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Superconductivity at magnetic quantum critical points: recent surprises in $YbRh_2Si_2$ and in $CeCu_2Si_2$

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The onset of superconductivity (SC) at a quantum critical point (QCP), where a phase transition to an (usually antiferromagnetic) ordered state is continuously driven to $T = 0$ by tuning a non-thermal parameter, is one of the hot topics in present solid state physics. $CeCu_2Si_2$ and $YbRh_2Si_2$ are two paradigmatic heavy fermion systems which are extremely close to such a QCP already under normal conditions, without external tuning. In the past two years, astonishing observations where made in these two compounds, which I shall present and discuss. $CeCu_2Si_2$ was the first discovered superconducting heavy fermion system, and as such, the first candidate for an unconventional, magnetic mediated superconducting state. Despite this discovery is now 38 years old, the symmetry of its SC order parameter and the nature of the SC pairing interaction are yet not settled. For long time, based on NMR, neutron scattering and further results, the SC order parameter was thought to be d-wave, with nodal lines. However recent experiments provided conclusive evidence for a fully gaped SC order parameter[1]. This surprising result has triggered new experiments and new theoretical proposals for possible SC order parameter and sparked a vivid and controversial discussion[2][3][4]. In $YbRh_2Si_2$ competition between a Kondo interaction and a RKKY exchange of similar magnitude results is an extremely weak AFM state with a Neel temperature of only 70 mK and an ordered moment of only 0.002 μ_B, locating this system extremely close to a QCP. Despite very high sample quality, no evidence for superconductivity had been observed until very recently. Last year, clear evidence for a phase transition at only 2 mK was reported[5]. The behavior at (comparatively) large magnetic fields indicates an underlying magnetic transition, but a sharp and large drop in χ(T) at very small fields suggests this magnetic transition to induce a superconducting state. It was proposed that the onset of a new combined nuclear-electronic order at 2 mK weakens the antiferromagnetic state formed at higher temperatures, and thus induces superconductivity[5]. However, the scenario proposed in [5], being based on a Landau model with a large number of free parameters, met some skepticism. Here we shall analyze the specific properties of $YbRh_2Si_2$ in view of possible mechanisms for this 2 mK transition. After introducing how hyperfine interaction works for Yb, we single out some very peculiar properties of $YbRh_2Si_2$. They result in a specific and unique situation for the interplay between 4f and nuclear moments. Below a few mK the AFM state formed at 70 mK, because of its tiny ordered moment, becomes inherently unstable against the formation of a larger ordered 4f moment state. Our analysis strongly support the existence of a combined nuclear electronic transition in the mK range in $YbRh_2Si_2$, but indicate that the size of the ordered 4f moment should increase at this transition, in contrast to the decrease proposed in [5].

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