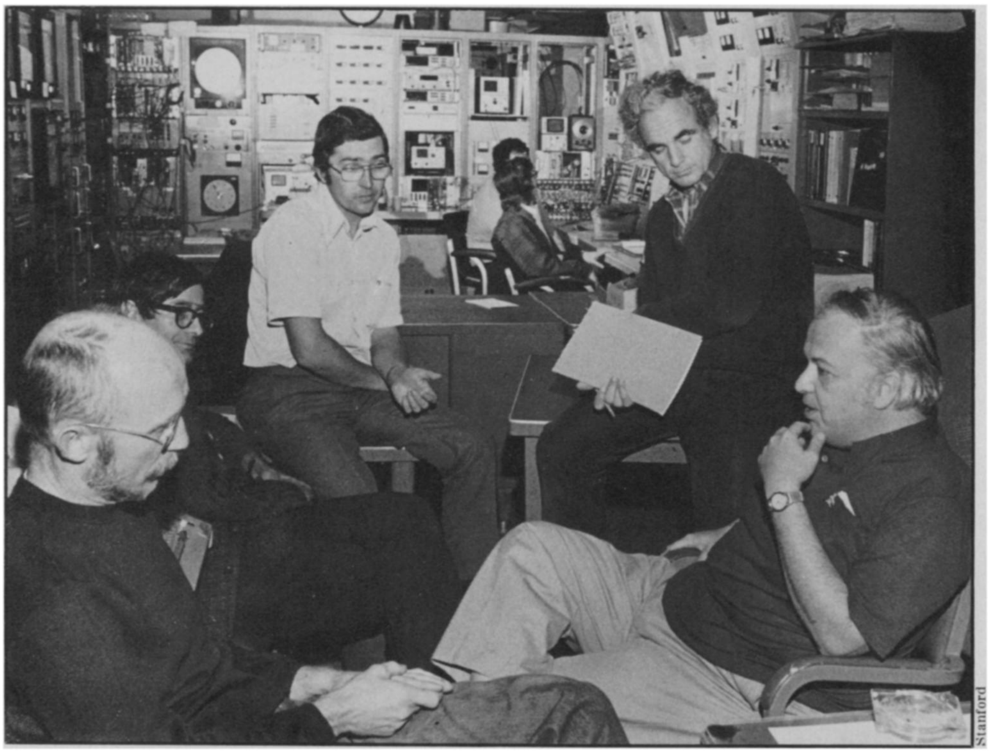
CHARMED I'M SURE?

First published responses of theoretical physicists to the surprising new discovery of psi or J particles include suggestions that they are made of charmed, colored quarks. If so, they may be a new bound state called 'charmonium.'

by Dietrick E. Thomsen



The SLAC-Berkeley group in the control room where the psi's peak appeared in the data.

In physics a new and unexpected discovery may or may not cause consternation among theorists; it always causes publication. If the discovery is in a highly specialized branch of the science, one or two theorists whose interest it touches may try to assess its significance. If the discovery is a new subatomic particle with extremely unusual properties, a grand multitude of theorists sharpen their pencils and reach for fresh reams of yellow paper.

Now 20 theorists in nine papers in PHYSICAL REVIEW LETTERS (Jan. 6) present the earliest published theoretical response to the momentous discovery in November of the J or psi particles (SN: 11/23/74, p. 324; 11/30/74, p. 340). The list includes many of the most prominent names in particle theorizing. It is presented here in the order of printing in PRL (with institutional attributions omitted for the sake of space): Alfred S. Goldhaber and Maurice Goldhaber; Julian Schwinger; S. Borchardt, V. S. Mathur and S. Okubo; R. Michael Barnett; Thomas Appelquist and H. David Politzer; A. De Rújula and S. L. Glashow; H. T. Nieh, Tai tsun Wu and Chen Ning Yang; C. G. Callan, R. L. Kingsley, S. B. Treiman, F. Wilczek and A. Zee; J. J. Sakurai.

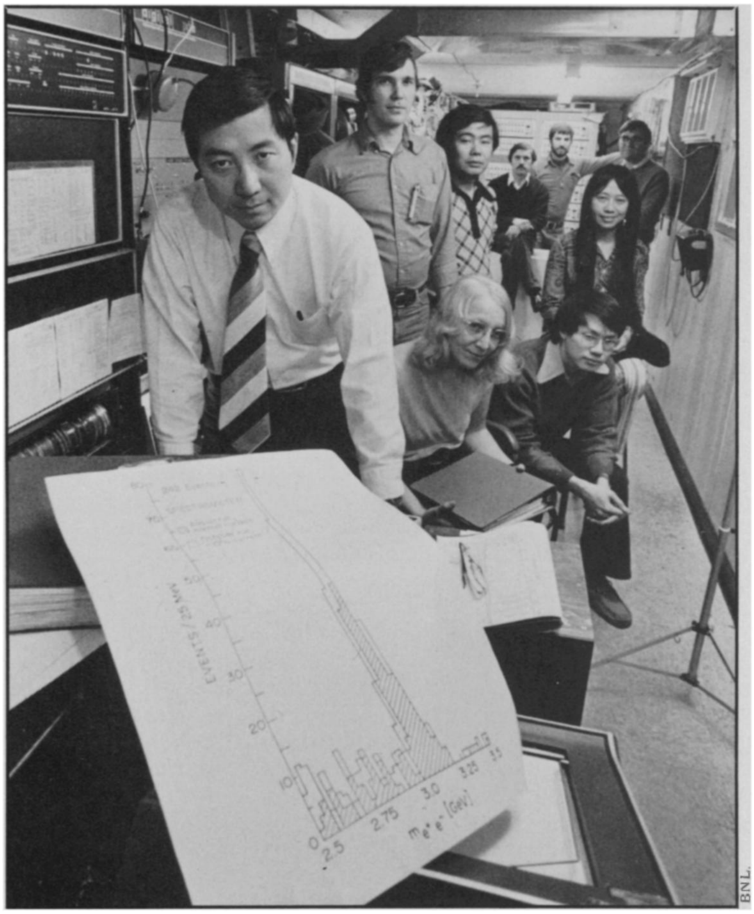
For such a large group the amount of agreement would be surprising if recent trends had not weighted expectation somewhat in the direction of the phenomenon agreed upon. The majority seem to feel that the new particles manifest a heretofore unverified property of subatomic particles, known to theorists under the name "charm." More on that later.

The first of the two new particles, psi(3105) or J, was discovered simultaneously Nov. 8 at the Stanford Linear Accelerator Center and at Brookhaven National Laboratory. Psi is SLAC's appellation; J is Brookhaven's. The second particle, psi(3700), was reported by SLAC 12 days after the first.

The most gripping things about them are their enormous masses and their lifetimes against radioactive decay. Their masses are 3,105 million electron-volts (MeV) and 3,700 MeV. They are, by a thousand MeV or more, the heaviest particles yet known. They last an unbelievably long time for particles of such large masses subject (ostensibly) to the strong interaction, the force that holds atomic nuclei together.

Charm, specifically the operation of what is called a charmed quark, was one of the first off-the-cuff suggestions to explain the unusual properties of the new particles, but there were other proposals too, and others surely yet to come. (By no means all prominent particle theorists are represented in this printed symposium organized by the editors of PRL; some important people have yet to vote.)

One of the early suggestions was that the new particles may be the intermediate vector boson or related particles that embody the forces of the weak interaction (a class of force responsible for certain slow radioactive decays) and are important in newly unified theories of that interaction and electromagnetism. This is a suggestion that seems to be made about every new particle discovery or supposed discovery and very quickly gets retracted. This idea is mentioned, but dubiously, in three of the current papers, the Nieh-Wu-Yang, the Borchardt-Mathur-Okubo and the De Rújula-Glashow. Borchardt-Mathur-Okubo throw cold water on it by remarking, "The identification of psi with the intermediate vector boson mediating weak interactions, at a mass value [3,105 MeV], would contradict the mass constraint imposed by the currently popular unified . . . theory models of weak and electromagnetic interactions." De Rújula and Glashow say "not likely." Most of these models would expect a much heavier boson.



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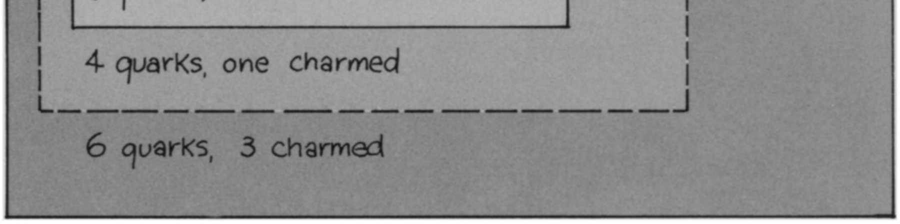
The MIT-Brookhaven group displays the data showing the peak that they decided to call J.

In a contribution included as a "comment" rather than a "letter," Sakurai argues for the intermediate boson interpretation of psi(3105) but admits that his interpretation cannot explain the psi(3700) nor certain weak-interaction experimental results at very high energies.



	Charm O	Charm O	Charm O	Charm 1	Charm 1	Charm 1
RED	P	N	λ	P'	N'	λ'
WHITE	P	N	λ	P'	N'	λ'
BLUE	P	N	λ	P'	N'	λ'

3 quarks, none charmed

4 quarks, one charmed

6 quarks, 3 charmed

Coloring quarks gives three versions of each of the basic quarks, P, N, and lambda. The new theories now add either one or three charmed quarks. Coloring these brings a grand total of 18. There are also 18 corresponding antiquarks.

Two of the present letters (the Goldhabers' and Schwinger's) attribute the structure of the new particles to something other than charm. The Goldhabers' suggestion is that the new particles are really a new and unusual sort of atomic nucleus, a case in which a baryon, a member of the class of heavy particles that the proton and neutron belong to, is bound to its antiparticle. Such a baryon-antibaryon bound state has a parallel, the Goldhabers point out, in the recent observation by T. E. Kalogeropoulos and collaborators of a similar state that appears fleetingly when a baryon and an antibaryon come together to annihilate each other (SN: 1/11/75, p. 20).

Schwinger relates the appearance of the psi's to a unified theory of electromagnetic and weak interactions that he has worked out in recent years. This theory proposes that two types of mesons (a class of particles lighter than the baryons, some of which appear to embody the forces of the strong interaction) with unit spin can mix together, producing entities that appear as new particles. One of these, he avers, would have exactly the characteristics of the psi(3105). Others should exist so that there will be counterparts for all three of the mesons Schwinger is particularly concerned, with rho-zero, omega and phi. He is well pleased with the discovery of psi(3700): "The public announcement by the Stanford Linear Accelerator group of a second very sharp resonance at [3,700 MeV] lends additional support to this interpretation, and diminishes the appeal of any alternative interpretation that does not provide a natural setting for more than one such particle," he notes.

Nieh, Wu and Yang are less interested in the structure of the new particles than in how they interact with the rest of the world. Their analysis leads to a rather striking suggestion: that a new class of interaction, medium weak, is at work in the decay of the new particles. So far physicists agree on the existence of four interactions or classes of force: the strong, the electromagnetic, the weak and the gravitational. A fifth, the superweak, has been suggested to explain certain meson decays. The medium weak is the sixth suggestion; it would be weaker than the strong and the electromagnetic, but stronger than the weak and the gravitational. In this connection Nieh, Wu and Yang suggest that there are some new quantum numbers, qualities that account for the unusual stability of the J-psi and could lend similar exceptional stability to other new hadrons. They recommend a search for such particles.

Quantum numbers represent qualities that are important for the ways particles interact with each other. By keeping books on the right quantum numbers, physicists can predict or "explain" what behavior is allowed and what is forbidden for a given particle. Some quantum numbers, like electric charge or spin, have points of reference to the world at large. Others are arbitrary possessions of the microcosm. Examples are baryon number and strangeness. The class of particles called baryons behave in certain ways but not in others that seem equally plausible. Why not? The standard answer is that there is a quality of intrinsic "baryonness" that must be conserved in the decays and other activities of these particles. If you say that every baryon has a baryon number one (minus one for an antibaryon) and keep book so that the total baryon number on both sides of an event is the same, the right processes come out right and the wrong ones don't happen.

Not so many years ago a new group of particles began to appear, at first in the cosmic rays, particles that didn't decay in the expected manner. They were strange particles, and the problem of their behavior was solved by inventing the quantum number "strangeness." Each strange particle has a given amount of strangeness, and there are complicated rules about if and how strangeness can change.

There is no essential definition of what baryonness or strangeness is; they are just qualities that account for conservation laws, or vice versa. Essential definitions are the province of philosophy, not physics. We don't have an essential definition of electric charge either, but we are so used to it that we don't bother to ask for one.

Charm—and color, which gets into this act too—are quantum numbers particularly associated with quarks, the hypothetical building blocks out of which particles (hadrons, anyway) are supposed to be made. The original quark theory proposed three quarks, usually designated P, N and lambda, and three antiquarks designated by the same letters with bars over them. The properties of the hadrons could be explained by viewing them as composed of two or three of those entities.

But some nitty-gritty got into the smooth workings of the theory. From the point of view of statistics, quarks are fermions. This means they obey a statistical rule (Fermi-Dirac statistics) which says no two of them in a given place can have exactly the same set of quantum numbers, but it seemed as if that did in fact happen as long as one confined one's reckoning to quantum numbers already known. The solution was to invent a new quantum number, called "color." Color comes in three varieties, red, white and blue. The terms have absolutely no relationships to wax crayons or water paints; it is just that physicists are running out of names for things. With three colors the basic set of quarks goes up to nine, which obey Fermi-Dirac statistics.

Then there are some kinds of radioactive decay that should happen, but don't. To explain their absence, another new quantum number was found. This one is called "charm." Again, in this context, the word has no meaning except as five pronounceable letters that designate a quantum number. The final five papers published in the Physical Review Letters presentation regard the newly discovered particles as examples of the workings of a charmed and possibly colored quark. A special attraction of the idea is that charmed particles should have difficulty decaying into uncharmed ones, and that could explain the long lifetime.

The simplest way to bring in charm is to postulate a fourth basic quark with a single unit of charm. If color and charm are combined, this fourth could take all three colors, raising the basic set to 12. The fourth quark option is taken in different ways by Borchardt, Mathur and Okubo, by Appelquist and Politzer and by De Rújula and Glashow. All three see the new particle psi(3105) as a combination of the charmed quark (P′) and its antimatter counterpart, the charmed antiquark (designated ditto with a bar over it).

In the view of Borchardt, Mathur and Okubo a little of the uncharmed quarks are mixed into this structure. They also see the psi structure as an analogue to the group of particles called vector mesons (psi, rho, phi and K*), which are of great theoretical and experimental interest these days. They propose that psi is a member of a group in which there is a charmed analogue for each vector meson.

Appelquist and Politzer, presenting what they call a "colored quark-gluon model" (gluons are what hold quarks together), say their charmed quark is a heavy quark in contrast to the three uncharmed, or light quarks. (Since no one knows the mass of a light quark, don't ask the mass of a heavy one.) They designate the charmed-quark-charmed-antiquark bound state as "charmonium" and say that what has been found is specifically orthocharmonium. Paracharmonium (a version with slightly different quantum numbers, but still charmed) should also exist at a slightly different mass, and they think it ought to be looked for. (The terms ortho and para come from analogy with hydrogen molecules.)

De Rújula and Glashow also use a heavy charmed quark to come up with ortho and paracharmonium. They too suggest that many more charmed mesons exist (charmonium is a mesonic structure) as well as charmed baryons (combinations of one charmed and two uncharmed quarks), and they point out ways of looking for them. They surmise there may be more heavy quarks and new quantum numbers beyond charm.

Barnett's attitude is more radical. He will not stop at four basic quarks; he wants six, three charmed and three uncharmed (add prime marks to all three basic letters). Since he maintains three colors, this gives a fundamental set of 18. He too sees the psi as a combination of charmed quarks and antiquarks and predicts more charmed particles.

Callan, Kingsley, Treiman, Wilczek and Zee offer charmed quarks that may or may not be other people's (notably Glashow's) charmed quarks. They also interpret the psi's as bound states of charmed quark and charmed antiquark. They, too, see a close relationship with the vector mesons, and they, too, predict many more charmed particles and estimate their mass ranges. They interpret the psi(3700) as a particular, excited state of the lower-mass psi.

So a first theoretical look at the new particles shows both wide and narrow differences of opinion among representative theorists. Meanwhile back at the accelerator. . . . □