Heavy-Fermion Superconductors

This descriptive name has recently been attached to a class of superconductors in which the effective mass of the fermions (in this context, electrons) responsible for the superconductivity is several hundred times greater than the mass of a free electron. Such a large effective mass implies that the electrons behave less like a gas of independent particles (the usual picture of conduction electrons) and more like a liquid of interacting particles The unmistakable sign of a heavy-fermion superconductor is an extremely large value of *y,* the proportionality constant relating electronic specific heat to temperature. (The effective mass is deduced from this parameter, which is determined experimentally by extrapolating low-temperature specific heat data to absolute zero.)

Two heavy-fermion superconductors are now known: $CeCu_2Si_2$, the first, and UBe_{13}. In each case the superconductivity is surprising (so much so that the fact was initially reported, almost apologetically, in a footnote) since near room temperature the magnetic susceptibility follows a temperature dependence like that of a material with local magnetic moments. Thus magnetism (an ordering of the moments), not superconductivity, is the expected response at lower temperatures.

We became involved in heavy-fermion superconductivity by being the first to grow high-quality single crystals of $CeCu_2Si_2$. These crystals helped to dispel some of the confusion about the properties of this material, which had varied wildly from sample to sample. Then, in collaboration with H. R. Ott and H. Rudigier of Eidgenossische Technische Hochschule-Honggerberg, we showed that UBe_{13} was another heavy-fermion superconductor. Its properties are very similar to those of $CeCu_2Si_2$ and fortunately vary little among different samples.

The existence of a second example has made heavy-fermion superconductivity more appealing for study but as yet little better understood. More examples must be found before interesting questions about the phenomenon, such as whether p-state superconductivity is involved, can be answered. ■

September 18 we had some disappointing news-the ground powder was *not* superconducting down to 0.45 kelvin. More measurements followed. We cooled the powder in the dilution refrigerator but again found no indication of superconductivity, this time down to 0.050 kelvin. We measured the specific heat of UPt_3 at temperatures down to 1.5 kelvins. and the news from this front was good, The data fitted beautifully to the $-T^3 \ln T$ dependence predicted for a spin fluctuator (Fig. 2).

We now knew that UPt_3 was a bona fide spin fluctuator and that the ground powder was not a superconductor. Why, at this point. did we persist with further. perhaps fruitless. tests for superconductivity'? We had several reasons. One was the lack of a reasonable suspect for a superconducting second phase. Uranium is a superconductor, but its presence in UPt_3 is not to be expected since two other phases of the uranium-platinum system (UPt and UPt_2, neither of which are likely superconductors) are closer in composition to UPt_3, and a second phase is usually adjacent to the major phase in composition. In addition, crystals in the form of whiskers are generally free of other phases. A second reason was the behavior of a single crystal of UPt_3 prepared by Franse's group in a totally different way than our samples. (Franse had sent this crystal to us earlier as an encouragement to measure its heat capacity in a magnetic field.) We had measured its susceptibility> in the dilution refrigerator along with that of the ground powder and found a superconducting transition at 0.35 kelvin. This fact made the negative result from the ground powder more suspect than the positive result from the whiskers. The final reason for persistence was the chance that our initial interpretation was correct. If UPt_3 *was* a p-state superconductor, our measurements on a ground powder could easily be misleading since grinding introduces defects into the lattice that would be extremely destructive of p-state superconductivity. (*p-* State superconductivity is more strongly inhibited by lattice defects than is s-state superconductivity because the effective diameter of the interacting electron pairs is greater and thus encompasses a greater number of defects.)

Fortified by these arguments (hopes?), we proceeded to look for the only sure sign of bulk superconductivity in UPt_3-a large upward step in its specific heat curve. A superconducting second phase present at a con-