

vortex lattice.

The first experimental evidence for the oscillatory state came from neutron-diffraction studies of powdered samples of ErRh_4B_4 . The work⁴ was done by David E. Moncton (Brookhaven and Bell Labs), Denis B. McWhan and Paul H. Schmidt of Bell Labs, Gen Shirane and William C. Thomlinson of Brookhaven and Maple, MacKay, Woolf, Johnston and Zachary Fisk, then at San Diego. Working at the High-Flux Beam Reactor at Brookhaven, this team investigated the small-angle neutron scattering and found that a peak developed in a narrow temperature region (of about 0.5 K) just above T_{c2} . The angle at which the peak occurred corresponded to a periodic structure with a wavelength of about 100 Å. An important feature of this peak was the hysteresis it displayed: The peak was larger when the system was cooled down through the superconducting region than when the system was warmed up from the ferromagnetic region. The ferromagnetic Bragg peak exhibited similar hysteresis but in the opposite direction, being smaller upon cooling. Such behavior implied that both superconducting and ferromagnetic regions are present and that the magnetic fluctuations are associated with the superconducting regions. The other reentrant superconductor— HoMo_6S_8 —manifests similar properties except that the oscillatory magnetic phase is completely absent when the sample is warmed up from below T_{c2} . Research on this compound was done⁵ by Jeffrey W. Lynn (University of Maryland), Shirane and Thomlinson, and Robert M. Shelton (Ames Lab, Iowa State University). They also do not see the ferromagnetic peak in conjunction with the oscillatory phase when the sample is cooled.

Recently, David Hinks (Argonne) succeeded in growing a single crystal of ErRh_4B_4 on which he and Sunil K. Sinha and George W. Crabtree, also of Argonne, together with Herbert Mook (Oak Ridge Labs) conducted neutron diffraction measurements at the High Flux Isotope Reactor at Oak Ridge. Sinha reported the results at the Sixteenth International Conference on Low Temperature Physics in Los Angeles last August. As in the preceding studies on this compound, they saw both the modulated magnetic phase with a period of about 100 Å and the hysteretic behavior (see figure). The appearance in a single crystal of both the ferromagnetic domains and the superconducting regions with modulated magnetic spins establishes more definitively that these regions are simultaneously present. The narrowness of the scattering peaks implies that these regions are at least 2400 Å wide. By studying the intensities of diffraction

peaks in different planes, the researchers concluded that the magnitudes of the magnetic spins must vary sinusoidally and the vectors cannot spiral. They furthermore established the direction of the propagation vector. Finally, this team ruled out the possibility that the magnetic superconductor might consist of a lattice of vortices, as some theories have predicted. A vortex lattice would give rise to higher harmonics and hence more satellite peaks, and its wavelength would shrink as the temperature was lowered to preserve flux quantization. Neither of these effects was observed. Lynn and his collaborators had earlier ruled out the possibility of vortex lattices for HoMo_6S_8 by studying the variation of the wave vector with the applied magnetic field.

With this additional detail about the magnetic, superconducting state, the theoreticians have both greater input and greater constraints. Henry S. Greenside (Bell Labs), Blount and Varma had shown that the coexistence state can be linearly polarized if the

magnetic anisotropy is sufficiently great. Tachiki discussed at the Los Angeles meeting the idea of a laminar structure of vortices that would not be subject to flux quantization. Other theories are being discussed. A critical but difficult feature that all must eventually explain is the relation between the ferromagnetic phase and the magnetic superconducting phase. —BGL

References

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How long does the tau lepton live?

The often-quoted remark of I. I. Rabi, made when the muon was discovered—"Who ordered that?"—is again an apt commentary about the third charged lepton to be found, the tau. A recent experiment, by Gary Feldman, George Trilling and their collaborators at the PEP electron-positron collider at SLAC has determined the lifetime of the tau. They find it to be $(4.6 \pm 1.9) \times 10^{-13}$ sec, a value entirely consistent with the universality of the weak interaction. That is, the weak interaction between the tau and other particles appears, within experimental limits, to be the same as that of the electron and muon. They're all spin- $1/2$, charged, pointlike particles, differing only in mass: the electron with 0.511003 MeV, the muon with 105.6595 MeV and the tau with 1782 MeV.

Since the first evidence for the tau lepton was found by Martin Perl and his collaborators in 1975, the tau has been widely studied (PHYSICS TODAY, November 1977, page 17). Although the electron neutrino was observed by Clyde Cowan, Frederick Reines and their collaborators in 1956 and the muon neutrino by Gordon Danby and his collaborators in 1962, no direct observation of the tau neutrino has been made yet.

In August, at the International Symposium on Lepton and Photon Interactions at High Energies, held in Bonn, Germany, J. G. Branson reported on an experiment at PETRA using the Tasso detector. This group reported a tau lifetime measurement of (-0.25 ± 3.5)

$\times 10^{-13}$ sec, corresponding to an upper limit of 5.7×10^{-13} sec at the 95% confidence level. In 1980 they had reported an upper limit of 14×10^{-13} sec at the 95% confidence level.

The new experiment at PEP, done with the Mark II detector (previously used at SPEAR), was a collaboration among physicists from SLAC, Berkeley and Harvard, who say that theirs is the first measurement¹ of the tau lifetime that has a statistically significant nonzero value. As Feldman pointed out at the APS Division of Particles and Fields meeting in Santa Cruz in September, previous evidence is consistent with the tau decay occurring through the normal $V-A$ charged current. But does the tau couple to this current with the same strength as the muon? The answer can be found unambiguously by measuring the tau lifetime, τ_τ . If the coupling strength is the same, τ_τ is given by:

$$\tau_\tau = (m_\mu/m_\tau)^5 \tau_\mu B_e$$

$$= (2.8 \pm 0.2) \times 10^{-13} \text{ sec}$$

where B_e is the branching ratio for $\tau \rightarrow e \nu \bar{\nu}$.

The Mark II experimenters measured the tau lifetime by reconstructing the vertex of three-pronged tau decays and calculating the flight distance between the interaction point and the vertex projected along the direction of the tau momentum. Because the expected mean flight distance of the tau (0.7 mm) is smaller than their resolution, the group had to do statistical averaging and achieve good control

of systematic errors to obtain the necessary precision.

The Mark II experimenters used a new trigger chamber built by Perl for improving the on-line triggering of the detector. Feldman and Trilling realized that the trigger chamber would help measure the tau lifetime because it is relatively close to the interaction point and has reasonably good spatial precision.

Positrons and electrons with 29 GeV center-of-mass energy were allowed to collide, tau particles were produced, and they decayed in a variety of ways. Examining tracks exiting perpendicular to the beam pipe, the experimenters selected four- and six-pronged events. The four-pronged events had a jet of three tracks moving in the forward direction and one track in the backward direction. The six-pronged events had a jet of three tracks in the forward direction and a jet of three tracks in the opposite direction.

To eliminate the only important background, they rejected events in which any pair of particles is an electron-positron pair. The remaining events in the sample are almost all tau pair production, that is, $e^+ + e^- \rightarrow \pi^+ + \pi^-$. The single prong comes from the tau decaying into an electron and two neutrinos, a muon and two neutrinos, a pion and a neutrino, a charged pion, neutral pion and a neutrino, or a kaon and a neutrino. The triplet of prongs comes from the tau decaying into three pions and a neutrino or three charged pions, a neutral pion and a neutrino.

Surrounding the beam pipe and coaxial to it are first the trigger chamber and then the main chamber. To determine the location in the beam pipe where the tau decayed, the group determined the distance, l , between the position where $e^+ + e^- \rightarrow \tau^+ + \tau^-$ and the reconstructed vertex where the τ decayed into a triplet. Because the tau is known to have 14.5 GeV energy, its velocity is known and the time, t , it lived can be determined. In principle, from the distribution of l 's, one can determine the lifetime. In practice, however, the group looks at the distribution of l 's and fits it with a calculated l distribution, which depends on the lifetime of the tau.

If conventional weak-interaction theory holds, then the coupling constant for the tau decaying to ν_τ and W , $g_{\tau\nu_\tau}$, is the same as g for an electron decaying to ν_e and W and a muon decaying to ν_μ and W , and the theoretical value for τ_τ is 2.8×10^{-13} . If $g_{\tau\nu_\tau} \neq g$, then

$$\frac{\tau_\tau(\text{theor.})}{\tau_\tau(\text{meas.})} = \frac{g_{\tau\nu_\tau}^2}{g^2} \quad (1)$$

Plugging in the Mark II value for τ_τ ,

$$0.66 < g_{\tau\nu_\tau}/g < 1.02$$

for one-standard-deviation limits. So, Perl told us, within the errors of their measurement they found the tau vertices have the same strength as the electron vertices and the muon vertices.

Is there a tau neutrino? If there were no tau neutrino, but only the electron and muon neutrinos, the tau decay would have to occur through a $\tau\nu_e$ coupling with coupling constant $g_{\tau\nu_e}$ and/or through a $\tau\nu_\mu$ coupling with $g_{\tau\nu_\mu}$. Then equation 1 would be replaced by

$$\frac{\tau_\tau(\text{theor.})}{\tau_\tau(\text{meas.})} = \frac{g_{\tau\nu_e}^2}{g^2} + \frac{g_{\tau\nu_\mu}^2}{g^2} \quad (2)$$

The 90% confidence level (2.3σ) lower limit on this ratio is 0.40 from the Mark II data. So the right-hand side of equation 2 is greater than 0.40. The present limits on $g_{\tau\nu_e}$ and $g_{\tau\nu_\mu}$ are so small that this inequality could not be satisfied were $g_{\tau\nu_\tau} = 0$.

A number of particle-physics experiments have searched for tau production by either muon neutrinos or electron neutrinos, thus also measuring $g_{\tau\nu_\mu}$ and $g_{\tau\nu_e}$. (Such production could either signal the presence of neutrino oscillations or an admixture of different neutrinos in the original neutrino beam.) In 1978 a Columbia-Brookhaven group, using the 15-foot bubble chamber at Fermilab, set² an upper limit of $g_{\tau\nu_e}^2/g^2 < 0.025$ (90% confidence level). A recent emulsion experiment by N. Ushida and his collaborators, working at Fermilab, reduced³ this limit to 0.0063 (90% confidence level). Upper limits (at the 90% confidence level) on $g_{\tau\nu_e}^2/g^2$ of 0.35 and 0.30 have been obtained in neutrino bubble-chamber experiments using BEBC at CERN⁴ and the 15-foot chamber at Fermilab⁵ respectively. These electron neutrino searches for tau production

combined with the muon neutrino search by Ushida and his collaborators set upper limits on the right side of equation 2 of 0.36 and 0.31. But these limits disagree with the lower limit of 0.40 set by the tau lifetime measurement, thus indicating, Perl says, that an additional neutrino exists and couples to the tau. "This we call the tau neutrino. Of course, this result is still statistically weak. We need a more precise measurement of the tau lifetime and on the upper limit on $g_{\tau\nu_e}^2$ to get a stronger result."

Charles Baltay (Columbia) told us that he and his collaborators are now designing an experiment to look directly for the tau neutrino. The experiment has been approved to run at the Fermilab Tevatron about three years from now. To produce the tau neutrino beam, the experimenters would use the decay of F mesons produced by 1000-GeV protons. The F is a charmed particle with 2-GeV mass already observed in some Fermilab emulsion experiments; it is expected to have a 3% branching ratio into τ and ν_τ . At 1000 GeV the upgraded Fermilab accelerator is expected to produce ten times as many F particles as at 500 GeV. In addition, the experimenters plan to put their target 200 meters from the 15-foot bubble chamber instead of 1400 meters away, gaining an additional factor of more than ten. The signature of the tau neutrino would be an interaction of a penetrating neutral particle producing a tau but no muon or electron.—GBL

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RF drives tokamak plasma currents

A steady-state scheme for plasma-current drive would greatly enhance the attractiveness of the tokamak as a fusion reactor. The fact that a conventional tokamak reactor would have to operate in a pulsed mode presents serious engineering difficulties. Even though the length of such pulses could be as long as an hour (followed by a recovery time of less than a minute), pulsed operation raises the problem of thermal fatigue.

The "ohmic" plasma current that twists the confining magnetic field and heats the plasma in a conventional tokamak is induced by the transformer

action of external induction coils. Plasma current is induced only so long as the external current is increasing. Thus the duration of a tokamak pulse is limited by the current capacity of the induction coils.

This high-voltage induction poses another problem, even more serious than thermal fatigue. To avoid unwanted currents in the walls of the vacuum vessel, one must interrupt this metallic torus with sections of resistive bellows. These voltage breaks, however, permit undesirable pulsed currents and stresses to be induced in the external coils when all-too-frequent plasma disrup-