LETTER TO THE EDITOR

Response of the Heavy-Fermion Superconductor CeCoIn₅ to Pressure: Roles of Dimensionality and Proximity to a Quantum-Critical Point

M. Nicklas¹, R. Borth², E. Lengyel², P. G. Pagliuso¹, J. L. Sarrao¹, V. A. Sidorov¹, G. Sparn², F. Steglich², and J. D. Thompson¹

¹ Los Alamos National Laboratory Los Alamos, NM 87545, USA
² Max-Planck-Institute for the Chemical Physics of Solids, D-01187 Dresden, Germany

Abstract. We report measurements of the pressure-dependent superconducting transition temperature $T_c$ and electrical resistivity of the heavy-fermion compound CeCoIn₅. Pressure moves CeCoIn₅ away from its proximity to a quantum-critical point at atmospheric pressure. Experimental results are qualitatively consistent with theoretical predictions for strong-coupled, d-wave superconductivity in an anisotropic 3D superconductor.

PACS numbers: 74.70.Tx, 62.50.+p, 73.43.Nq, 71.27.+a

to appear in: J. Phys.: Condens. Matter 13 No 44 (5 November 2001) L905-L912

Although heavy-fermion superconductivity has been known for over two decades, a microscopic theory of this broken-symmetry state has remained elusive. Experiments have established, however, that the unconventional superconductivity in heavy-fermion compounds most likely is mediated by magnetic fluctuations, which also are responsible for enhancing the effective mass of itinerant quasiparticles by two to three orders of magnitude. In spite of 20 years of searching, there has been, until very recently, only one example of a Ce-based heavy-fermion compound, CeCu₂Si₂, that is superconducting at atmospheric pressure. In contrast, several examples of Ce-based heavy-fermion antiferromagnets have been found in which superconductivity appears as their Néel temperature is tuned toward $T = 0$ with the application of pressure. This recent series of discoveries re-foresces the belief not only that a magnetic interaction is responsible for superconductivity in these materials but also that heavy-fermion superconductivity may be favored at a particular 'soft-spot' in phase space, i.e., near a quantum-critical point.

‡ Permanent address: Institute for High Pressure Physics, Russian Academy of Science, Troitsk.
In heavy-fermion superconductors, the characteristic spin-fluctuation temperature $T_{sf}$ appears to set the scale for $T_c$, in much the same way that the characteristic phonon frequency does in the BCS theory of conventional superconductors. The most direct measure of $T_{sf}$ comes from the linewidth of neutron quasi-elastic scattering, but it frequently is estimated from the magnitude of the specific heat Sommerfeld coefficient $\gamma \propto 1/T_{sf}$. A very large Sommerfeld coefficient, the hallmark of heavy-fermion behavior, implies, then, a small $T_{sf}$ and consequently low $T_c$. As might be expected, the $T_c$'s of all pressure-induced Ce superconductors are less than 0.5 K and that of CeCu$_2$Si$_2$ is about 0.7 K. At the other extreme are the cuprates, in which $T_{sf}$ and $T_c$ are both larger by roughly two orders of magnitude than in heavy-fermion systems. Besides $T_{sf}$, Monthoux and Lonzarich have argued, specifically in the context of cuprates, that dimensionality is a factor in determining the transition temperature of magnetically-mediated superconductors.[10] Their solution of Eliashberg equations shows that, for all other factors being the same, the mean-field $T_c$ of a 2-dimensional system will be higher than its 3D analogue. There have been no examples, however, of families of magnetically-mediated superconductors that crystallize in related 3D and 2D structures to test these suggestions.

The very recent observation of heavy-fermion superconductivity in CeMIn$_5$ (M=Co, Ir, and Rh) offers the opportunity for at least a qualitative inspection of the role of dimensionality. These compounds form in the tetragonal HoCoGa$_5$ crystal structure that can be viewed as layers of CeIn$_3$ and \'MIn$_2$ stacked sequentially along their c-axis. CeCoIn$_5$[11] and CeIrIn$_5$[12] superconduct at atmospheric pressure with bulk $T_c$'s of 2.3 and 0.4 K, respectively, while CeRhIn$_5$[13] is an incommensurate antiferromagnet that transforms to a superconductor with $T_c$ = 2.1 K at pressures greater than about 1.6 GPa. For comparison, cubic CeIn$_3$, which is the infinite-layer variant of these compounds, becomes a superconductor at pressures near 2.5 GPa with a maximum $T_c$ of about 0.25 K.[8] A very crude approximation of the role of $T_{sf}$ in determining the magnitude of $T_c$ in these materials comes from taking $T_c \propto T_{sf} \propto 1/\gamma$. For CeMIn$_5$, $T_c$ = 2.3, 0.4 and 2.1 K for M=Co, Ir and Rh, respectively. Their corresponding values of $\gamma$ are 250[11], 750[12] and 380[14] mJ/mol K$^2$ for $T \geq T_c$. Within the CeMIn$_5$ family, then, $T_c$ scales approximately with $1/\gamma \propto T_{sf}$. The Sommerfeld coefficient of CeIn$_3$ at 2.5 GPa is not known, but an upper limit should be its $P = 0$ value of 130 mJ/mol K$^2$.[13] With all other factors assumed equal, we would expect from this comparison that $T_c$ of CeIn$_3$ should be over 3 K at 2.5 GPa, a factor of 10 higher than observed experimentally. In view of the calculations by Monthoux and Lonzarich, the high transition temperatures of CeMIn$_5$ members, relative to that in CeIn$_3$, may be due in part to their layered crystal structure.

In the following, we present results of pressure-dependent measurements on CeCoIn$_5$ and discuss the relationship of its layered structure particularly in the context of predictions by Montoux and Lonzarich[10], and apparent proximity to a quantum-critical point to an interpretation of its pressure response.

Four-probe AC resistivity measurements, with current flow in the tetragonal basal plane, were performed on a single crystal of CeCoIn$_5$ grown from excess In flux. Pressure was produced in a conventional Be-Cu clamp-type cell using pentene as the pressure medium, and the clamped pressure at low temperatures was determined from the shift in the inductively measured $T_c$ of small piece of Pb located in close proximity to the sample. A comparison of the $T_c$'s of Pb and CeCoIn$_5$ with literature values at atmospheric pressure showed that there was a small temperature gradient, at most 0.7% the thermometer temperature, between the sample volume and the calibrated
Cernox thermometer that was thermally anchored in the wall of the pressure cell. Independent measurements of the pressure dependence of $T_c$ of CeCoIn$_5$ were carried out over a more limited pressure range using a small clamp cell in a Quantum Design Superconducting Quantum Interference Device magnetometer, with Flourinert FC 75 (3M) as the pressure medium and a Pb manometer.

The pressure dependence of the resistivity of CeCoIn$_5$ over a broad temperature range is plotted in figure 1. At atmospheric pressure, $\rho(T)$ reaches a maximum at $T_M = 50$ K that generally is associated with a crossover from incoherent Kondo-like scattering at high temperatures to a heavy-fermion band state at low temperatures. With increasing $P$, $T_M$ moves to higher temperatures, and the resistivity above $T_M$ increases monotonically; whereas, the resistivity below $T_M$ decreases. This overall pressure response is typical of Ce-based heavy-fermion materials and is consistent with a $P$-induced shift of the characteristic spin-fluctuation temperature $T_{sf}$ and spin-fluctuation scattering to higher temperatures. A more detailed view of the low-temperature behavior, given in the inset, shows that the resistivity just above $T_c$ decreases from slightly over 0.06 to about 0.02 $\mu\Omega m$ and $T_c$ increases from 2.25 to 2.6 K as the pressure is raised.

Explicit pressure dependencies of $T_M$ and $T_c$ are shown in figure 2. $T_M$ is linear in $P$ over the entire pressure range, with $dT_M/dP = 28$ K GPa$^{-1}$. Assuming that $T_M \propto T_{sf} \propto 1/\gamma$, such a large rate of increase implies a rapid decrease in the electronic contribution to the specific heat. Indeed, direct measurements of $\gamma(P)$ show this expected behavior, and we find that $1/T_M(P)$ is linearly proportional to the normal-state $\gamma(P)$. The relative change $\partial \ln \gamma/\partial \ln (1/T_M)$ = 1.2 falls well within the range of values where this comparison has been possible on other heavy-fermion systems. Over this same pressure interval, $T_c$ increases initially at a rate $dT_c/dP = 0.5$ K GPa$^{-1}$ and reaches a maximum value of 2.61 K near 1.5 GPa before decreasing. The inset shows that the resistive transition width sharpens substantially from $\Delta T_c = 80$ mK at $P = 0$ to around 20 mK for $P > 0.9$ GPa.

It is interesting to compare these trends with the pressure response of CeRhIn$_5$. In that case, pressure induces a rather abrupt (as measured by the Néel temperature) change from antiferromagnetic to superconducting states near 1.6 GPa. Just beyond the critical pressure required for superconductivity, the resistivity at $T \geq T_c$ is large and $\Delta T_c$ is relatively broad, but with increasing $P$, $\rho(T \geq T_c)$ drops, $\Delta T_c$ sharpens, $dT_M/dP$ is comparable to that found in CeCoIn$_5$, and $T_c$ passes over a maximum near 3.0 GPa. From this comparison, it appears that CeCoIn$_5$ at atmospheric pressure is very similar to CeRhIn$_5$ at a pressure of about 1.6 GPa, and one might infer that CeCoIn$_5$ is near a quantum-critical point at atmospheric pressure. Indeed, specific heat measurements on CeCoIn$_5$ in a magnetic field sufficiently large to suppress $T_c$ to zero find $C/T \propto -\ln T$ over more than a decade in temperature above 100 mK, behavior that is accompanied by a resistivity $\rho \sim \rho_0 \times T^\alpha$, with $\alpha \approx 0.95$. These temperature dependencies of $C/T$ and $\rho$ are clear indications of a non-Fermi liquid state.

A variation in $T_c$ with tuning parameter, similar to $T_c(P)$ in figure 2, also is predicted in the calculations of Monthoux and Lonzarich for a p-wave or d-wave superconductor in proximity to ferromagnetic and commensurate antiferromagnetic instabilities, respectively. There is substantial evidence pointing to the conclusion that CeCoIn$_5$ is a d-wave superconductor and, thus, we focus on that case. Before comparing our measurements to these calculations, we briefly summarize relevant assumptions and results of those calculations. In ref. [10], the authors consider a
square (2D) or cubic (3D) lattice in which the dominant scattering of quasiparticles is magnetic, with a constant spin-fluctuation temperature $T_{sf}$. From a mean-field solution of Eliashberg equations, they obtain $T_c/T_{sf}$ as a function of two dimensionless parameters, the square of the inverse magnetic correlation length $\kappa^2$ and an effective interaction parameter $g^2\chi_0/t$ arising from the exchange of magnetic fluctuations. $\kappa^2 \to 0$ corresponds to the quantum-critical point where the magnetic correlation length diverges. For fixed values of $\kappa^2 > 0$, $T_c/T_{sf}$ increases monotonically from zero as a function of $g^2\chi_0/t$ and saturates in the strong coupling limit, whereas, for fixed $g^2\chi_0/t$, $T_c/T_{sf}$ decreases monotonically with $\kappa^2$ for a 3D superconductor but passes over a maximum at small $\kappa^2$ for the 2D case. In the absence of direct measurements of either $\kappa^2$ or $g^2\chi_0/t$, we follow the suggestions in ref. [10] and take pressure as a qualitative measure of $\kappa^2$ and the resistivity $\rho_0$ just above $T_c$ as a comparable measure of $g^2\chi_0/t$ for a comparison of the theoretical calculations to experimental quantities.

The theoretical prediction of $T_c/T_{sf}$ versus $\kappa^2$ for a relatively strong-coupled, 2D, d-wave superconductor near an antiferromagnetic quantum-critical point is qualitatively like $T_c(P)$ for CeCoIn$_5$, particularly in the sense that both exhibit a maximum. Because CeCoIn$_5$ is strong-coupled [11] and appears to be a d-wave superconductor near a quantum-critical point, we might conclude from this comparison that it also is in the 2D limit. The model calculations, however, take $T_{sf}$ to be a rather large energy scale, a substantial fraction of the tight-binding hopping integral, and thus to be independent of either $\kappa^2$ or pressure $\rho_0$. Though this assumption may be quite reasonable for cuprate superconductors, $T_{sf}$ in heavy-fermion systems is typically much smaller, by one to two orders of magnitude, than in the cuprates and pressure dependent. [16] Taking $T_M \propto T_{sf}$, we find that the ratio $T_c(P)/T_M(P)$ is a monotonically decreasing function of pressure, as shown in figure 4. Explicitly including this pressure dependence of $T_M$ makes a definitive comparison between our experimental results and the theoretical expectation for a 2D superconductor ambiguous.

We emphasize this ambiguity by comparing theoretical predictions for a 3D superconductor to $T_c(P)/T_M(P)$ versus pressure in figure 3 and in figure 4 to $T_c/T_M$ as a function of the electrical resistivity $\rho_0(P)$. We have narrowed the phase space of possible theoretical parameters by comparing logarithmic derivatives of the theoretical curves and the experimental data. This type of comparison is independent of proportionality factors between experimental observables and theoretical parameters. As shown in the inset to figure 3, the experimental data $\partial \ln(T_c/T_M)/\partial \ln P$ versus $\ln P$ are described best by the theoretical prediction for $\partial \ln(T_c/T_{sf})/\partial \ln \kappa^2$ versus $\ln^2$ when the coupling constant $g^2\chi_0/t = 60$. The only free parameter in this comparison is a proportionality factor between $T_{sf}$ and $T_M$ and a factor relating $P$ to $\kappa^2$. We plot in the main body of figure 3 the theoretical curve from ref. [10] for $T_c/T_{sf}$ as a function of $\kappa^2$ at fixed $g^2\chi_0/t = 60$. The value of $T_c/T_{sf}$ has been multiplied by 1/8.8 and $\kappa^2$ by 0.64. These scaling factors produce semiquantitative agreement with the experimental data $T_c/T_M$ vs. $P$, shown by solid circles. Likewise, in the inset of figure 4, the experimental determined $\partial \ln(T_c/T_{sf})/\partial \ln \rho_0$ versus $\ln \rho_0$ is compared to the theoretical predictions for $\partial \ln(T_c/T_{sf})/\partial \ln(g^2\chi_0/t)$ versus $\ln(g^2\chi_0/t)$. Best agreement between experiment and theory is found for values of $\kappa^2$ less than $\sim 1.0$. The main body of figure 4 shows experimentally determined $T_c/T_M$ versus $\rho_0$ and the theoretical prediction of $T_c/T_{sf}$ as a function of $g^2\chi_0/t$ for fixed $\kappa^2 = 0.5$. $T_c/T_{sf}$ has been multiplied by 1/8.8, as in figure 3, and $g^2\chi_0/t$ has been multiplied by $9.2 \times 10^{-8}$. Again, agreement between experiment and theory is
Response of the Heavy-Fermion Superconductor CeCoIn$_5$ to Pressure

satisfactory. Overall, the theoretical predictions shown in figures 3 and 4 describe the experimental results reasonably well. The value $\kappa^2 = 0.50$, which provides a reasonable approximation of $T_c(P)/T_M(P)$ versus $\rho_0$, implies that CeCoIn$_5$ is close to a quantum-critical point. Likewise, the theoretical curve for $g^2\chi_0/t = 60$, which corresponds to very strong coupling, qualitatively reproduces the $T_c(P)/T_M(P)$ versus pressure data. (For simplicity in this comparison, in figure 3 we have taken $\kappa^2 = 0$ at $P = 0$, which implies that CeCoIn$_5$ is precisely at a quantum-critical point at atmospheric pressure. Somewhat better agreement between experimental values and the theoretical prediction would result if we had chosen $\kappa^2$ correctly, they also should ‘predict’ $\rho_0(P)$ with no other adjustments. From theoretical curves [10] of $T_c/T_{sf}$ versus $\kappa^2$, for fixed $g^2\chi_0/t = 60$, and of $T_c/T_{sf}$ versus $g^2\chi_0/t$, for fixed $\kappa^2 = 0.5$, we can obtain $g^2\chi_0/t$ ($\propto \rho_0$) as a function of $\kappa^2$ ($\propto P$), using $T_c/T_{sf}$ as the implicit variable. The rather good agreement found in figure 3 between direct measurements of $\rho_0(P)$ and the solid theoretical curve for $g^2\chi_0/t$ versus $\kappa^2$ indicates that our choice of $g^2\chi_0/t = 60$ for varying $\kappa^2$ in figure 3 and $\kappa^2 = 0.5$ for varying $g^2\chi_0/t$ in figure 3 are reasonable. Strong coupling, d-wave symmetry and proximity to a quantum-critical point are also conclusions drawn in the preceding paragraph. Unlike the previous conclusions, however, those drawn from solid curves in figures 3-5 are based on theoretical curves for a 3D superconductor. Comparable agreement between experiment and theory for the 2D limit was not possible.

The semi-quantitative agreement between experiment and theory must be considered somewhat fortuitous. As noted earlier, the calculations of ref. [10] assume that $T_{sf}$ is independent of pressure, and, further, that the coupling constant $g^2\chi_0/t$ and $\kappa^2$ are independent parameters. The substantial pressure dependence of $T_M$ and specific heat Sommerfeld coefficient in CeCoIn$_5$ point to an intrinsic pressure dependence of its characteristic spin-fluctuation temperature. Though we have used $\rho_0$ as an approximation to $g^2\chi_0/t$, more direct measurements of the coupling, from specific heat measurements on CeCoIn$_5$ as a function of pressure [17], find that $\Delta C/\gamma T_c T_c$ is a monotonically decreasing function of $P$, qualitatively similar to $\rho_0(P)$. Therefore, it appears that $T_c$, $T_{sf}$, $g^2\chi_0/t$ and $\kappa^2$ are intimately coupled in CeCoIn$_5$ in a much more complex way than assumed in ref. [10]. In spite of these difficulties, the general trends found experimentally and in the theoretical calculations are those that might be expected from what is known about magnetically-mediated superconductivity and CeCoIn$_5$ specifically, and we believe that, at least qualitatively, the two are consistent. Further refinement of theory to account for the interdependence of parameters would allow a more straightforward comparison to experiment. Beyond this is the issue of dimensionality that has not been resolved. However, very recent calculations by Monthoux and Louzarich [23] show that any amount of anisotropy enhances $T_c$ above a strictly 3D value for any $\kappa^2$ and $g^2\chi_0/t$. A comparison of CeCoIn$_5$ to cubic CeIn$_3$ supports this conclusion and suggests that CeCoIn$_5$ should be considered to be an anisotropic 3D system.

In summary, a comparison to CeRhIn$_5$ indicates that the electronic state of CeCoIn$_5$ at atmospheric pressure is analogous to that of CeRhIn$_5$ at a pressure of about 1.6 GPa, where superconductivity develops as its Néel transition disappears. Thus, from its pressure response as well as its properties at atmospheric pressure, $\kappa^2$ we note that RPA estimates of $g^2\chi_0/t$ given in ref. [14] find expected values of the coupling parameter $\kappa^2$ in the range 5 to 20. The large jump in specific heat $\Delta C/\gamma T_c \approx 4.5$ found for CeCoIn$_5$ [2] indicates very strong coupling that could exceed the RPA estimate.
CeCoIn$_5$ appears to be close to a quantum-critical point. We have analyzed data in terms of theoretical predictions for a d-wave superconductor in both 2D and 3D limits and find that, though the 3D predictions semi-quantitatively reproduce experimental observations, this agreement must be taken with caution. The analysis, however, does suggest avenues for extending the calculations to make a comparison to experiment more meaningful. It is unlikely that CeCoIn$_5$ should be considered a formally 2D system, but its clear electronic and crystallographic anisotropy plays a role in determining $T_c$ at both atmospheric and applied pressures.

We thank P. Monthoux for helpful discussions. Work at Los Alamos was performed under the auspices of the US Department of Energy. Work at the MPI-CPfS was conducted within the FERLIN program of the ESF.

References

[1] Fisk Z et al 1988 Science 239 33
[2] Grewe N and Steglich F, in: Handbook on the Physics and Chemistry of Rare Earths, vol. 14 1991 Gschneidner K A and Eyring L (ed) (North-Holland, Amsterdam) p. 343
[3] Sato N K et al 2001 Nature 410 340
[4] Steglich F et al 1979 Phys. Rev. Lett. 43 1892
[5] Jaccard D et al 1992 Phys. Lett. A 163 475
[6] Grosche F et al 1996 Physica B 223&224 50
[7] Movshovich R et al 1996 Phys. Rev. B 53 8241
[8] Walker I R et al 1997 Physica C 282 303
[9] Mathur N D 1998 Nature (London) 394 39; Sachdev S 2000 Science 288 1089
[10] Monthoux P and Lonzarich G G 1999 Phys. Rev. B 59 14598; Monthoux P and Lonzarich G G 2001 Phys. Rev. B 63 054529
[11] Petrovic C et al 2001 J. Phys.: Condens. Matter 13 L337
[12] Petrovic C et al 2001 Europhys. Lett. 53 354
[13] Hegger H et al 2000 Phys. Rev. Lett. 84 4986
[14] Fisher R A et al to be published (preprint cond-mat/0109221)
[15] Nasu S et al 1971 J. Phys. Chem. Solids 32 772
[16] Thompson J D and Lawrence J M, in: Handbook on the Physics and Chemistry of Rare Earths and Actinides Gschneidner K A et al (ed) vol. 19 1994 (North-Holland, Amsterdam) p. 385
[17] Sparn G et al Physica B submitted; Lengyel E et al High Press. Res. at press
[18] Muramatsu T et al Physica B submitted
[19] Kim J S et al 2001 Phys. Rev. B 64 134524
[20] Stewart G R Rev. Mod. Phys. at press
[21] Movshovich R et al 2001 Phys. Rev. Lett. 86 5152
[22] Izawa K et al 2001 Phys. Rev. Lett. 87 057002
[23] Monthoux P and Lonzarich G G unpublished.
[24] Settai R et al 2001 J. Phys.: Condens. Matter 13 L627; Haga Y et al 2001 Phys. Rev. B 63 060503R
[25] Murphy T P et al to be published (preprint cond-mat/0104178)
Figure 1. Temperature dependence of the in-plane resistivity of CeCoIn$_5$ at various fixed pressures noted in the inset. With increasing pressure, the resistivity increases at high temperatures and decreases at low temperatures. The inset shows the pressure response of the low-temperature resistivity and superconducting transition temperature.

Figure 2. Pressure dependence of the temperature $T_M$ at which the resistivity is a maximum (solid squares) and the superconducting transition temperature $T_c$, determined where the resistivity is zero (solid circles) and by the mid-point of the magnetic transition (open circles). The inset plots the resistive transition width as a function of pressure. $\Delta T_c$ was obtained from the temperatures at which the resistivity reached 90% and 10% of its value just above onset of superconductivity.
Figure 3. $T_c(P)/T_M(P)$, left ordinate, versus pressure, bottom abscissa. Experimental values plotted as solid circles were taken from data in figure 4. The solid line is a theoretical prediction (right ordinate, top abscissa) of $T_c/T_{sf}$ versus $\kappa^2$ for a 3D superconductor with coupling constant $g^2\chi_0/t=60$. See text for details. In this comparison, we have taken $0.64\kappa^2=P$ and $8.8T_{sf}=T_M$. A value of $g^2\chi_0/t=60$ was chosen for the comparison on the basis of results shown in the inset, where theoretical values (broken curves) of $\partial\ln(T_c/T_{sf})/\partial\ln(\kappa^2)$ versus $\ln(\kappa^2)$ for fixed $g^2\chi_0/t$ are plotted on the same scale as experimental values (solid curve) of $\partial\ln(T_c/T_M)/\partial\ln P$ versus $\ln P$. 

Response of the Heavy-Fermion Superconductor CeCoIn$_5$ to Pressure
Response of the Heavy-Fermion Superconductor CeCoIn$_5$ to Pressure

Figure 4. $T_c(P)/T_M(P)$, left ordinate, versus electrical resistivity $\rho_0$ determined just above the onset of superconductivity, bottom abscissa. Solid circles are experimental data taken from figures 1 and 2. The solid line is a theoretical prediction (right ordinate, top abscissa) of $T_c/T_M$ versus $g^2\chi_0/t$ for a 3D superconductor with $\kappa^2 = 0.5$. For the theoretical curve, we have taken $9.2 \times 10^{-8} g^2\chi_0/t = \rho_0$ and $8.8T_{sf} = T_M$. The inset shows $\partial \ln(T_c/T_M)/\partial \ln(g^2\chi_0/t)$ versus $\ln(g^2\chi_0/t)$ for fixed $\kappa^2$ (broken curves) and the experimentally determined $\partial \ln(T_c/T_M)/\partial \ln \rho_0$ versus $\ln \rho_0$ (solid curve) on the same scales.

Figure 5. Resistivity $\rho_0$, determined just above the onset of superconductivity, as a function of pressure. Solid circles are experimental results and the solid curve is a theoretical prediction for a 3D superconductor with $\kappa^2 = 0.5$ and $g^2\chi_0/t = 60$. For the theoretical curve, we have used, as in figures 4 and 5, $P = 0.64\kappa^2$ and $\rho_0 = 9.2 \times 10^{-8} g^2\chi_0/t$. 
