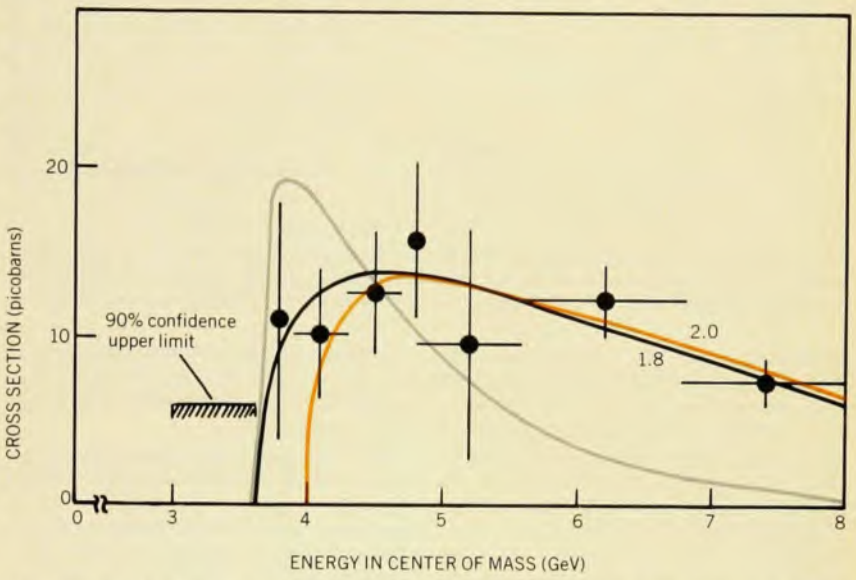
search & discovery

Evidence grows for charged heavy lepton at 1.8–2.0 GeV

Early in 1975 Martin Perl and his collaborators at SLAC observed anomalous production of an electron–muon pair in electron–positron annihilation. At the time (PHYSICS TODAY, October 1975, page 17) the group thought they could be observing a heavy lepton, a heavy meson or an elementary boson. By now, the returns from four additional detectors are in. The detector groups reported their results at the International Symposium on Lepton and Photon Interactions at High Energies held in Hamburg late in August. All the groups believe the most likely explanation for the anomalous events is a charged heavy lepton, now called the "tau," a pointlike particle with mass 1.8–2.0 GeV. The heavy lepton would join its lighter siblings—the electron, muon, electron neutrino and muon neutrino. Presumably the τ would also have its own neutrino. The particle is called τ because it appears to be the third charged lepton to be found, and the Greek word for third begins with τ.



Cross section for electron-muon events produced in electron–positron annihilation at SPEAR. The solid curves show the behavior expected for the production of a pair of heavy leptons, each lepton having a mass of either 1.8 or 2.0 GeV/c^2 as indicated. The gray curve shows the behavior expected for the production of a pair of hadrons with a form factor that is inversely proportional to the square of the total energy. Figure from Martin Perl of SLAC.

In the original experiment, done at the SLAC storage ring, SPEAR, by the SLAC–Lawrence Berkeley Laboratory magnetic detector group, Martin Perl had started analyzing the data, following an old hunch of his (shared with many others), that a lepton heavier than the muon might exist. Out of the first 10 000 events he scanned, he found 24 events in which an electron, positive muon and lots of energy were produced or else a positron, negative muon and lots of energy were produced, with no photons and no other charged tracks in the detector. One interpretation was that the electron and positron had produced a pair of charged heavy leptons, each of which then decayed into a charged lepton and two neutrinos. (At the time, the group called the new particle the U, for unknown.)

The anomalous events could have come

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Energetic oxygen ions stream up to magnetosphere

It has been generally believed that essentially all of the hot (0.1 to 50 keV) plasma ions and most of the more energetic Van Allen radiation belt ions contained within the Earth's magnetic field (the magnetosphere) originated on the Sun and were protons and a few percent helium ions. Now it has been discovered from satellite measurements that energetic (0.5–16 keV) oxygen ions that originate in the Earth's cold (eV) ionosphere are a major component of the hot plasma trapped in wide regions of the radiation belts during geomagnetic storms. These new findings, along with observations with the same instrument of energetic (keV) oxygen ions and protons streaming upward from the ionosphere into the magnetosphere, have stimulated a major reassessment of the physical processes responsible for the injection, acceleration, transport, and loss of the hot magnetospheric plasma.

Richard G. Johnson, Richard D. Sharp and Edward G. Shelley of the Lockheed Palo Alto Research Laboratory reported in last month's issue of *Geophysical Research Letters*[1] their observations of large fluxes of energetic oxygen ions in the three largest (though still moderate) geomagnetic storms from July 1976 to July 1977. Preliminary reports had been presented earlier at the May meeting of the American Geophysical Union in Washington, D.C. and at the Seattle meeting of the International Association of Geomagnetism and Aeronomy in August. Their measurements were made with three coupled ion mass spectrometers, covering the energy range from 0.5 to 16 keV in 12 energy steps; the mass-per-unit-charge ranged from 1 to about 32 AMU. The instrument was placed into a polar orbit in July 1976 aboard the S3-3 spacecraft with an apogee altitude of 8000 km and perigee of 350 km. It is still acquiring data.

The Lockheed group found that at the higher altitudes during the main phases of the 29 December 1976, 6 April 1977 and 19 April 1977 geomagnetic storms, the number density of O^+ ions within the instrument energy range exceeded the number density of protons on those

lines. According to Robert Hoffman of Goddard Space Flight Center, NASA's designated project scientist, a number of other instruments will be flown to provide additional information on this specific problem. The high-altitude satellite will carry two antennas about 215 meters tip to tip, which will allow a direct measurement of the potential difference between them, or the strength of the electric field. Both satellites will carry particle detectors that measure electron and total ion fluxes, with their angular and energy distributions. Investigators for these instruments are J. L. Burch of the Southwest Research Institute (the high satellite), and J. D. Winningham of the University of Texas at Dallas (low satellite). Hoffman explained that these measurements will show the effects of the overall plasma acceleration in two ways:

- If a thermal plasma is energized by an electric field it will retain the characteristic shape of its original thermal energy distribution, but with the average energy increased by the amount of the electric potential.
- A comparison of the angular distributions of the particles in the electric field region and below it will depend also upon the altitude of the electric field region and its electric potential.

William Hanson, also at the University of Texas at Dallas, explained that low-energy particle detectors will also be looking for thermal plasma drift on the lower satellite to correlate with upward ion currents and with the aurora. He reported in Seattle on preliminary observations from similar instrumentation on the Atmosphere Explorer satellites that showed that thermal oxygen ions do leave the ionosphere at approximately the rate required by the Lockheed measurements. —*William A. Flanagan*

References

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Stellar disk suggests planet formation

A group of astronomers from Steward Observatory of the University of Arizona and NASA-Ames Research Center have found evidence for a central star surrounded by a disk seen face on, a surrounding HII region and circumstellar dust. They feel that they have presented "the first substantial case for a newly formed star with a preplanetary disk." In fact, the group feels that the object, MWC 349, in the constellation Cygnus, may contain a planet or planets in formation.

The group, consisting of Rodger I. Thompson and Peter A. Strittmatter (Steward), Edwin F. Erickson, Fred C. Witteborn and Donald W. Strecker (Ames), reported[1] their results at the American Astronomical Society meeting in Atlanta in June.

The group has been looking at regions where star formation was believed to be occurring, places where dust makes it very hard to see in the optical region. However, they chose to look at objects that could be seen both in the infrared and the visible. They first made ir observations with the 2.3-meter Steward telescope, and the 91-cm telescope on the Gerard P. Kuiper Airborne Observatory. Their ir spectroscopy showed Paschen and Brackett lines of hydrogen, OI fluorescence lines and He I recombination lines. In the visible range, using spectra taken at Lick Observatory by Steven Grandi, they measured Balmer lines, some further oxygen fluorescence lines, and from the HII region of the object, they saw forbidden lines.

The source appears to be in the Cygnus OB2 association; so its distance can be inferred. Using the ir and optical hydrogen lines, the group calculates how much dust surrounds the object and makes a correction for it. Taking the measurements of the HII region and the dust corrections, they compared their observed continuum intensity and spectrum with theoretical predictions for a central star alone. Instead of a Rayleigh–Jeans optical spectrum expected from a lonely star, whose slope with respect to frequency, ν, varies as ν^2, the group finds a slope varying as $\nu^{1/3}$. Furthermore, the intensity in the visible is far greater than would be anticipated.

Instead of a lone star, Strittmatter told us, their results are consistent with what one would expect from a viscous dissipating disk from which matter is flowing towards the central source. The Steward–Ames results are of the form predicted (under certain conditions) for a circumstellar disk by Donald Lynden-Bell and James E. Pringle (Institute of Astronomy, Cambridge University). In the radio region, one can also observe bremsstrahlung from the ionized gas in the HII region around the object. This is consistent with a central star, a surrounding disk, and a dusty HII region.

Another intesesting feature of MWC 349 is that its apparent visual luminosity has been decreasing over the past forty years at a rate of about 1% per month, but Strittmatter says this steady decrease is not crucial to the interpretation.

The new star is about ten times the size and 30 times the mass of our Sun. The disk appears to have a visible diameter 10–20 times that of the central star. As Strittmatter explained, the portion of the disk near the star is hotter and whirling faster. Further out, the disk is cooler, less dense, and hence more difficult to observe. If the disk actually extends to distances 400 times the diameter of the central star, the effective temperature of the outer material would be about 400 K, the group says. Then the density in the disk at that radius would be 10^{14} cm^{-3}.

Strittmatter told us, "Once you have a dense, cool region, conditions ought to be ideal for particles sticking together, forming grains, then rocks, perhaps even a planet."

In their paper, the group says the conditions are ideal for formation of molecules and dust grains and for rapid growth of the latter. They go on to say, "Although this does not necessarily imply formation of larger masses such as planets, the physical circumstances seem favorable to such a process." They say that a natural consequence of star formation from material with initial non-zero angular momentum is the formation of a central source and a surrounding disk in centripetal equilibrium orbit. Because of viscous dissipation in the disk, matter accretes onto the central object, which eventually becomes condensed and massive enough to begin nuclear burning. Most of the mass in the disk, they say, accretes onto the central star. However some mass moves out to larger radius to conserve angular momentum. They conclude that although most of this mass is probably lost to the system, any matter that is condensed enough to resist viscous and radiative forces can remain in orbit in the form of planetary objects. —GBL

Reference

1. R. I. Thompson, P. A. Strittmatter, E. F. Erickson, F. C. Witteborn, D. W. Strecker, Ap. J., to be published in 15 Nov. issue.

Heavy lepton

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from hadrons being misidentified as electrons or muons in the detector. After six months the group showed that only 25–30% could be coming from such background.

A more-difficult-to-eliminate possibility was that the events came from production of charmed mesons, now called D mesons, which at that time had not yet been found, although they had been predicted by Sheldon Glashow (Harvard) and his collaborators. Gary Feldman (SLAC) analyzed the e–μ events, which by then numbered 100. If the events were caused by a charmed meson, one should sometimes observe decays with an electron, a muon and additional

charged tracks or photons. Although some such events were indeed found, they could all be explained as misidentified hadronic events. By December, 1975, Feldman and Perl thought[1] they had found heavy leptons. However, other groups at SPEAR and at DORIS, the storage ring at DESY in Hamburg, were not seeing them.

The following year a new signature for heavy-lepton production was observed. This was an event with two charged particles, one of which was identified as a muon. A Princeton–Maryland–Pavia group reported 12 such events. Then the SLAC–LBL group observed 100 μ–X events in which X could be a hadron or electron but not a muon. By then, Perl recalls, his group was fairly convinced they were not seeing charmed mesons.

In the summer of 1976 Hinrich Meyer (University of Wuppertal) reported at the SLAC summer institute that the Pluto group was seeing electron–muon events. Although the DASP group at DESY saw some indication of the heavy lepton, their statistics were not significant. At this point many physicists questioned the heavy-lepton explanation for the e–μ events.

Then Perl and his collaborators joined forces with Lena Barbaro-Galtieri (LBL) and her group, calling the team the lead-glass wall group. In this experiment, they covered $\frac{1}{8}$ of the magnetic detector with lead glass to improve the detection of electrons.

By the beginning of 1977 the DASP and Pluto[2] groups began to see e–μ, e–X and μ–X events. Meanwhile, still another group was tooling up at SLAC, installing the Delco detector in the East Pit of SPEAR. (The SLAC–LBL magnetic detector was installed in the West Pit.) The Delco group was a collaboration among Stanford, University of California at Irvine and UCLA. Delco has ten times the solid angle of the lead-glass wall detector and can reject pions down to very low momentum, making it more difficult for a pion to fake an electron. The Delco group was able to analyze their data in time for the Hamburg meeting. At that time Jasper Kirkby (Stanford) said his group, too, finds no contradiction with the heavy lepton. The most interesting evidence was an apparent smooth (pointlike) production of e–X events as the beam energy was increased, in contrast with the violent oscillations they observed in multi-pronged events (which are due to charmed particles).

"How can you be sure you're seeing a heavy lepton and not a meson?" we asked. Kirkby wryly remarked, "There's no smoking gun." Perl described five pieces of evidence for a heavy lepton:

- If one has a charmed meson, one would expect the number of e–μ events to go up by factors of two or three at 4.1 and 4.4 GeV because the D mesons would be produced at those energies. Such an increase in production cross section is not seen.
- At higher energies, in the range 6–7.8 GeV, charmed mesons would be produced with lots of hadrons. Instead, the purity of the signal stays the same, even at high energy.
- When the D meson decays into an electron plus hadrons or a muon plus hadrons, the electron or muon generally has a momentum less than 100 MeV/c, whereas in typical electron–muon events the electrons and muons have momenta greater than 100 MeV/c.
- If the new particle were an ordinary baryon, the production cross section would be lower. Furthermore, once the energy was high enough to produce them, as the energy were increased further, additional hadrons would be observed. They were not observed.
- If the τ is a heavy lepton, it should follow the predictions of quantum electrodynamics, which says that the production cross section should vary as the inverse square of the total energy. The observed[3] cross section agrees with theory within 20–30%.

What next? All the experiments have had difficulty pinning down the exact mass of the τ. Because it decays with at least one undetectable neutrino, it is tough to tell exactly what the mass is. The $\psi''(3772)$ resonance is just a trifle more massive than half the mass of the D_0 (1863 MeV) or D_0^+ (1868 MeV); so the ψ'', recently reported by the SLAC–LBL group, decays to D mesons. While running in that energy region, one can look for the τ. If it is not seen, the τ mass is greater than 1868 MeV. If it *is* seen, the τ mass is less than 1868. Both the lead-glass wall and Delco groups have seen some indications of τ being formed.

The very convenience of the D meson's mass being so close to that of the τ is also a profound disturbance to the experimenters. Perhaps the τ is in reality the D. Yet for all the reasons he outlined, Perl is sure that it is not. Is the similarity in mass just a coincidence or does it mean something? Only two groups have published values for the mass. The SLAC–LBL group gives (1.9 ± 0.1) GeV. Gerhard Knies (DESY) of the Pluto group said at the Hamburg meeting that the τ mass is (1.93 ± 0.05) GeV.

Another problem is that not all the expected decays of the τ are observed. So far the experimenters at DESY and SLAC have seen τ going to e + 2 neutrinos, μ + 2 neutrinos, ρ + 2 neutrinos and the A_1 meson plus a neutrino. But if τ is a conventional lepton, one would expect to see $\tau^- \rightarrow \pi^- + \nu$. At the Hamburg meeting, S. Yamada of the DASP group reported that this decay is not observed with a 3–4-standard deviation error.

Assuming that the τ *is* a heavy lepton, very likely it has its own neutrino associated with it. Perl explained that the τ cannot have the same lepton number as the muon or the τ would have been observed as neutrino-induced events at bubble chambers, and it was not. However, the τ could have the same lepton number as the electron. Both the SLAC–LBL and Pluto groups have established upper limits on the mass of the tau neutrino, in the same fashion as the mass of the ordinary neutrino is obtained from a beta-decay spectrum. From the e–μ mode, SLAC–LBL finds that the mass is less than 600 MeV/c^2. And from e–X events, Pluto sets an upper limit of 540 MeV/c^2. From their two-body decay events into A_1 and neutrino, Pluto infers an upper limit of 300 MeV/c^2. If there is a τ neutrino, we would have six leptons. And one can argue, we should by symmetry have six quarks. Or more. —GBL

References

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Solar test facility yields 1.7-MW power

ERDA's Solar Thermal Test Facility, at Sandia Laboratories near Albuquerque, recently produced 1.7 MW, making it the largest operational solar installation in the world, although it is still being constructed. It exceeded the 1-MW capacity of the solar facility at Odeillo, France.

The facility is expected to reach its full capacity of 5 MW in December. It cost about $21 million. When operational, the test facility will be used to resolve technical questions concerning the design and development of commercial solar electric power plants, to test prototype solar boilers and other components under development for the planned 10-MW electric power plant near Barstow, California, to develop high concentration ratio photovoltaics, and for advanced high-temperature materials studies.

in brief

Michigan State University recently received $400 000 from NSF, the first installment of an award of $1.2 million, to build the first of a pair of superconducting cyclotrons. NSF is considering a $12-million proposal to build a second cyclotron. The facility would be used to accelerate heavy ions.

A $1-million laser center will be established on the Chicago campus of IIT Research Institute and will be dedicated to the extension of laser technology into manufacturing and production. The facility will have an Avco 15-kW cw industrial laser. □