Are all ferromagnetic phase transitions at low enough temperature first order? Case of Itinerant Ferromagnet $ZrZn_2$.

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Experimental investigations have recently focused on a class of strongly correlated electron systems, namely heavy-fermion metals, where (weak) magnetic order can in many cases be suppressed to nearly zero temperature by the application of external pressure or magnetic field. While in most cases the magnetic order is antiferromagnetic in nature, in some other cases, as in $ZrZn_2$, ferromagnetic order is observed.

Usually the observed (critical) behavior is compared to the theoretical predictions of the standard itinerant (spin density wave) model (ref. 3 and others). Experimental deviations from the predicted behavior are frequently interpreted in terms of the need for new and fundamentally different models. A prerequisite for the comparison of experimental results with the standard itinerant model is the second-order nature of the quantum phase transition. In many cases this issue has been taken for granted. In fact, it can be a formidable experimental task to decide whether an observed phase transition is of first or second order. More dramatically, as clearly shown in the present paper, a second-order phase transition can turn into a first-order one as the critical point is approached. Since approaching a zero-temperature phase transition experimentally means conducting the experiments at ever lower temperatures, and finally extrapolating the results to T=0, it might never be possible to strictly rule out the possibility of second- to first-order transformations.

The present paper provides convincing evidence for the first-order nature of the pressure-driven zero-temperature phase transition from a ferromagnet to a paramagnet in the case of $ZrZn_2$. The DC magnetization was measured on single-crystalline samples between room temperature and 1.5 K in magnetic fields up to 12 T and at different pressures up to 21 kbar. Both the ferromagnetic ordered moment and the Curie temperature first decrease approximately linearly with increasing pressure but then drop discontinuously (within the resolution of the experiment) at a critical pressure of 16.5 kbar. Isothermal magnetization vs field curves show metamagnetic-like behavior above the critical pressure. $ZrZn_2$ is the first essentially three dimensional itinerant ferromagnet for which a first-order zero-temperature phase transition has been demonstrated. The authors speculate that quantum phase transitions in itinerant ferromagnets are generically first order, as suggested theoretically (refs. 8 and 10). Further experiments on other itinerant ferromagnets will have to test this conjecture. In the case of antiferromagnetic quantum phase transitions the question of second- or first-order transitions will also have to be looked at in greater detail.