron storage ring experiments when *J*/psi particles in sufficiently highly excited states are produced. The states that may exist near 4.1 and 4.4 Gev, for example, would be energetic enough to decay into two 2-Gev particles.

With the electron-positron storage ring experiments and the neutrino beam experiments both suggesting charm, in the words of one physicist, "Things are really coming to a boil, not just in one spot, but all over the pot."—ARTHUR L. ROBINSON