spectrum with evidence for an intermediate state. The best evidence is presumably from the muon decay, where the resolution is better. The electron decay, on the other hand, gives better statistics and allows a crude branching fraction to be calculated. The DESY team estimates that the branching fraction for the 3.7-GeV particle to produce two gamma rays and a 3.1-GeV particle is 2–12% of the total decays of the 3.7-GeV particle.

The SPEAR experimenters led by Burton Richter and Martin Perl (SLAC), William Chinowski, Gerson Goldhaber and George Trilling (Lawrence Berkeley Laboratory), looked at the 3.7-GeV particle decaying into a gamma plus an intermediate state, which then decays into hadrons.

They find two peaks in the mass distribution, at 3.53 and at 3.41 GeV. Presumably the 3.53-GeV state corresponds to the possible 3.5-GeV particle reported by the DESY group. But the 3.41-GeV state seen by the SPEAR experimenters was apparently not seen by the DESY team.

Richter told us that their 3.53-GeV state seems broader than their experimental resolution; hence it is either wide or there is more than one state near that mass value. In addition, the SPEAR experimenters looked at branching fractions. They find that the 3.41-GeV particle does not decay into the 3.1-GeV particle plus a gamma as readily as the 3.53-GeV particle does.

Related experiments. An earlier experiment looking for the intermediate state was done by a Stanford University-University of Pennsylvania group at SPEAR using sodium iodide detectors. The experimenters reported their results at the Washington meeting of the American Physical Society in April. They find no compelling evidence for monochromatic photon emission in the energy interval 50–1000 MeV with a branching ratio larger than 5–6%.

In a different search for the intermediate state, Samuel C. C. Ting, Ulrich Becker, Min Chen and their collaborators at MIT and Brookhaven, using the Brookhaven AGS, have looked for the reaction proton plus proton produces a P_c particle. They reported at the Palermo International Conference on Nuclear Physics late in June that the reaction has a cross section less than 1 nanobarn. In the same experiment they looked for the decay of a charmed meson into a positive kaon and a negative pion and the decay of a charmed baryon into a negative kaon and a proton. Within the range 1.8–5 GeV they found a cross section of less than 0.1 nanobarn.

Theory. What does the existence of the intermediate state suggest? We discussed the discovery with Sheldon Glashow (Harvard University), who together with J. D. Bjorken of SLAC suggested the existence of charmed quarks in 1964. Subsequently he, John Illiopoulos (Ecole Normale Superiere) and Luciano Maiani (Institut di Sanita, Rome) used the charm concept in a theory of weak interactions. Glashow feels that the P_c is convincing evidence that the 3.1-GeV particle is made up of some new quark and its antiquark, so that more than three quarks are certainly needed. If the charm hypothesis is correct, the new quark should bind to ordinary quarks to form charmed particles. The discovery of these new particles with predicted decay properties remains the ultimate test of charm. Actually one charmed particle may have been observed at Brookhaven National Laboratory by Nicholas Samios and his collaborators. As always, Glashow says, with the observation of one unique event, confirmation via the accumulation of one or more similar events is clearly necessary.

Harvard theorists Thomas Appelquist, Glashow, Alvaro De Rujula and H. David Politzer, have proposed that the 3.1-GeV particle 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. There two states have spin one. They also predict the existence of paracharmonium with spin zero; these states would lie slightly below each of the orthocharmonium states, several dozens of MeV below, the group believes. In addition one would expect several P-wave states, the group says, in which there is of course one unit of orbital angular momentum. The 2S state of orthocharmonium is expected to decay into the 2P state by photon emission and then the 2P state would decay into the 1S state by emitting a photon. The argument is analogous to that of positronium, which was always expected to have excited states. However, it took many years to find the positronium excited states (recently reported by Stephen Berko and his collaborators at Brandeis University), whereas it has only taken a few months to do it for charmonium.

Glashow explains that a naive calculation using a Coulomb potential gives the first P-wave state an energy of 3.7 GeV. A harmonic-oscillator potential gives an energy of 3.4 GeV. The Harvard group believes the correct energy lies between the two values. Other groups have made similar predictions of where the P-wave states would lie. These have been done by Curtis G. Callen, R. L. Kingsley, Sam B. Treiman, Frank Wilczek and Anthony Zee (Princeton University), by E. Eichten, Kurt Gottfried, Toichiro Kinoshita, John Kogut, K. Lane and Tung Mow Yan (Cornell University), by Kogut and Leonard Susskind (Tel Aviv University) and by Barry Harrington and Asim Yildiz (Harvard). Most of the theorists predicted a larger branching ratio than actually observed by the DESY experimenters.

DASP detector at DESY used to detect P_c particle. From front to rear are: iron absorber plus range counters, space for spark chambers, magnet, inner detector (centered around interaction point) plus two spectrometer arms on other side of interaction point.

Commenting on the DESY discovery, theorist Treiman says, "I was a firm believer in the qualitative idea of a charm–anticharm pair and that intermediate states would exist. But I was getting depressed that intermediate states weren't being found. Now those who had faith seem to have been proved right." —GBL

Do solar variations affect Earth's weather?

As far back as biblical times, Man has searched for correlations between events in the heavens and events on Earth. In more recent times, scientists have looked for a connection between solar phenomena and the weather on Earth. Over the past twenty years evidence has been growing that variations in solar magnetic activity correlate with low-pressure troughs in the Northern Hemisphere. The work has been pioneered by Walter Orr Roberts (University of Colorado and the National Center for Atmospheric Research, Boulder). In recent years others have collaborated with Roberts, for instance John M. Wilcox, Philip Scherrer and Leif Svalgaard at Stanford University, Roger H. Olson (University of Colorado) and Roy L. Jenne (National Center for Atmospheric Research).

In 1972 Roberts and Olson[1] studied the development of 300-millibar (a height of about 9 km) low-pressure trough systems in the north Pacific and North American region. They reported that troughs that enter or are formed in the Gulf of Alaska two to four days after a sharp rise of geomagnetic activity tend to be bigger than average size.

A parameter known as the vorticity area index was defined as the sum of the area (in square kilometers) over which the absolute vorticity (curl of the velocity vector per unit area) exceeded $20 \times 10^{-15}\ sec^{-1}$ plus the area over which the vorticity exceeded $24 \times 10^{-5}\ sec^{-1}$.

Soon afterward the Stanford group joined forces with the Boulder team, to see what connection there was between the vorticity area index and solar magnetic sector structure. From spacecraft observations made about ten years ago, it had been learned that the solar magnetic sector structure is extended outward from the Sun by the solar wind, which flows radially. As observed from the Earth, one can consider the resulting interplanetary magnetic field to be divided into sectors such that within each sector the field polarity is either toward the Sun or away from the Sun. Adjacent sectors have opposite polarity and are separated by a very thin boundary. The sector boundary provides a sharply defined time marker. Most commonly there are four sectors, each with a width of about 90 deg in solar longitude. Viewed from Earth the sector structure rotates with a 27-day period, with a sector boundary intersecting the Earth about every seven days. At times during the few years of maxima in the solar cycle, one finds two sectors superposed, Wilcox explains, with a 28.5-day rotation period. This two-sector structure introduces some variation over the course of a year.

For many years, Wilcox told us, it has been known that the sector structure influences geomagnetic activity, apparently causing it to increase 1–2 days after a boundary passes.

In their joint effort, the Stanford–Boulder workers measured[2] the integrated vorticity area, which they calculated using the vorticity area index for the portion of the Northern Hemisphere north of 20 deg N (unlike the earlier work, which was for the Gulf of Alaska only). These calculations were done twice each day for the period 1964–1970. It is well known that regions of high positive vorticity are associated with low-pressure troughs. Then they looked for the average response of the hemispheric vorticity area index to the passage of a sector boundary by the Earth (taking this as zero time), using the method of superposed epochs. The group emphasizes that, although the sector boundary provides a well-defined time, the meteorological response is associated with the large-scale sector structure during the interval of several days before and after the passing of the boundary.

They found that the vorticity area index reaches a minimum about one day after the passing of the sector boundary. Following this, the index increases about 10% in magnitude during the next 2–3 days. When the group did the analysis by dividing the list of sector boundary times (54 of them) in two in three different ways, they found the result persisted essentially unchanged. However the effect was only observable during the winter months, November to March.

Shortly afterward, the group reported that the effect is present at all levels in the troposphere but not found in the stratosphere. Also, they said that the effect is not confined to a single interval of longitude or latitude; that is, the effect is hemispheric. The analysis was not done for the Southern Hemisphere because there are not enough observations there to determine the vorticity area index in sufficient detail.

An independent examination of the Stanford–Boulder results has been done by Colin O. Hines and Itamar Halevy (University of Toronto).[3] Originally the Toronto workers were quite skeptical, they say. Subjecting the reported correlation to a variety of statistical tests, they failed to undermine the credibility. Instead they felt that the Stanford–Boulder results exceeded a 95% confidence level.

Just as the Toronto team reached that conclusion, a new report[4] came in from Wilcox, Svalgaard and Scherrer. This time they analyzed 131 cases, including 50 of the original 54; this was accomplished in part by increasing the number of years covered to 1963–1973, and by making inferences from ground-level observations. The Stanford group removed effects of seasonal variations and short-term fluctuations. Results are similar—the effect is about 10% of the average value of the index.

Hines and others have commented that, particularly regarding the original work of Roberts and Olson, a meteorological disturbance could produce winds that would cause electric currents to flow and lead to geomagnetic activity. The big advantage of solar structure analysis is that the solar structure cannot be produced by terrestrial weather, Wilcox explains.

In addition to observing the solar field in its extended form with a spacecraft magnetometer, one can observe the Sun itself by means of the Zeeman effect. With a new solar observatory just completed (at a cost of $500 000) at Stanford, Wilcox and his collaborators expect to be observing solar sector structure.

At Hines's and Halevy's request, Wilcox and Svalgaard did further superposed-epoch analyses, first for the new 81 solar sector boundaries and then for the 46 of these 81 that could be clearly identified from spacecraft observations alone (without depending on Earth-bound measurements of magnetic field as an indicator of solar magnetic reversals). The restricted analysis proved consistent with the analysis of the original 54 and the present 131 cases. It was because of this consistency, Hines told us, that he and Halevy became convinced that the signals reported by the Stanford workers now require a physical explanation.

Explanation? Hines and Halevy were scheduled to report on 4 September at the meeting of the International Union of Geodesy and Geophysics on their new work. They had found during their statistical tests that the solar signal was more strongly present during periods of relatively large-amplitude meteorological noise. Hines and Halevy propose that the solar influence acts as a modulator of meteorological noise that would have occurred in any event, rather than as the generator of a signal that is superimposed on that noise. They believe that the Sun introduces a phase modulation so that the rises and declines of the index are shifted in time. They argue that the solar influence can selectively advance, retard, or both, the timing of the natural amplitude variations of the vorticity area index so that in the end, minimum values of the index tend to be found at about the times that solar sector boundaries move past the Earth rather than at times that are random relative to the times of boundary passage. Hines remarks that he can neither know nor postulate what physical mechanism causes the phase shifts, but he and Halevy have been able to simulate the observed effects by phase shifting vorticity data obtained from randomly selected days.

The lack of a physical theory bothers many workers, such as A. J. Dessler (Rice University). Furthermore, Dessler notes, it is difficult to define the problem because it is not clear what is to be explained. For example, in addition to the correlation with sector boundary crossings, there are a variety of weather phenomena that have been correlated with an 11-year sunspot cycle, a 22-year sunspot pair-polarity cycle or individual solar flare events. In contrast, there is no pronounced 11-year cycle in the number of sector boundary crossings per year. With these conflicting experimental findings, it is difficult to develop a theory, Dessler feels. —GBL

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