Tokyo. They used the double-arm spectrometer (DASP) at DESY. Both groups find that the angular distributions have the form $1 + \cos^2\theta$, consistent with spin one. Data from both DORIS and SPEAR have failed to show any front–back asymmetry in the angular distribution of muon pairs; such an asymmetry was reported earlier by another group and would have implied a parity violation in the decay of the 3.1-GeV particle.

The 3.7-GeV particle probably has the same spin and parity as its relative at 3.1 GeV. This conclusion stems from the isotropic distributions of the final state hadrons, including the pions from the decay of the 3.7-GeV into the 3.1-GeV particle. This cascade decay of the higher resonance into the lower one plus two pions has been observed by the SLAC–LBL/UC group. If you include neutral as well as charged pions, the 3.7-GeV particle decays in this mode 50% of the time.

Another quantum number—a negative G parity—may be assigned to the 3.1-GeV particle, according to the California team, because its only direct hadronic decays are to states with an odd number of pions.

Other particles? Although they have not found any new particles in their search up to a center-of-mass energy of 5.9 GeV, the SLAC–LBL/UC group did encounter a broad peak near 4.1 GeV. Its width is from 250 to 300 MeV and its strength is 13 nanobarns above background. The area under the broad peak is comparable to those under the two narrow resonances, which suggests they may be related, but the 4.1-GeV structure would have a much shorter lifetime than the others.

The other codiscoverers of the 3.1-GeV particle, a team from MIT and Brookhaven National Laboratory, has started an eight-week run at Brookhaven to look for other long-lived particles that decay into $p\bar{p}$, $K^+\pi^-$, K^+K^- and so forth, but do not decay into e^+e^-. According to Samuel Ting (MIT), preliminary runs have indicated a three to four standard-deviation effect that could be either statistical fluctuations or real particles with new decay modes. They have also measured the excitation curve of the 3.1-GeV particle and were surprised to find that it varies quickly with energy from 20 to 30 GeV.

One experiment performed by the DASP group at DORIS was a direct test of a prediction based on the ideas of charm. According to this theory,[1] the new particle at 3.1 GeV is a bound state of a charmed quark–antiquark pair, called "orthocharmonium," and the 3.7-GeV particle is a radially excited state of it. The theorists predict other excited states of orthocharmonium as well as various states of paracharmonium (with $J^P = 0^-$)—in short, an entire charmonium spectroscopy. The experimenters looked for one of the predicted transitions—from the 3.1-GeV particle into the lowest state of the predicted paracharmonium plus a gamma ray, and the subsequent decay of this 0^- particle into two gamma rays.[1] The measurements set an upper limit on the branching ratio for this particular decay mode that, while small, is still larger than the upper limit predicted by the charm theories.

A Stanford University team working at SPEAR and the SLAC–LBL/UC group are currently testing another prediction from the charmonium spectroscopy—the decay of the 3.7-GeV resonance into one gamma and an intermediate state and the decay of that state into one gamma plus the 3.1-GeV resonance. Thomas Appelquist (Harvard), one of the proponents of charm, believes this second cascade decay should have a larger branching ratio.

A new production mode in which both new particles have been seen is photoproduction. This observation shows that the particles are not weakly interacting. Photoproduction was observed by a group at Fermi Lab who bombarded a beryllium target with 80–200-GeV photons. They detected the lower-mass particle by its two-muon decay and the higher-mass one by its decay into four charged particles—two pions and two muons, the latter from the decay of the 3.1-GeV particle. The experimental group consisted of a collaboration from Columbia University, the University of Illinois and Fermi Lab, together with students from Cornell University and the University of Hawaii.

The cross section measured at Fermi Lab is about 15 nb per nucleus; this number represents the product of the total cross section for photoproduction times the branching ratio of the 3.1-GeV particle into muon pairs. If one takes the current value of the branching ratio—1/16—measured at SPEAR and the mass number of 9 for beryllium, one can find the cross section for photoproduction of the 3.1-GeV resonance off a single nucleon. The Fermi Lab team puts it in the range from 10 to 30 nb.

Photoproduction of the 3.1-GeV particle was also detected at much lower energies (around 18 GeV) by two groups working at SLAC. One collaboration from MIT, the University of Massachusetts and SLAC[2] used the same apparatus that had been used for electroproduction experiments to look for photoproduction of this and possible other new resonances. Another collaboration from University of Wisconsin and SLAC used two large spectrometers set right on the mass of the 3.1-GeV object. Both groups measured a cross section that is an order of magnitude smaller than that measured at the higher energies of Fermi Lab.

The Fermi Lab experiment also produced the 3.1-GeV particle in reactions with neutrons on beryllium, analogous to the (p,Be) reactions in which the MIT–Brookhaven team originally found this particle. However, the cross section measured at the higher energies of Fermi Lab is about 100 times that measured by the MIT–Brookhaven team. Wonyong Lee (Columbia) cautions that the experiments are not directly compared because they had different kinematical conditions. One surprising aspect of the neutron-production data, felt Lee, is the large momentum transfer to the 3.1-GeV particle. —BGL

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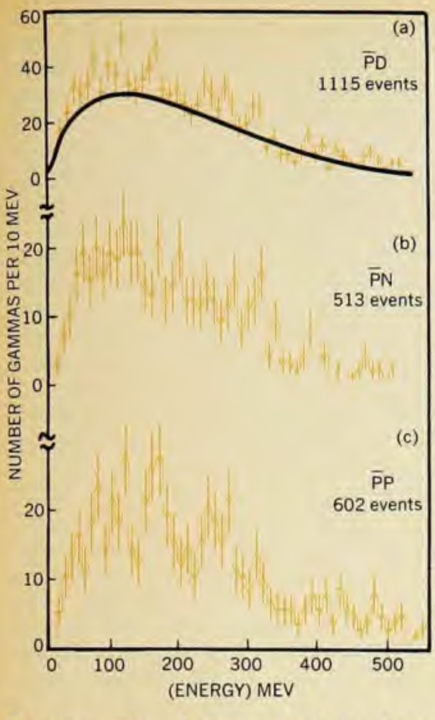
Nucleon–antinucleon bound states suggested

Does positronium have an analogy in the nucleon–antinucleon system? The existence of such narrow bound states is a possible explanation for results of a recent experiment that seem to contradict predictions of charge independence. Specifically, a team from Syracuse University, New York and from the Nuclear Research Center Demokritos in Athens, Greece[1] found that in pionic annihilations at rest of antiprotons on deuterium, the resulting charged pions carried away less energy than is expected if the strong interaction forces are independent of charge. The Syracuse–Athens team then gathered evidence that the "missing" energy is taken away by an excess number of gamma rays; that is, more gamma rays than should be produced by decay of the neutral pions into two gammas. The experimenters feel that these extra gammas represent electromagnetic transitions between narrow nucleon–antinucleon resonances or bound states, which they have named "cosmion."[2] If their interpretation is correct then perhaps such narrow nucleon–antinucleon resonances or bound states are connected to the newly discovered J or ψ particles at 3.1 and 3.7 GeV; such is the suggestion of Alfred Goldhaber and Maurice Goldhaber.[3] Another interesting feature of such possible states is that their characteristic gamma rays could identify regions of the universe where antimatter (if it exists) meets matter.

The experiment was conducted by a group consisting of Tassos A. Fillipas, George Grammatikakis, Theodora Papadopoulou, Errietta Simopoulou and



Energy spectra of gamma rays in all $\bar{p}d$ events (a) compared with the background (curve) expected if all gammas result from π^0 decays and if the π^0's have the same energy spectrum as $\pi^{\pm}$. Significant fluctuations do not correlate as well with annihilations on the neutron (b) as with those on the proton (c). From T. E. Kalogeropoulos et al, reference 2.

Anna Vayaki of Demokritos and Lee Gray, Jaya Roy, and George Tzanakos of Syracuse, under the direction of Theodore E. Kalogeropoulos of both Demokritos and Syracuse. They used the 30-inch deuterium bubble chamber at Brookhaven National Laboratory.

The Syracuse–Athens team measured all charged tracks associated with the pionic annihilation

$$\bar{p} + d \longrightarrow \text{pions} + \text{nucleon}$$

where the final state might consist of any number of pions from 1 to 7. In such annihilations, charge independence predicts that the total number of charged pions should equal twice the number of neutral (unseen) pions. It follows that the charged pions should have 2/3 of the available energy. In a study of about 3000 events the Syracuse–Athens team found that the total energy of the charged pions, after correction for events with invisible kaons, was 1169 ± 10 MeV, less than 2/3 the total available energy (1862 ± 2 MeV) by 72 ± 10 MeV. The experimenters calculated the contribution to this energy from gammas resulting from electromagnetic decays of the η and ω particles, which violate isotopic spin invariance, but found that this contribution totalled only 14 ± 3 MeV and cannot account for the observed effect.

In order to investigate the source of this excess energy further, Kalogeropoulos, together with Vayaki, Grammatikakis, Takis Tsilimigras and Simopoulou of Demokritos, studied the gamma-ray energy spectrum from the same bubble-chamber film. Their analysis revealed that an excess of about 0.73 gamma rays per event had been emitted above those normally associated with the neutral π^0.

There is evidence from the gamma-ray spectra, especially that from the $\bar{p}$ p annihilation (see figure) that these gammas are emitted when the nucleon–antinucleon system goes from a higher to a lower state prior to annihilation. However, an exact determination requires better measurement of the gamma-ray energy than can be made in deuterium bubble chambers. A Brookhaven–Syracuse collaboration is planning to repeat the experiments with a large sodium-iodide crystal detector, which will yield an order of magnitude more gammas. A counter experiment now in progress at Brookhaven to look for the charge independence violations in $\bar{p}p$ annihilations has so far yielded negative results; however these results may only mean that the resonances cannot be produced as effectively in $\bar{p}p$ as in $\bar{p}d$ systems because the total energy is above that required to produce the resonance and the $\bar{p}p$ system has no spectator nucleon to carry off some of the excess energy.

The current experiment is not the first to give evidence for the existence of nucleon–antinucleon bound states: Kalogeropoulos has called attention to the evidence in several review papers[4] and has participated in some of the relevant experiments. Among some of the experimental indications that he feels support the existence of bound states in the $\bar{N}N$ system at low energy are:

- the presence of unusually high angular momentum waves at rest and at low energies; this contradicts earlier beliefs of S-wave capture dominance for such annihilation.
- the lack of final-state interactions between the spectator nucleon and the annihilation products; this implied to Kalogeropoulos that a resonance was produced and lived long enough to be separated from the spectator nucleon before it decayed.
- the dependence of the reaction $\bar{p}d \rightarrow \pi^-\pi^0 p$ at rest on the momentum of the spectator proton; this suggested that the annihilation is very sensitive to energy and may go through a resonance.
- a peak in the momentum spectrum of the spectator proton in $\bar{p}d$ events with an even number of pions but no peak for an odd number of pions.
- two bumps observed in $\bar{p}p$ and $\bar{p}d$ annihilations measured in recent high statistics experiments.

In addition to the experimental indications, Iosif S. Shapiro and other theorists at the Institute for Theoretical and Experimental Physics have done calculations that predict resonant states in $\bar{N}N$.[5] —BGL

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A pulsar that doesn't slow down fast enough

A pulsar that is slowing down much less rapidly than any other known pulsar may have some interesting implications for current theories of pulsar formation and perhaps even for theories of expansion of the universe. David Richards, John Rankin and Gustave Zeissig studied the pulsar, JP 1953, as one of 13 in a continuing program of precise pulse timing[1] at the Arecibo Observatory in Puerto Rico. A surprising result of the study, they comment in *Nature*, is that for JP 1953, dP/dt, the change in its 0.4 sec period with time, is only about 0.003 $\pm$ 0.007 $\times$ 10^{-15} seconds per second. The previously known smallest value for any pulsar had been 0.15 $\times$ 10^{-15}, and a typical value exceeds 10^{-15}.

When the "age" of this pulsar is calculated, a puzzling situation arises: JP 1953 is apparently older than the universe. But, as Frank Drake (Cornell University, Ithaca) explains, this so-called "age" is not necessarily the past lifetime of the pulsar, and what we may be observing is a pulsar that was born spinning more slowly than other pulsars so far observed. Drake suggests that this pulsar may be a neutron star with a very low magnetic field, which he considers to be strange because no intermediate cases have been observed, or it may even be a white dwarf, which has a much larger moment of inertia than a neutron star.

A sufficiently low pulsar spindown rate could be a test of certain theories of expansion of the universe: This possibility has been pointed out by several astrophysicists, among them Charles Counselman and Irwin Shapiro (both of the Massachusetts Institute of Technology)[2] and Malvin Ruderman (Columbia University, New York), who connected the idea with this pulsar. As Ruder-