Reply to "Comment on 'Phase diagram of reentrant and magnetic-field-induced superconducting states with Kondo impurities in bulk and proximity-coupled compounds' "

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The existence of Kondo impurities has recently been suggested as an explanation for the long-standing puzzle of paramagnetic reentrance in thick proximity systems. We show here that despite recent claims to the contrary such impurities may still be the source of this effect.

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The reentrant phenomenon in thick cylindrical proximity systems has intrigued theoreticians since its discovery in 1990 by Visani *et al.*[1] This phenomenon occurs in cylindrical proximity systems consisting of a superconducting core (Nb, Ta) and normal metal coating (Ag, Cu) where below a certain temperature ($\sim$20 mK) the proximity-induced Meissner effect gradually disappears and then reappears upon the application of a small magnetic field (of the order of 20 Oe).

The phenomenon has stimulated much theoretical work,[2–8] including our most recent explanation.[9] Our work, which used the intricate interplay between the Kondo and the Meissner effects to show that reentrance and magnetic-field-induced superconducting behavior should be expected in any system that exhibits both effects for the right parameters, led us to suggest that such an interplay is at the heart of the paramagnetic reentrance seen in proximity systems. We also provided a rough estimate for the range of Kondo impurities which would explain the experimental results at $\sim$100 ppm.

In a recent work, Deutscher *et al.*[10] claimed to have disproved the existence of magnetic impurities in sufficient amount in such samples by measuring their resistance. They measured the resistance of a NbAu sample which had shown reentrance 12 years ago. In addition, a NbAg sample was taken from a wire from which a reentrance showing sample was taken 12 years ago. Due to the superconducting niobium core of the sample they could measure the resistance of the samples in zero field only above the core's transition temperature of 9 K and below it they applied a magnetic field of $\sim$1.5 T to suppress niobium's superconductivity. They did not demonstrate that their samples still exhibited the reentrance effect and it would have been very helpful had they done so.

Deutscher *et al.* used the lack of a Kondo minimum above 2 K in their measurements to put an upper bound on the amount of magnetic impurities in their samples at a few ppm. They did this using an analogy with nonproximity samples made out of the same materials as the normal metal coating on their samples (Ag, Au) impregnated with homogeneously distributed magnetic impurities (Mn, Fe) measured without any applied magnetic field. However, strong magnetic fields can have a dramatic effect on the resistance of samples with Kondo impurities[11,12] especially when $\mu_B H \gg k_B T_K$ as is the case for this field if we assume $T_K \sim 1$ mK, as our suggested explanation does. Therefore, even glossing over other difficulties, the temperature dependence characteristic of the Kondo effect should be valid only (much) above $T \approx \mu_B H / k_B \approx 2$ K; therefore, since the magnetic field suppresses the Kondo effect, taking it into account might allow for much higher impurity concentrations.

Moreover, a compound sample made of two metals may add to the complexity of the analysis and reduce the validity of the analogy, especially since one of the materials considered is a magnetically suppressed superconductor. The effect of the samples' layered structure might become crucial if the impurities lie in or near the niobium-Au/Ag interface (as was recently seen for similar systems[13])—a possibility mentioned by us but unaddressed by Deutscher *et al.* even though they showed the Nb in their samples to be dirty. With the impurities at the interface their effect on the proximity-induced Meissner currents might be very dramatic while their effect on the Au/Ag's conductance would still be small. Furthermore, for an unspecified reason, Deutscher *et al.* have considered only specific types of impurities while the samples may contain others. Given all these unaddressed setbacks Deutscher *et al.*'s figures for the maximal Kondo impurity concentrations can be taken as rough estimates at best.

A further point is made in Ref. 10 regarding trends in the dependence of the reentrant effect on sample purity. The claims made in this section stand in direct conflict with past claims of one of the authors that samples with similar dimensions and mean free path show significantly different reentrant behaviors.[14] They also implicitly assume a monotonic relation between concentrations of regular and magnetic impurities for no apparent reason.

Even if one accepts Deutscher *et al.*'s rough estimates of the maximal impurity concentrations present in the samples they measured it is perfectly plausible that it is consistent with our rough estimate of the impurity concentration needed for reentrance.[9] Further theoretical work which will improve both estimates or a new experiment is needed in order to settle this issue. We wish to reiterate that our prediction of both reentrance and magnetic-field-induced superconducting behavior in proximity effect samples with magnetic impurities still holds even if somehow a different explanation arises for the exact same behavior in the samples in question.

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