duction by administering indomethacin to the intact animal will increase or decrease blood pressure is unclear. Indomethacin is sometimes used as a substitute for aspirin, but McGiff says that there is no evidence that it increases the blood pressure of individuals taking it. McGiff and his colleagues found that the drug did increase the blood pressure of rabbits and dogs.

On the other hand, Jürgen Frölich, John Oates, and their colleagues at Vanderbilt University, found that indomethacin decreased blood pressure in a small number of hypertensive patients and in normal individuals. They gave the drug to human volunteers because they and other investigators had evidence that prostaglandins stimulate the release of renin by the kidneys. This would favor angiotensin production and should increase blood pressure. But angiotensin increases PGE_2 production by the kidney and this should decrease blood pressure. This situation will obviously require further clarification.

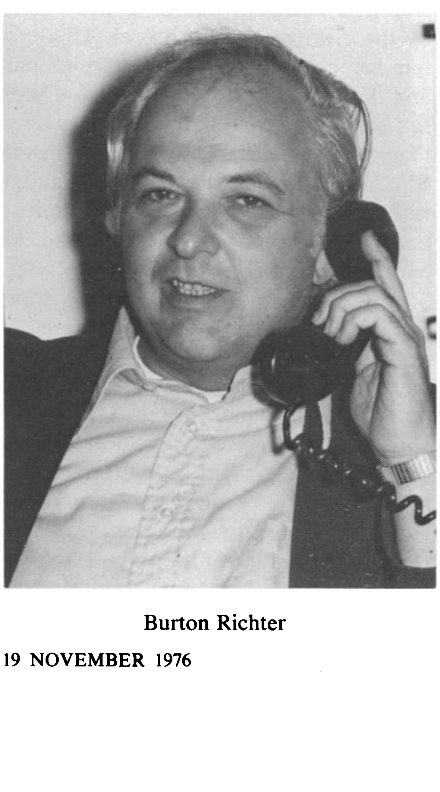
Part of the problem may be that several systems are interacting to control blood pressure, and they are all influenced not just by each other but by such experimental conditions as the water and salt balance of the subjects. In other words, investigators of the mechanisms controlling blood pressure still have some problems to solve.

—JEAN L. MARX

The 1976 Nobel Prize in Physics

On 11 November 1974, the world of high energy physics was electrified by the news of the discovery of a new particle with remarkable properties. Just as remarkable was the fact that two groups had found it—one a group from Massachusetts Institute of Technology and Brookhaven National Laboratory led by Samuel C. C. Ting, and the other a Stanford Linear Accelerator Center–Lawrence Berkeley Laboratory (SLAC-LBL) collaboration led by Burton Richter. The sudden but permanent impact of that discovery on the field has been recognized by the award of this year's Nobel Prize in Physics to Richter and Ting, only 2 years after the great discovery.

Ting's group was studying production of an electron in conjunction with its antiparticle—the positron—in proton-nucleon collisions at Brookhaven. They found (*1*) a remarkable yield of electron-positron pairs of rest energy 3.1 Gev, indicating the production of a new particle, which they named *J*. Richter's collaboration was studying the process in reverse: what is formed when beams of electrons and positrons are made to collide head-on and annihilate to produce other forms of matter. Data taken near a total electron-positron energy of 3.1 Gev had shown erratic, irreproducible behavior, convincing the SLAC-LBL experimentalists to go back and explore that region again more carefully. During their next running period it only took a few days to find (*2*) that at precisely 3.098 Gev the rate of annihilation increased more than a hundredfold, indicating resonant production of a new particle, which they named ψ.



Burton Richter

By chance, Ting was on his way to SLAC to attend a committee meeting when the SLAC-LBL discovery occurred. Both results were presented in a memorable session at SLAC, attended by a huge crowd that included not only the usual physicists but many staff people swept up in the excitement. The euphoria spread worldwide, and in my experience not since the discovery of parity nonconservation (including the perhaps more profound discovery in 1964 of the violation of CP invariance) has an experiment had such a sudden and revolutionary psychological impact. This immediate recognition of the importance of J/ψ came about because of its relatively large rest mass, more than three times that of the proton, its relatively long lifetime, and the ease of formation by the colliding electron-positron beams. The intervening 2 years have confirmed the original expectation: the ψ (*3*) had led to the apparent discovery of a new property of matter called charm.

Richter, after obtaining his degree at MIT, went to Stanford in 1956 determined to carry out experiments testing the foundations of quantum electrodynamics—the marriage of the Maxwell theory to the Dirac electron theory and to quantum mechanics. Richter first made measurements of the production of electron-positron pairs by 100-Mev gamma-rays, under conditions designed to strain the theory to the utmost. The results agreed with quantum electrodynamics. Around this time, G. K. O'Neill of Princeton made the audacious suggestion that intense electron beams could be stored and made to collide with each other at rates so high that processes of interest to high energy physics would be observable. Ordinary scattering of electrons at large momentum transfer would provide a quite sensitive test of electrodynamics at small distances. Richter, along with W. C. Barber and B. Gittelman, joined with O'Neill and built at Stanford a pair of electron storage rings with the 550-Mev linear electron accelerator as injector, and they successfully observed the electron-electron collisions. Again quantum electrodynamics was verified, this time on a distance scale small compared to the size of the proton.

Samuel C. C. Ting

Meanwhile measurements of electron-positron pair production with higher energy gamma-rays had been carried out at the Cambridge Electron Accelerator (CEA) at Harvard University. The results did not agree with the predictions of quantum electrodynamics. Ting, after obtaining his degree at the University of Michigan, had joined Columbia University, and was finishing an experiment at Brookhaven (which included the experimental discovery of antideuterium). He decided to repeat the pair production measurement, and chose to go to Hamburg, Germany, where a 6-Gev electron-synchrotron (DESY) had been recently completed. Ting and his group built a double arm spectrometer to catch the electron and positron. With remarkably careful, thorough measurements and analysis, Ting's experiment gave results in precise agreement with the predictions of quantum electrodynamics. Ting then went on to study the production of hadrons (strongly interacting particles) by gamma-rays, using the same apparatus.

Up, Down, Strange, and Charmed Quarks

The most accessible and interesting of these are mesons known as ρ, ω, and ϕ. The ρ and ω are presently described as states of a quark bound to its antiquark by the same strong force which binds three quarks into the proton or neutron. The ϕ which Ting (and many others) studied turns out to have special significance for the new physics of the ψ. While the first two mesons are built from the same quarks ("up" and "down") that build the proton and neutron, the ϕ appears to be built from a third, "strange" quark bound to its antiquark, and is a prototype for the ψ, which is now believed to be a similar object constructed of a fourth, heavier "charmed" quark bound to its antiparticle.

Meanwhile, Richter moved to SLAC and turned to a series of precision studies of meson production by gamma-rays. At the same time he led the design effort for a higher energy electron-positron storage ring, with the 20-Gev SLAC linear accelerator as injector. However, funding was not forthcoming, and other laboratories further developed the storage ring art. The French, with their storage ring ACO, made beautiful studies of ρ, ω, and ϕ, which were found to be formed abundantly when the total energy of the colliding-beam system was tuned to the rest energy of the appropriate particle. This was followed by more research at higher energy at other storage rings in Frascati, Italy, and Novosibirsk in the Soviet Union. Richter kept trying to find ways of building a storage ring, and proposed a less expensive version. In 1970, W. K. H. Panofsky, the SLAC director, made the decision to go ahead with construction of the machine, called SPEAR, to be headed by Richter. Funds for SPEAR had to be found within the normal budget for the laboratory, and consequently it is considerably more austere than the earlier design. From the outside, the machine has all the elegance of the Berlin wall—nothing but a ring of concrete shielding blocks and barbed wire. But it possesses hidden charm, perhaps even beauty, when the actual instrument is seen from within. SPEAR incorporated much of the wisdom accumulated over the years on how best to control and avoid the many instabilities inherent in the electron and positron beams. In addition, a sophisticated and innovative detector incorporating a large solenoid magnet (with a field volume of several cubic meters) full of scintillation counters, shower counters, and wire chambers was designed, which turned out to have a versatility and capability well matched to the physics produced by the storage rings.

The construction was completed just after measurements at CEA—itself turned into a storage ring—indicated exceptionally large production of hadrons at higher energies (4 to 5 Gev)—a factor of at least 5 or so over early optimistic estimates. Those measurements were confirmed and extended at SPEAR during 1974. These results led to a period of near hysteria in the theoretical community, and stimulated the concentration on improved accuracy, which led by the end of the year to the discovery of the ψ.

Ting meanwhile was completing the successful program started at DESY and had accepted a position at MIT. He decided to mount a new experiment at Brookhaven, again to look at pairs of charged particles—especially his old friends the electrons and positrons—primarily to search for heavier versions of ρ, ω, and ϕ. A BNL experiment headed by Leon Lederman, with whom Ting had collaborated in the early Brookhaven days, had recently been completed, and a large yield of muon pairs of high mass had been observed. For everyday life the mu is a most inconsequential object. But to the elementary particle physicist it is a close relative of the electron. Once the difference in rest mass (the muon is 200 times heavier) is taken into account, the ways the mu couples to matter appear identical to those of the electron. Ting realized that by using his spectrometers for electron and positron detection he could make much more sensitive measurements of the process studied by Lederman, who meanwhile chose to repeat the same experiment (also with electron detection) at the much higher energies available with colliding proton-proton beams at CERN, the European high energy physics laboratory in Geneva, Switzerland, and at the Fermilab accelerator at Batavia, Illinois.

Even with his years of experience with spectrometers at DESY, Ting did not find it easy to remove the larger background of unwanted particles at BNL. The apparatus had to be immersed in many tons of shielding, making access difficult. This included 10,000 pounds of Borax soap (a cheap neutron shield) which guaranteed that it would be a clean experiment. Evidence for his sharp *J* peak first appeared in August 1974, but Ting, always a most cautious and thorough worker, checked and rechecked to be sure the effect was real. By 11 November, when everything became public, the Ting group was very close to publication of their results.

What has happened since the discovery? Almost immediately, the favorite hypothesis of the theoretical community was that the ψ consisted of a fourth "charmed" quark bound to its antiquark. This was not just phenomenology; there had been a growing need for such an object for more basic reasons—reasons that had to do with weak interactions, and which we return to later. The analogy of ψ to ϕ turned out to be powerful. The ψ should be produced by gamma-rays in a way similar to the ϕ, and this was soon found to be the case in experiments at SLAC, Cornell, and Fermilab. Also, if ψ were a bound system of two spin 1/2 particles, there could be excited levels with a spectrum similar to that of positronium (the system of electron and positron, bound to each other by the electromagnetic force). This system has become known as charmonium, and the 1*S*, 2*S*, and 2*P* states have been reasonably well delineated by now, thanks to a series of beautiful studies at SPEAR as well as at the DESY storage ring DORIS. There was early optimism that charmonium would literally be the hydrogen atom of the strong interactions. The idea was that at the short distances (of order 10^{-14} cm) appropriate to the bound system, the strong force would be weakened and similar in form to the electromagnetic force. This indeed stimulated the rapid discovery at SPEAR of the 2*S* level, called ψ', with rest energy 3.7 Gev, the predicted position of the level. However, the early optimism concerning the nature of the force has been tempered: charmonium is to the quark

(Continued on page 865)

search, of seeking knowledge for knowledge's sake (and with no forseeable applied value) be supported by public funds? (ii) Is it fair, ethically speaking, to use animals in studies—to create and destroy life and sometimes cause suffering (if unavoidably "essential" for the research) for purely intellectual reasons? (iii) If relevance of such animal studies to an understanding of human diseases or other "humanocentric" problems is claimed, does not the basic researcher create his own trap? Relevance, after years of reductionism and nonapplied research on esoteric subjects, may be very difficult to demonstrate.

The complex area of basic biomedical research—including many studies in animal behavior and physiological psychology—needs to be looked at from a new perspective. Beginning with animal rights is only a start. We will get nowhere if the basic researcher remains locked in his own conceptual world of consensus values, approved standards of animal care, and so forth. We must all be free to look "objectively" at ourselves and avoid being defensive under the fire of outside criticism by others who do not share the same world view. Basic research, and biomedical research in general, may well benefit once open and constructive dialog on animal research is achieved—with ultimate benefit, one would hope, to the animals themselves.

MICHAEL W. FOX
Institute for the Study of Animal Problems, 2100 L Street, NW, Washington, D.C. 20037

I regret that Aronson finds hostile an article in which his assailants' two most serious charges are dismissed as groundless or absurd and the third is discussed but not endorsed. It is only in general terms, not in their specific attack on the Museum, that I think the animal rights groups' arguments are at least worth considering. Their campaign has undoubtedly been hard on Aronson and on the Museum. Aronson, as the article concludes in discussing the campaign, "is an established and productive scientist whose work, in the aspects for which it is being assailed, differs in no way from the research carried on by a great many other investigators."—N.W.

Erratum: In the letter from William R. Havender (1 Oct., page 9, column 2, paragraph 1, the next-to-last-sentence), the word "not" was inadvertently omitted from the parenthetical phrase, "... (or else, the within-group heritabilities would *not* be high, as posited)."

Erratum: In the reply to the letter from Vladimir J. Konečni by Harry W. Power (5 Nov., page 563, column 2, paragraph 1), the last sentence should have read "To treat a functional dichotomy as a continuum is to do as great a violence to truth as to treat a continuum as a dichotomy."

RESEARCH NEWS

(Continued from page 826)

force as deuterium is to the nuclear force. The interaction appears to be quite complicated. There is a need for large spin-orbit and tensor forces which are as as yet incompletely understood. The central force is not an inverse-square or harmonic-oscillator one, but something intermediate; roughly a force independent of the quark-antiquark separation. But in any case great optimism remains that in the long run the charmonium system can teach much about whether, why, and how quarks of fractional charge are confined within hadrons.

Thus, rather rapidly, the evidence for ψ being a member of the hadron family as well as a bound state of a spin 1/2 constituent with its antiparticle became quite decisive. Just this much explains its production by gamma-rays, the charmonium levels and helps to interpret the large yield of hadrons at high energy observed by CEA and SPEAR. The crucial test came in the expectation that charmed quarks will bind to uncharmed antiquarks, forming overtly charmed hadrons. Their rest energy could be estimated at about 2 Gev, and in analogy to the behavior of strange particles they would be unstable with respect to the weak interactions. This leads to an estimated lifetime of order 10^{-13} second for a 2-Gev charmed particle. No time was wasted in embarking on the search. Ting was in an especially good position to attempt the search himself, using his spectrometers to detect charmed particles which decayed into two oppositely charged hadrons. Ultimately 10 million events were accumulated, but no positive evidence was found. A similar experiment at Fermilab extended his result to higher energies, and as yet charmed hadrons have not been detected as products of hadron-hadron collisions.

Actually, it was expected that electron-positron annihilation and neutrino reactions would be the best sources of charmed particles, but for a long time the search was inconclusive. Neutrino-induced reactions did provide positive evidence for charm, but not until the discovery of charmed mesons at SPEAR this year did the case for charm become highly persuasive. There is perhaps still room for the skeptic to doubt the existence of charm (not to mention the quark) but it is a severe uphill battle to do so.

The charm concept is more than just a label for a fourth quark; it has specific implications for problems of the weak interactions. The word charm was introduced by Sheldon Glashow (*4*) as early as 1964. Given the introduction of a fourth degree of freedom for hadrons, a formulation of weak interactions was found that was more symmetrically balanced between hadrons and leptons (the family containing electrons, muons, and their neutrinos). The unique feature of this charm picture was the prediction that charmed matter should decay weakly and predominantly into states containing strange matter. This signature made the search for charm quite specific, and the prediction so far appears to be borne out by experiment—although much remains unclear. But in 1964 this was mostly speculation and esthetics.

In 1970 real operational use was found for the charm concept in dealing with problems of the high-energy behavior of the weak interactions. The basic description Fermi so brilliantly provided in 1932 (as refined by a few others in the subsequent 30 years) necessarily fails at high energies, of order 1000 Gev of center-of-mass energy. Corrections must exist. During the late 1960's, confidence in the technique of estimating such corrections grew (thanks to large extent to the work of the Soviet theorist B. L. Ioffe) and it was found that unless some new physics intervened at an energy scale of only a few Gev, it was difficult to understand why the two neutral strange mesons, K_L and K_S, should possess such a small mass difference (experimentally it is less than one part in 10^{11} of the electron mass). In 1970 Glashow, with J. Iliopoulos and L. Maiani, showed that the 1964 charm scheme did the job, provided the charmed quark was not too heavy.

This observation lay dormant for a couple of years, until some beautiful mathematical physics by a young Dutch physicist Gerard 'tHooft opened the way for a quantitative theory of weak interactions, where such corrections can be systematically computed. Not only is such a theory practical from the point of view of computation, but its starting point is modeled after quantum electrodynamics. Even more, quantum electrodynamics is subsumed into the larger structure, somewhat as electrostatics and magnetism are subsumed within Maxwell's electrodynamics. Finally, the simplest version of such a unified weak electromagnetic theory, as formulated by Steven Weinberg and Abdus Salam, requires the existence of muonless neutrino-nucleon interactions ("neutral currents"). These not only have been found but, most importantly, agree quantitatively with the theory. It is no wonder that this theory is by far the most serious candidate for a successful description of the weak force in its natural energy domain. But, for essentially the reasons discovered earlier, inclusion of the charmed quark appears to be an unavoidable ingredient in this theory as well.

Thus the existence of charm lends support of sorts to the present viewpoint on weak interactions and its potential synthesis with electrodynamics. Nowadays, with charm scarcely established, many are already looking far beyond the detailed study of charmed matter. Ting has followed Lederman to the CERN storage rings and is now mounting a large experiment, this time to detect muon pairs with rest energies up to 15 Gev, in the hope that history may repeat again: there is no particular reason why the number of quark types should stop at four. Richter is deeply involved in a large electron-positron storage ring project (PEP) which is under way at SLAC. Center-of-mass energies of more than 30 Gev will be available upon completion of the project in about 1980. Ting is also planning an experiment at a similar project (PETRA) under construction at DESY. Beyond that, Richter is a strong proponent of the eventual construction of very large electron-positron rings of center-of-mass energy up to 200 Gev. If the present viewpoint of weak interactions is correct, at these energies quantum electrodynamics, as Richter and Ting knew it in the 1960's, *should* break down, and with their 30-Gev experiments at PEP and PETRA they should be able to see the breakdown occur. If they do not, and instead the old quantum electrodynamics is verified, there will be almost as much impact on the theory as had Ting or Richter found a breakdown in their early experiments.

J. D. Bjorken
Stanford Linear Accelerator Center, Stanford, California 94305

References and Notes

1. J. Aubert, U. Becker, P. Biggs, J. Burger, M. Chen, G. Everhart, P. Goldhagen, J. Leong, T. McCorriston, T. Rhoades, M. Rohde, S. C. C. Ting, S. L. Wu, Y. Y. Lee, *Phys. Rev. Lett.* **33**, 1404 (1974).
2. J. Augustin, A. Boyarski, M. Breidenbach, F. Bulos, J. Dakin, G. Feldman, G. Fisher, D. Fryberger, G. Hanson, B. Jean-Marie, R. Larsen, V. Lüth, H. Lynch, D. Lyon, C. Morehouse, J. Paterson, M. Perl, B. Richter, P. Rapidis, R. Schwitters, W. Tanenbaum, F. Vannucci, G. Abrams, D. Briggs, W. Chinowsky, C. Friedberg, G. Goldhaber, R. Hollebeek, J. Kadyk, B. Lulu, F. Pierre, G. Trilling, J. Whitaker, J. Wiss, J. Zipse, *ibid.*, p. 1406.
3. There is no general consensus on the ultimate name of J/ψ. With all due respect to Professor Ting, I choose to use the name ψ here. Not only is it a matter of habit, but also the ψ (3.1) appears to be a member of a family containing ψ' (3.7), ψ'' (4.1), . . ., whose names are not ambiguous. Given that J is married to these others, is it not appropriate to change its maiden name?
4. B. J. Bjørkén and S. L. Glashow, *Phys. Lett.* **11**, 255 (1964). The peculiar spelling of my name was used in order to maintain deniability, which I here affirm. in that paper our relative contributions to the development of the charm concept were in the same proportion as our subsequent contributions.