Two New Particles Found: Physicists Baffled and Delighted

Physicists around the world have been frantically pursuing the meaning of an extraordinary set of discoveries in the last few weeks. On 11 November two teams of researchers working at the Brookhaven National Laboratory, Upton, Long Island, and the Stanford Linear Accelerator Center (SLAC), Palo Alto, California, discovered a new subnuclear particle with properties so peculiar that it did not fit into any of the familiar categories. It was named J in the East, and psi in the West. Within days, researchers at the ADONE facility in Frascati, Italy, confirmed the new particle discovery, and practically every physicist who knew that $E = mc^2$ rushed to try to explain the new phenomenon.

But only 10 days after the original discovery, before the ink was dry on the first explanation, the team at Stanford found a second peculiar particle. They renamed the original particle psi(3105), for its mass of 3.105 Gev, and called the second one psi(3695) according to the same notation.

The suddenness of the discoveries has left almost everyone baffled about what it all means. Many physicists think that the discoveries may have opened a whole new dimension in the world of subnuclear particles, analogous to finding the first of many so-called strange particles in 1947. Apparently not just an isolated phenomenon, but a whole new family of particles has been found.

The most distinguishing characteristics of the new particles is that they are at the same time very massive and relatively long-lived. As a rule in particle physics massive particles are short-lived, but the two new particles live at least 80 times longer than the most similar particle known before, called the phi, even though the new ones are at least three times heavier. The new particles have not been seen directly, because the lifetime of 10^{-19} second is too brief for them to leave a visible track, but the ordinary considerations of particle physics suggest that the lifetime should be at least 1000 times shorter.

Many more experiments are needed to pinpoint other properties of the new particles. The biggest question is whether they are weak or strong, and no one knows the answer yet. If the particles can exert the strong force, which is responsible for nuclear energy, they would be called hadrons. But they may only be able to exert the weak force, which is responsible for radioactivity. Since neither particle has a charge, physicists already know that they do not have the electromagnetic force at their command.

The new particles could be funny types of hadrons. If so, they may never have been seen before because they are set apart by a quality called charm, which was predicted in 1963. One physicist called this the most conservative explanation, because many different families of hadrons have already been found, and one more family wouldn't be such a drastic change. But there is really only one family of weak particles, and so a new family—if the two discoveries lead to that—could be much more revolutionary for the weak interactions.

In a way, the idea that the first new particle might be charmed led the Stanford researchers to the right place to find the second one. Charmed elementary particles were postulated to exist if they were composed of charmed quarks. A popular explanation of the J or psi is that it is made of a charmed quark and a charmed antiquark bound together. The appeal of this suggestion is that it explains why the new particle does not decay quickly into ordinary hadrons, which are thought to be composed of uncharmed quarks. By making a rough analogy between the constituents of the new particle and the constituents of the hydrogen atom, the Stanford physicists were led to the mass of the second particle. But the analogy didn't work when they looked in the suggested place for a third particle. At the time of this writing, they had not stopped looking, but were playing a different game to guess where the next one might be found.

A completely different explanation is that the new particles may be weak. For many years physicists have searched in vain for the particle that is the carrier of the weak force. The new particles could be versions of the neutral carrier of the weak force, although various neutrino experiments suggest that the charged carriers of the weak force are much heavier, at least 10 Gev. Another possibility is that the new particles may be responsible for the phenomenon called neutral currents that was discovered last year at CERN, the European nuclear research center outside Geneva [*Science* **182**, 372 (1973)]. According to J. D. Bjorken at SLAC, it is natural to relate the new particles to neutral currents, but whether they are related to the rest of the weak interactions, or parity violation, is a matter of speculation.

The two suggestions for strong and weak particles only define the extremes of the spectrum of possible explanations, and every possibility in between may be viable too. So many theorists are busy preparing explanations that the journal *Physical Review Letters* "had better be braced for an avalanche," said one. None of the explanations advanced so far may be correct, but many physicists are nevertheless optimistic that the new discoveries will help with an assortment of problems that have accumulated in recent years, seeming to hint that something funny was happening in the mass range between 3 and 4 Gev.

The first new particle was discovered by scientists working separately at the Alternating Gradient Synchrotron (AGS) at Brookhaven and the SPEAR storage ring at SLAC.* At Brookhaven, a proton beam hitting a target generated pairs of electrons. At SLAC, colliding beams of electrons and positrons generated various hadrons. The two experiments were almost exactly inverses of each other. In both cases, the number of particles produced in the experiment peaked sharply at an energy of 3.1 Gev. The peaking effect, or resonance, indicated that a new type of particle had been produced with a mass of 3.1 Gev, which is more than three times heavier than the proton. The decisions to publish the two experiments were made within hours of each other (see box).

The experiment at Brookhaven seems

* The team working at Brookhaven included Samuel C. C Ting of the Massachusetts Institute of Technology, Y. Y Lee of Brookhaven, and 12 colleagues. The team working at Stanford included Burton Richter of SLAC, William Chinowsky, Gerson Goldhaber, and George H Trilling of the Lawrence Berkeley Laboratory, and 31 colleagues

to have been motivated by a sequence of curious results dating back several years. Generally the same phenomena can be studied with muons as with electrons, and Leon Lederman of Columbia University saw anomalies in the production of muon pairs in 1970. Over the years, interest in muon pair experiments grew to the point that the Fermi National Accelerator Laboratory had to hold a separate program meeting on the subject in September.

The brainstorm behind the Brookhaven experiment was the idea of looking for electron pairs instead of muon pairs, because the background of spurious electrons is much less than the muon background at a proton accelerator such as the Brookhaven machine. Nevertheless, the experiment at Brookhaven was a difficult undertaking. Approximately 10^9 particles had to be rejected for every two that were found.

Unlike proton accelerators, storage rings for electrons and positrons produce very little particle debris. Therefore, the peaks that indicated the new

Particle Search Ends in an Amazing Coincidence

After months of independently pursuing what seemed like an extraordinary new particle, two research teams ended the latest running of the particle physics race in an apparently dead-heat finish. Close races are not unheard-of in particle physics, one of the most competitive of sciences, but this one featured one of the fastest experiments in modern times.

Last spring a team working at Brookhaven National Laboratory had set up an elaborate experiment designed to look for new particles and by August thought they had seen one with a mass of about 3.1 Gev. But they were not sure whether the effect was real or an artifact. So Brookhaven kept the news secret for several months while they collected and checked more data.

The team at Stanford Linear Accelerator Center (SLAC) had taken related data in June, before the storage ring needed for their experiments was shut down for the summer. During the fall Stanford's upgraded storage ring was monopolized by the technical staff on weekdays, for testing, leaving only weekends for the physicists. The weekend of 2 and 3 November was apparently devoted to the new and higher energy, 6 Gev. During the following week, Burton Richter at SLAC and Gerson Goldhaber at the Lawrence Berkeley Laboratory (LBL) became convinced that the data taken in June at 3.1 Gev were inconsistent and should be checked.

The West Coast team says it had not heard rumors of the East Coast result at this energy, and they apparently didn't know that time was running out on them during the week of 3 November. As it happened, the chief experimenter of the East Coast team, Samuel C. C. Ting of Massachusetts Institute of Technology, was due to fly to California Sunday night, 10 November, for a previously scheduled meeting of the SLAC program committee. As Ting prepared to leave New York, the Stanford team tuned its storage ring—with much difficulty—back to lower energies, and began rechecking their data. By this time they apparently knew they were looking for a resonance—a sharp rise and then decline in the particle production rate. But on Saturday, 9 November, they were only able to get one data point. Sunday, things were working better. By early afternoon, two more data points showed that the particle production rate was rising rapidly as the ring was tuned upward by small steps toward 3.105 Gev. Simultaneously, Goldhaber started writing a draft of the paper that would announce their result. By the time he finished writing late that afternoon, the data had peaked, showing a remarkable resonance that rose more than 100 times higher than background. Richter then redrafted the paper, this time including the parameters of the resonance. The Stanford paper, only 700 words long, was in its final form less than 1 day after the experiment had begun.

Ting's first formal meeting with the officials at SLAC was not until Monday morning, just before the advisory meeting. According to SLAC director Wolfgang Panofsky, Ting walked into Panofsky's office before the meeting and said, "I'd like to talk a little physics." When he had finished describing the Brookhaven experiment, Panofsky related that SLAC had made essentially the same observations.

Apparently, however, Ting had had an inkling of the news the night before. At midnight on Sunday, Pacific time, probably no more than 6 hours after the last data point was measured at SLAC, Ting had called Ronald Rau, associate director of Brookhaven, and said, "I'm at SLAC, and they have found this thing too, so we're going to publish."

On Monday the various researchers were so excited they couldn't wait to tell their colleagues. That day, Richter and Goldhaber gave seminars on the West Coast result to their respective colleagues at SLAC and LBL, and Ting also gave a seminar at SLAC explaining the East Coast result. It is doubtful whether much advisory committee business was transacted. The news traveled so fast that by late Monday word of the discovery had reached scientists in Europe.

The paper on the East Coast work was apparently ready to go, and had only to be carried to the office of *Physical Review Letters*, which is conveniently located at Brookhaven. The paper on the West Coast work was hand-carried back to Brookhaven on Tuesday by Ted Kycia, returning from the advisory meeting.

The new particle has already brought some fame to the discoverers, and could bring greater recognition in the future. If Ting had published the East Coast result a month earlier it would have had clear priority, but he has the reputation of being a very careful researcher and had held back. How badly did Ting want to keep his result secret? Enough to wager a considerable sum against his own success. Mel Schwartz, a SLAC physicist but not a member of the experimental team, had heard rumors that Ting had found a resonance at 3 Gev and asked him sometime in October if it were true. Ting said no, so Schwartz challenged him to bet \$10 there was no resonance. Ting accepted the bet, and posted a sign in his office saying, "I owe Mel Schwartz \$10." Later, when the news was out, he paid the bet off gladly, and said he would have been willing to bet \$50.—W.D.M.

particles stood out sharply above the background in the data taken at the Stanford storage ring. After the team working at Stanford began tracking down the causes of inconsistencies in earlier experiments measuring the gross properties of the production of hadrons [*Science* **184**, 782 (1974)], they were quickly able to find the first new particle. For similar reasons, the discovery of the second particle was rapid. Experiments initiated with collisions of electrons and positrons are also well suited to measure the width of the resonance, which indicates how long the unseen particle lives. It was the team at Stanford that was able to establish that the new resonance was extremely narrow—probably less than 100 kev.

The new discoveries were not made with the world's most powerful accelerators. In fact, the Brookhaven AGS is the oldest accelerator in operation in the United States, though not the one with the lowest energy. The new particles are right in the middle of the mass range that can be studied with the AGS, and if sufficient motivation had been available in the past, the new particle might have been found sooner. At the Italian facility in Frascati, where the first electron-positron storage ring was built, the new particle could have conceivably been found 5 years ago.

Ironically, the Brookhaven AGS is running short of money just now, with funds for only 26 weeks of operation in this fiscal year, and the SLAC budget is also restricted. "We'll bend every effort to follow up the new discovery," says Ronald Rau of Brookhaven, "but we will run out of money in the not too distant future and have to quit. That's a shame because this is a hell of an exciting time."—WILLIAM D. METZ

Exploring the Solar System (III): Whence the Moon?

Whether or not the moon has lost any of its popular mystique since man's footsteps have crossed its surface, its reputation among planetary scientists as an enigmatic object has grown rather than diminished as a result of the Apollo explorations. "Why is it," one geophysicist put it, "that the body with the most mysterious origin in the solar system dominates the night sky?"

The debate over the moon's origin continues unabated, with participants asserting in one form or another the hypotheses that the moon fissioned from the earth, was captured by the earth, or was formed along with the earth by accretion of smaller bodies. None of these mechanisms, alone or in combination, can yet be said to have been ruled out, and none is without serious objections. But the constraints for a theory of lunar origin are now somewhat clearer than before Apollo and there is increasing emphasis in recent work on the accretion hypothesis. The result is to focus new attention on the details of the accretional process and on a common origin for both planets and satellites. Indeed, rather than inquire why only the earth of all the inner planets should have a major moon, several investigators have turned the question around and are now asking why Mercury, Venus, and especially Mars do not.

That the moon is chemically quite different from the earth is now widely agreed. The differences are at once the major stumbling block for accretional theories (which imply that the moon was made in the same place and by the same processes that made the earth) and the major motivation for alternative hypotheses. Compared to the earth, the moon is enriched in refractory elements such as aluminum and uranium that condense at high temperatures, low in iron and nickel (the moon's metallic core, if there is one, is extremely small), and greatly depleted in volatile elements such as sulfur and lead.

Also constraining models of lunar origin are several pieces of information about the moon's geochemical history which are inferred from the Apollo studies. The entire body is thought to have been covered at one time with a layer of molten rock at least 100 kilometers deep in which the moon's original crust was formed. This crust apparently formed early in lunar history, no later than 4.3 billion to 4.6 billion years ago; and because of the cooling time required, the molten layer itself must have been formed in the first 100 million to 200 million years after the origin of the solar system. The accretion of material to form the moon must have effectively ended, it is thought, by the time the original crust had cooled, despite continuing heavy bombardment by meteoritic bodies for several hundred million years thereafter.

Geophysical constraints can also be inferred from the moon's orbital parameters and from the angular momentum of the earth-moon system. A puzzling circumstance is that the moon seems to be decelerating and receding from the earth at a rate that, if extrapolated back into the past, would imply separation of the two bodies less than a billion years ago, long after the formation of the youngest rocks found on the moon.

One proposed explanation is that tidal dissipation, which accounts for the deceleration, was lower in earlier times when continental configuration and climates were different. Estimates of the number of days in a month (a measure of the moon's distance from the earth) based on growth lines in fossil seashells seem to support a reduced dissipation in the past, but accurate data do not extend more than 0.5 billion years back in time. The moon's rapid deceleration thus appears to contradict the geochemical evidence for a more ancient origin and is not fully explained.

The various models of lunar origin all suffer the difficulty that the obvious explanations for the chemical differences between the earth and the moon are dynamically improbable, while the more dynamically acceptable mechanisms seem to offer little scope for chemical variability. Fission and capture models, in particular, seem to be favorites among investigators who are most concerned with explaining the chemical evidence. Others are prone to propose that the moon accreted in orbit around the earth (binary accretion models) on the basis of dynamical considerations without being able to explain just how chemical differences arose.

The possibility that the moon was once part of the earth and spun off due to rotational instability was first proposed by Darwin. A modern version of the fission hypothesis, due to D. U. Wise of the University of Massachusetts, proposes that when the earth was formed it was a homogeneous body rotating very rapidly but within the bounds of stability (with about twice the angular momentum of the present earth-moon system or a rotation period of about 2.6 hours). Subsequently the earth differentiated into a dense core and lighter mantle, reducing its