Dragon hunting in Kondo-land, or the uses of particle-hole symmetry breaking

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Outline

1. Kondo effect primer

2. Intermission: dragons

3. Refining the model: particle-hole asymmetry

Conventional Kondo effect

▷ Magnetic impurity in a non-magnetic metallic host

$$H = H_{el} + \frac{1}{\nu} \sum_{i=1}^{3} g_a \psi_\alpha^\dagger (\mathbf{r}_0) \sigma_{\alpha\beta}^a \psi_\beta (\mathbf{r}_0) \cdot S^a \qquad (1)$$

▷ High temperature: logarithmic corrections to scattering matix

▷ Crossover at $T_K \sim D\sqrt{g_1 g_3} \left(\frac{g_1}{2g_3}\right)^{1/2g_3}$ if $g_1 << g_3$

▷ If $g_1 = g_2 = g_3 = g$: $T_K \sim De^{-1/2g}$ [1]

▷ At $T = 0$ magnetic moment is screened; Local spin + conduction electron spin $\rightsquigarrow$unitary *spin* $= 0$ scatterer ▷ At $T \ll T_K$ Fermi-liquid-like $O\left(T^2/T_K^2\right)$ deviations from perfect screening

[1]Cf. BCS transition temperature $T_c = \omega_{\text{Debye}} e^{-1/g_{\text{BCS}}}$

$\triangleright$ Observed since 1930's; explained in 1960's; "laboratory" for devlopement of RG (Anderson et al. 71', K. G. Wilson '75); exact solution (Wiegmann '80; Andrei '80) $\rightsquigarrow$theorists' favourite playground

Two-channel Kondo effect [1]

▷ Two types of electrons ("green" and "red")

$$H = H_{el} + \frac{1}{\nu} \sum_{i=1}^{2} \sum_{a=1}^{3} g_a \psi^{\dagger}_{i,\alpha} (\mathbf{r}_0)\, \sigma^a_{\alpha\beta} \psi_{i,\beta} (\mathbf{r}_0) \cdot S^a + hS^3 + \Delta S^1 \tag{2}$$

▷ "Overscreening": too many screening spins available

▷ Logarithmic behavior at $T > T_K$ as before

▷ Non-fermi-liquid $\sqrt{T}$ behavior at $T < T_K$

▷ Many-channel generalisations, etc. (even more enticing playground)

▷ Possible realisations: orbital angular momentum index, but: difficult to maintain channel degeneracy

▷ Never observed unambiguously

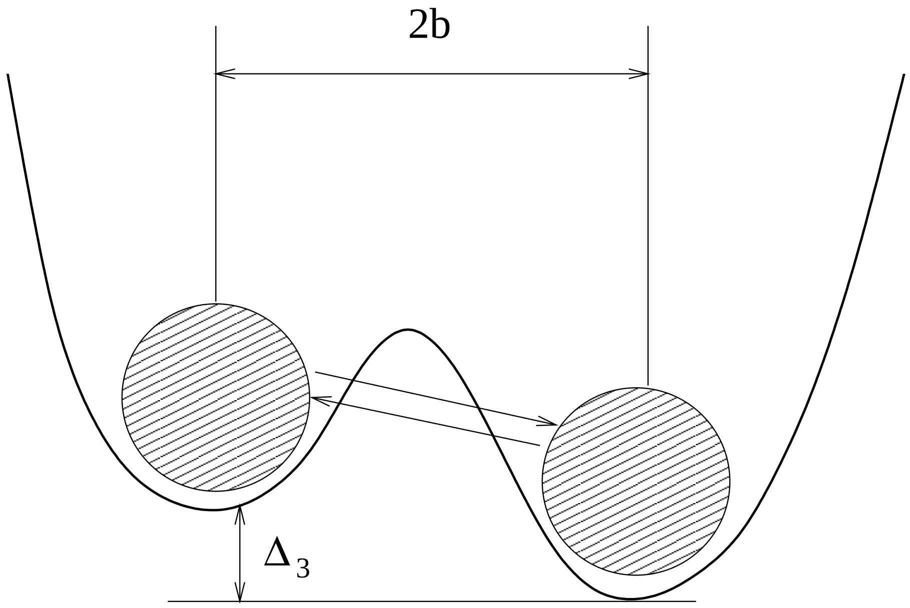
[1] Nozieres & Blandin, '80

Everyone knows that dragons don't exist. But while this simplistic formulation may satisfy the layman, it does not suffice for the scientific mind. The school of Higher Neantical Nillity is in fact wholly unconcerned with what does exist. Indeed, the banality of existence has been so aptly demonstrated, there is no need for us to discuss it any further here. The brilliant Cerebron, attacking the problem analytically, discovered three distinct kinds of dragon: the mythical, the chimerical, and the purely hypothetical. They were all, one might say, nonexistent, but each nonexisted in an entirely different way.

Stanislaw Lem, *The Cyberiad*

▷ Zawadowski '80, '83: Orbital Kondo effect

▷ Electrons + two-level system (TLS): assisted tunneling



▷ Orbital angular momentum $l = 0, 1 \rightsquigarrow$ "pseudospin"; spin $\rightsquigarrow$ "channel".

▷ Invoked to interprete $\sqrt{T}$ in Cu, Pd, or Ti nanoconstrictions (Buhrman and coworkers) – very controversial

Problems

▷ Need: $T_K > \sqrt{h^2 + \Delta^2}$ (h – asymmetry between "up" and "down" spin states, 'Δ – spontaneous tunneling)

▷ Magnetic one-channel: $D \sim E_F \rightsquigarrow T_K$ up to room temp.

▷ TLS: $D \sim 1/\tau_{\text{tunneling}}$: small for heavy atoms

▷ g and Δ not independent

Particle-hole asymmetry

▷ PHA increases T_K

▷ Generically: $\epsilon^* \sim E_F$ $\rightsquigarrow$small corrections $1/\tau_{\rm tunneling}\epsilon^*$

▷ Strong PHA: localised state (d- or f-electron) above E_F on the tunneling atom: $\epsilon^* \sim 1/\tau_{\rm tunneling}$

▷ E.g. bivacancy + light dopant?