Clues to the Hidden Order Parameter in URu_2Si_2 through Inelastic Neutron Scattering Measurements

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Recommended and a Commentary by Chandra Varma, University of California, Riverside.

The paper by Wiebe et al. offers an opportunity to revisit an unresolved and interesting puzzle in condensed matter physics: the nature of the order parameter discovered in the heavy itinerant fermion compound, URu_2Si_2, more than 20 years ago by Palstra et al. A specific heat singularity which looks almost mean-field like occurs at about 17 K and corresponds in magnitude to what would be expected for a magnetic ordering of moments of magnitude about $0.5\mu_B/$ per unit-cell. So, this is no small and subtle effect quantitatively. But no such ferromagnetic or antiferomagnetic order or structural order is observed in the numerous experiments performed to find it. After some confusion caused by detection of antiferromagnetic ordering with a moment less than an order of magnitude smaller, which is now known primarily through NMR experiments to be due to an impurity phase, and which varies from sample to sample, it is now fairly certain that no translational symmetry either of the structural or magnetic variety is broken below the transition. Enormous variety of experiments have been done and many new facts discovered: The magnetic susceptibility at the transition has a change of slope; the non-linear magnetic susceptibility has a singularity resembling the specific heat singularity; the Si-NMR relaxation rate acquires an extra inhomogeneous contribution below the transition; the transition temperature decreases to zero continuously in uniform magnetic fields of about 38 Tesla through a sequence of transitions seen in thermodynamic measurements; substitution of Ru by a few percent Rh removes the hidden order in favor of good old ferromagnetism; application of pressure removes the hidden order in favor of good-old commensurate antiferromagnetism. However the nature of the hidden order remains hidden.

Meanwhile there have been various theoretical proposal, including quadrupole order characteristic of insulating compounds, orbital magnetic order, varieties of itinerant antiferromagnetism, Spin helicity order or finite angular momentum magnetism, etc.

Wiebe et al's paper together with earlier work on the change in the inelastic spin-fluctuation spectrum appears to limit the possibilities for the nature of order without being able to tell us what it is. The really nice part of the work is that the specific heat difference from the normal heavy-fermi-liquid state to the hidden order state is calculated from the change of the inelastic spectrum just above to well below the transition in good agreement with the thermodynamic measurements. The spectrum on both sides is characteristic of itinerant electrons; above the transition it is fitted with the familiar spectrum of a fermi-liquid with the same fermi-velocity or mass inferred from thermodynamics, below it develops cones of gap in momentum space, without showing any new period. The authors correctly state that the transition points towards a magnetic order parameter which changes the fermi-surface without changing translational symmetry. This means that the order parameter changes the point group symmetry (of the fermi-surface) and is magnetic in nature.

One might have thought that a change in fermi-surface should have been discovered long ago. Indeed there have been de Haas van Alphen experiments by Onuki et al., many years ago and continuuing in Japan and at Los Alamos. Given the quality of the crystal, they can only be done well in the hidden phase; no oscillations which may be trusted to give the fermi-surface in the normal phase are observed to compare and decipher what changes at the transition. The situation is worse because one of the several the fermi-surface sheets calculated by band theory in the normal phase is simply missing in the low temperature phase. The missing sheet would provide more or less correctly the difference of entropy of the normal and the hidden phase. The inelastic scattering experiments may be taken to suggest that the missing piece is transformed in a way that the orbits in a de Haas van Alphen experiment cannot be completed due to intrinsic (rather than impurity related) reasons.

The situations calls for new kinds of experiments to observe the fermi-surface, perhaps positron annihilation experiments or new types of symmetry related transport experiments or new techniques to discover change in symmetry with the order parameter at $\mathbf{q} = 0$.

It seems wonderful that there are new forms of organization in condensed matter physics waiting yet to be deciphered.