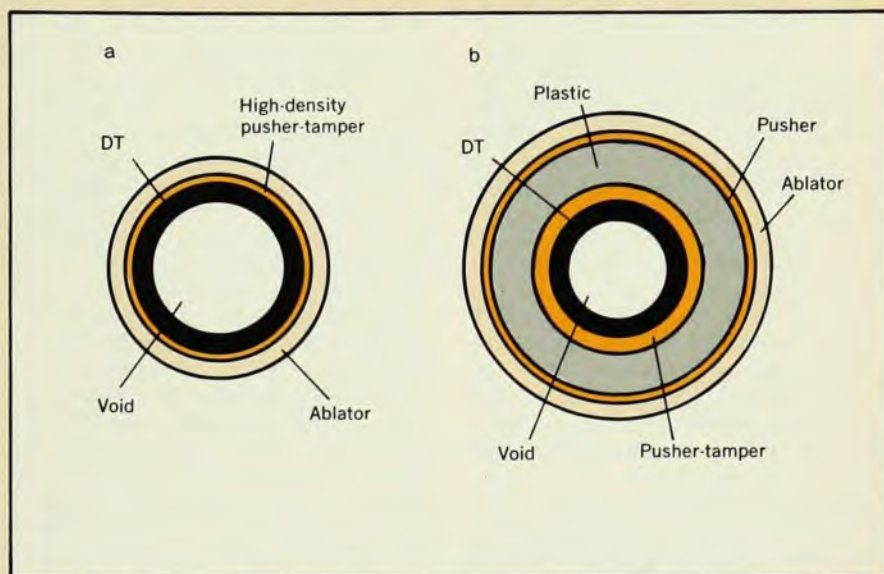


# search & discovery

## Problems with fuel pellets for laser-induced fusion

The nature of fuel pellets and their implications for laser-induced fusion are a little less mysterious since the AEC declassification of information regarding them. (See *PHYSICS TODAY*, February, page 78.) This previously withheld information was quickly disseminated because the secrecy was lifted just before two pertinent conferences—the meeting of the APS Plasma Division in Albuquerque, N. M. during 28–31 October and the Fifth IAEA Conference on Plasma Physics and Controlled Nuclear Fusion Research held in Tokyo, Japan 1–15 November.

Among the general conclusions from theoretical studies of various fuel pellets were that the hydrodynamic instabilities, which could break a fuel pellet apart, were more serious than had been expected and that for long-wavelength laser experiments the thermal conductivity of electrons, which must transport the energy from the region of laser absorption on the outside of the pellet toward the solid interior, was inhibited by plasma instabilities. Largely because of these hydrodynamic and plasma instabilities, John Nuckolls of Lawrence Livermore Laboratory has raised his estimate of the laser power required to achieve “breakeven” (where energy output equals laser energy input) from 1 kJ to 5 kJ. Both the problems of hydrodynamic instabilities and the lower thermal conductivity, together with the construction of high-powered lasers, constitute what Richard L. Morse of



**Two typical fuel pellets in theoretical studies.** The simpler one (a) is hollow with DT fuel (black) frozen onto a high-Z “pusher-tamper” (dark color) and with an ablator layer (light color) outside. Another variety of pellet (b) has multiple layers of pushers, separated by a layer of plastic (grey).

Los Alamos Scientific Laboratory termed the basic physics challenges in laser-fusion research today.

Such conclusions are drawn from computer models of fusion fuel pellets and their behavior during implosion and burn of the fuel. The various research groups are studying whether additions of layers of different materials to the bare fuel might help increase the energy gain, reduce the hydrodynamic

and plasma instabilities, eliminate the need for stringently tailored laser pulses, and so on. Most designs start with a hollow layer of frozen fuel, usually a deuterium-tritium mixture. The hollow target should reduce the laser power required for implosion. Originally, researchers hoped that the reduced power would mean that they could use longer-wavelength lasers, but the Livermore computer calculations

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## More data on the new particles: theory uncertain

High-energy experimentalists are starting to paint a more complete, although still sketchy, picture of the new particles at 3.1 and 3.7 GeV that were discovered by surprise last November (see *PHYSICS TODAY*, January, page 17). Results so far are consistent with the early expectations that both particles are vector particles. They have been photoproduced, and the high-energy resonance has been seen to decay into the lower one. Finally, these two particles appear to stand alone, as searches for other narrow resonances have so far yielded nothing except a broad peak at 4.1 GeV. Such was the picture presented by experimentalists from several in-

stitutions at the Annual APS Meeting in Anaheim, California from 29 January to 1 February. While the new results fit into some of the proposed theoretical schemes better than into others, they do not mesh completely with any of them. In a possibly related development, a weakly interacting particle carrying a new quantum number has been suggested by recent neutrino experiments. (See box on page 24.)

**Two-muon decay.** Evidence that the 3.1-GeV particle is a vector particle comes primarily from examinations of the two-muon decay of this narrow resonance. The collaboration from SLAC and the Lawrence Berkeley Laboratory/

University of California that was a co-discoverer of the 3.1-GeV particle have measurements of the interference between the muon pairs produced by the resonance and those produced by the normal electromagnetic process. The data so far give a three-standard-deviation effect in the right direction for the resonance to have the same spin and parity as the photon. The angular distributions of the produced muons and electrons have been measured by the California group and by a collaboration at DESY's new storage rings, DORIS. The collaboration consists of the University of Aachen, DESY, the Max Planck Institute and the University of



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  $\bar{p}p$ ,  $K^+\pi^-$ ,  $K^+K^-$  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,<sup>1</sup> 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 parachocharmonium (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 parachocharmonium plus a gamma ray, and the subsequent decay of this  $0^-$  particle into two gamma rays.<sup>1</sup> 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<sup>2</sup> 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<sup>1</sup> 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."<sup>2</sup> If their interpretation is correct then perhaps such narrow nucleon-antinucleon resonances or bound states are connected to the newly discovered J or  $\psi$  particles at 3.1 and 3.7 GeV; such is the suggestion of Alfred Goldhaber and Maurice Goldhaber.<sup>3</sup> 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