1. Introduction

2. Few Electron Dots

3. Double Quantum Dots

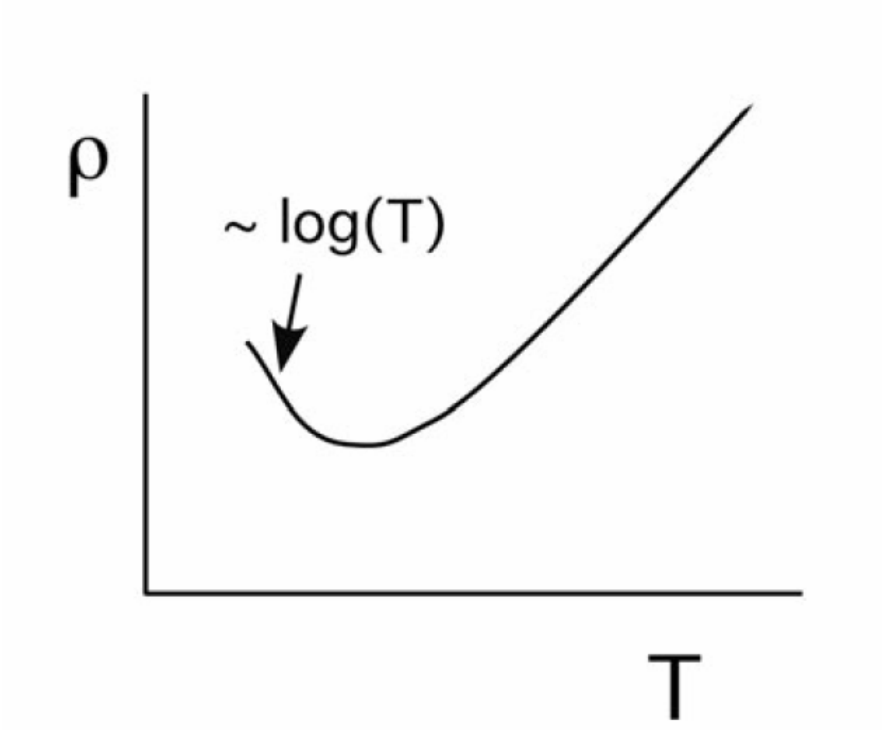
4. Kondo Effect

5. Open Dot Experiments

Goldhaber-Gordon et al., Nature **391**, 156 (1998)
Cronenwett et al., Science **281**, 540 (1998)
S. Cronenwett, Ph. D. Thesis (2001)

Kondo Effect in Metals

1930s experiments:



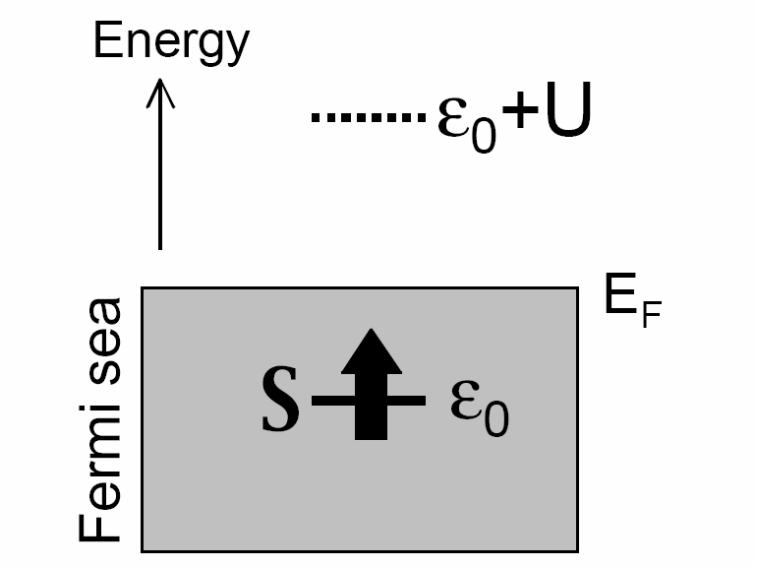
1960s: (exp) related to magnetic impurities

theoretical explanation by Jun Kondo
spin-fip scattering on mag. impurities

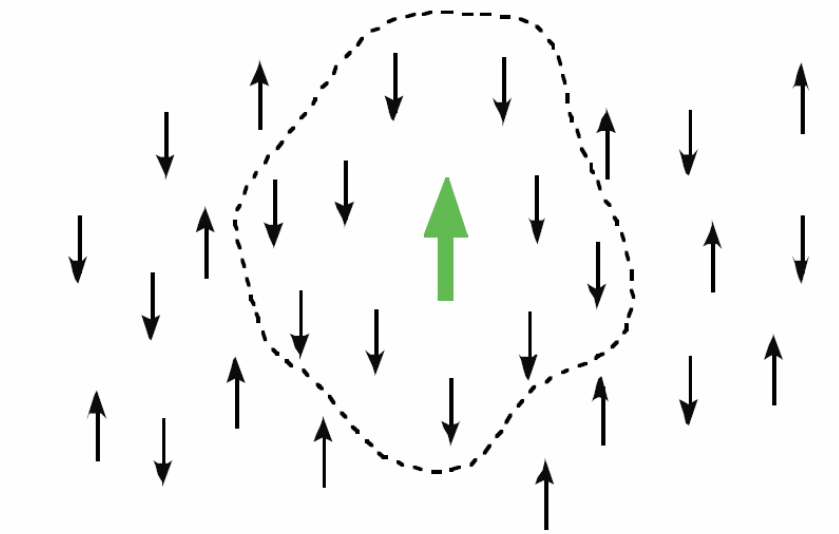
$$\rho \sim \rho_0 + aT^5 - b\log(T)$$

lattice phonons

Kondo Effect in Metals: Model



new energy scale: Kondo temperature T_K
formation of spin-singlet screening cloud



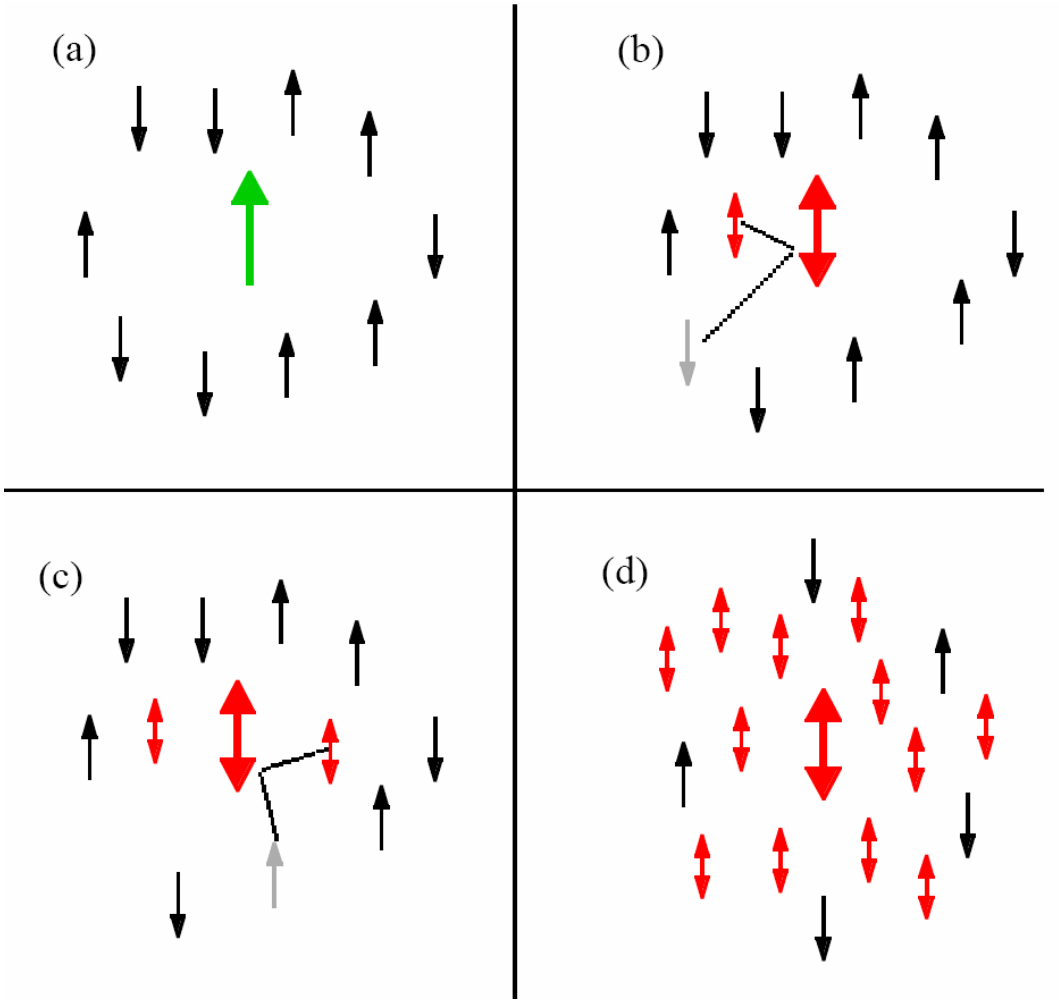
cloud: more effective scatterer
increase in resistance

Anderson Hamiltonian

$$H_A = \sum_{\sigma;k<k_f} \varepsilon_{k\sigma} c^{\dagger}_{k\sigma} c_{k\sigma} + \sum_{\sigma} \varepsilon_{\sigma} d^{\dagger}_{\sigma} d_{\sigma} + \frac{1}{2} U n_{\sigma} n_{\sigma'} + \sum_{\sigma;k<k_f} t_{k\sigma} c^{\dagger}_{k\sigma} d_{\sigma} + H.c..$$

free electrons	localized electrons	on site charging	coupling between localized and free ele.

Kondo Effect in Metals: spin flip scattering

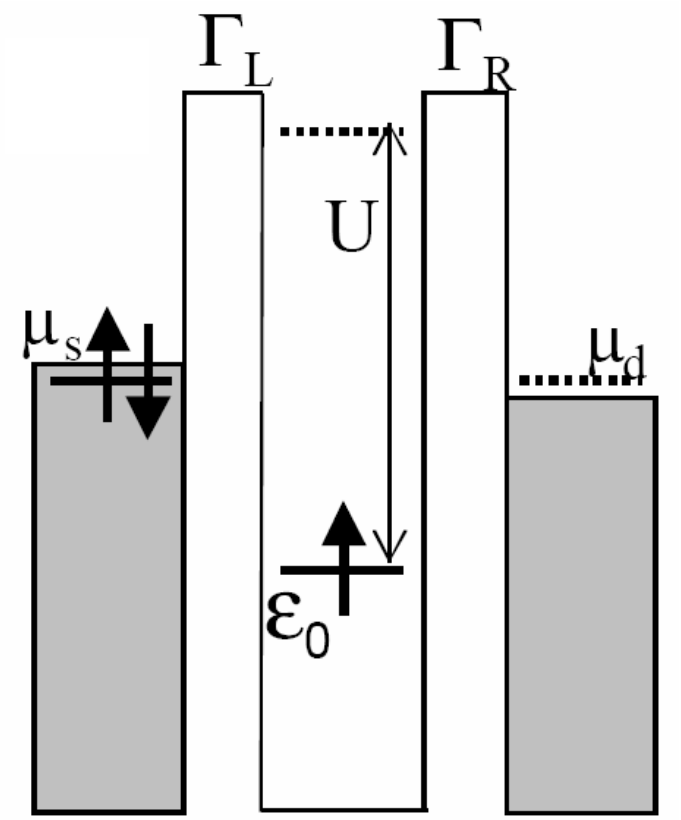


each scattering event engangles impurity with conduction electron

singlet cloud formation

temperature scale T_K

Kondo Effect in Quantum Dots

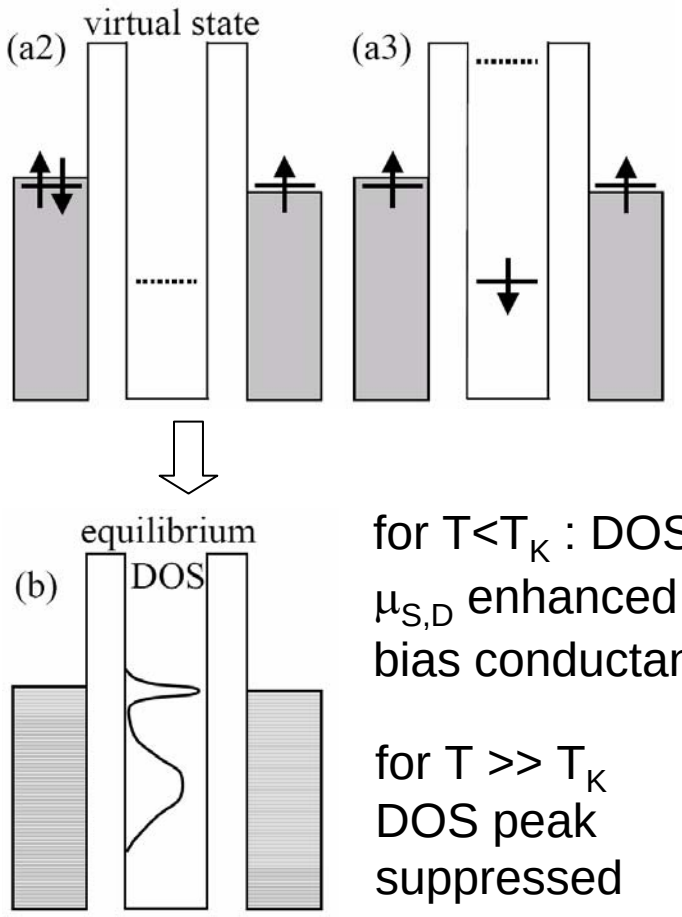


unpaired spin

$$T_K \propto \sqrt{U\Gamma}\exp(\pi\epsilon_0/2\Gamma)$$

$$\Gamma = \Gamma_L + \Gamma_R$$

spin-flip cotunneling (elastic)

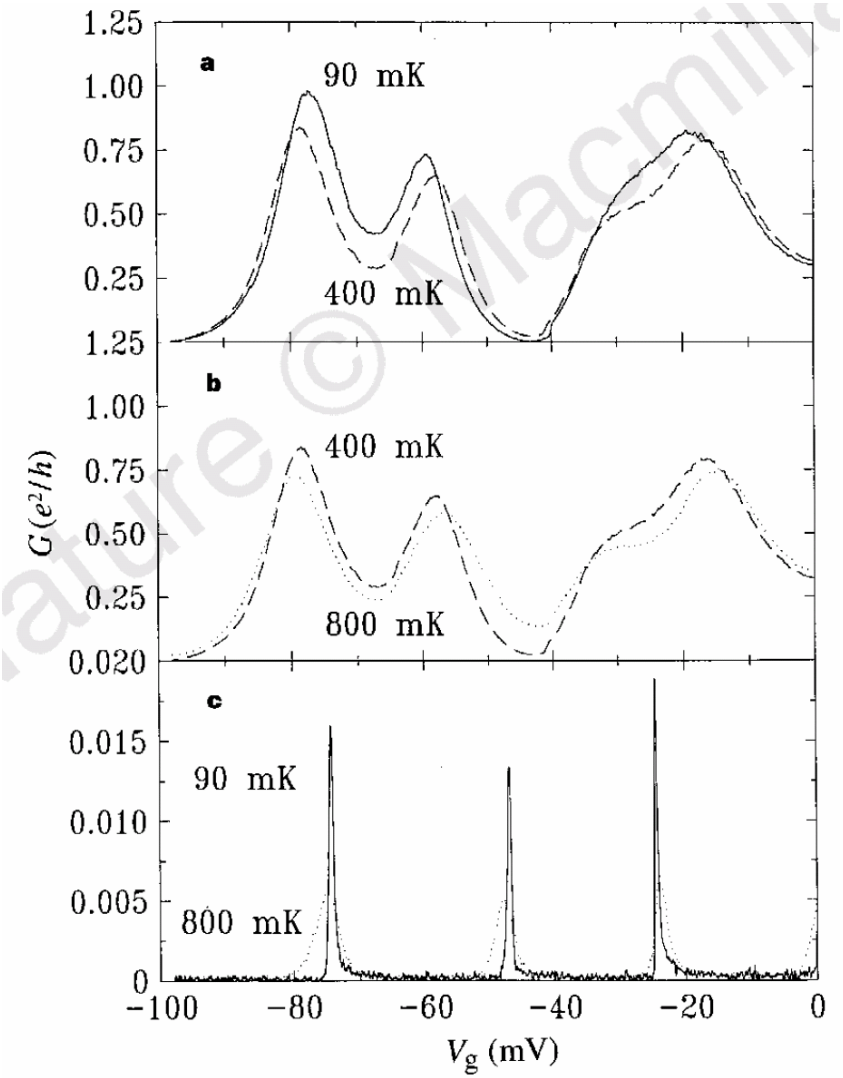


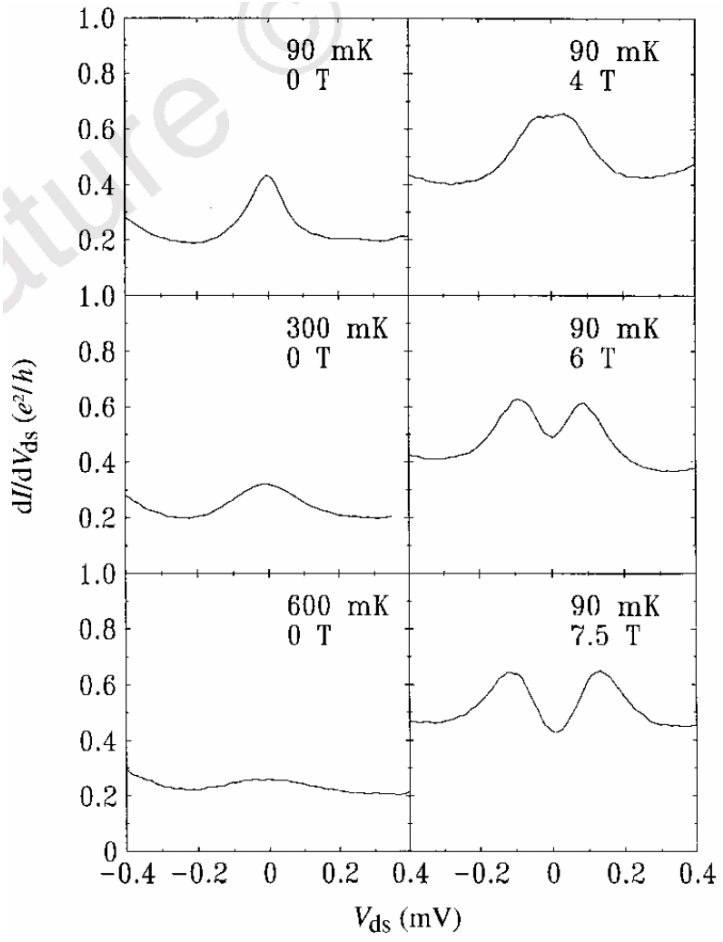
for $T<T_K$: DOS at $\mu_{S,D}$ enhanced zero bias conductance!!

for $T >> T_K$ DOS peak suppressed

dots: parameters tunable
SINGLE impurity

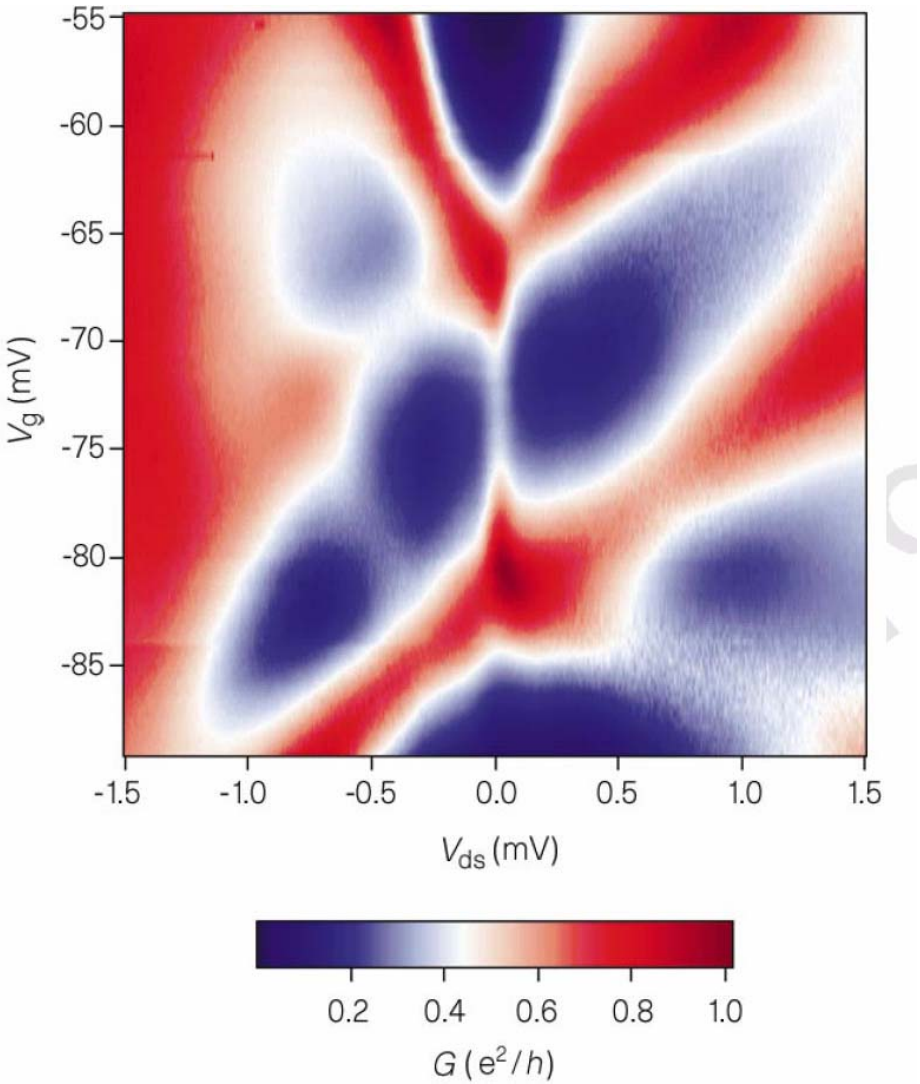
Kondo Effect in Quantum Dots: Experiment





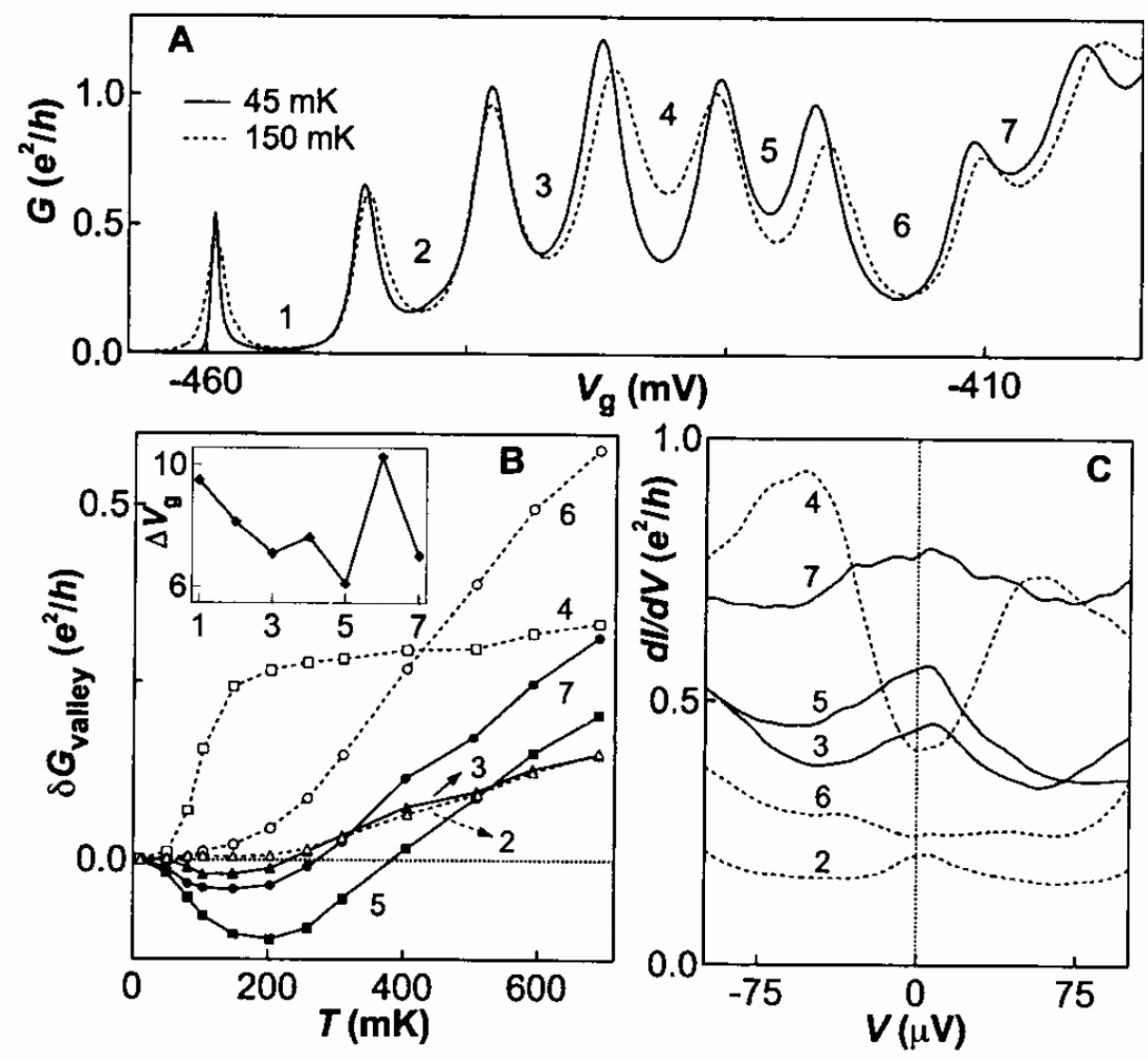
Goldhaber-Gordon et al., Nature **391**, 156 (1998)

Kondo Effect in Quantum Dots: Experiments



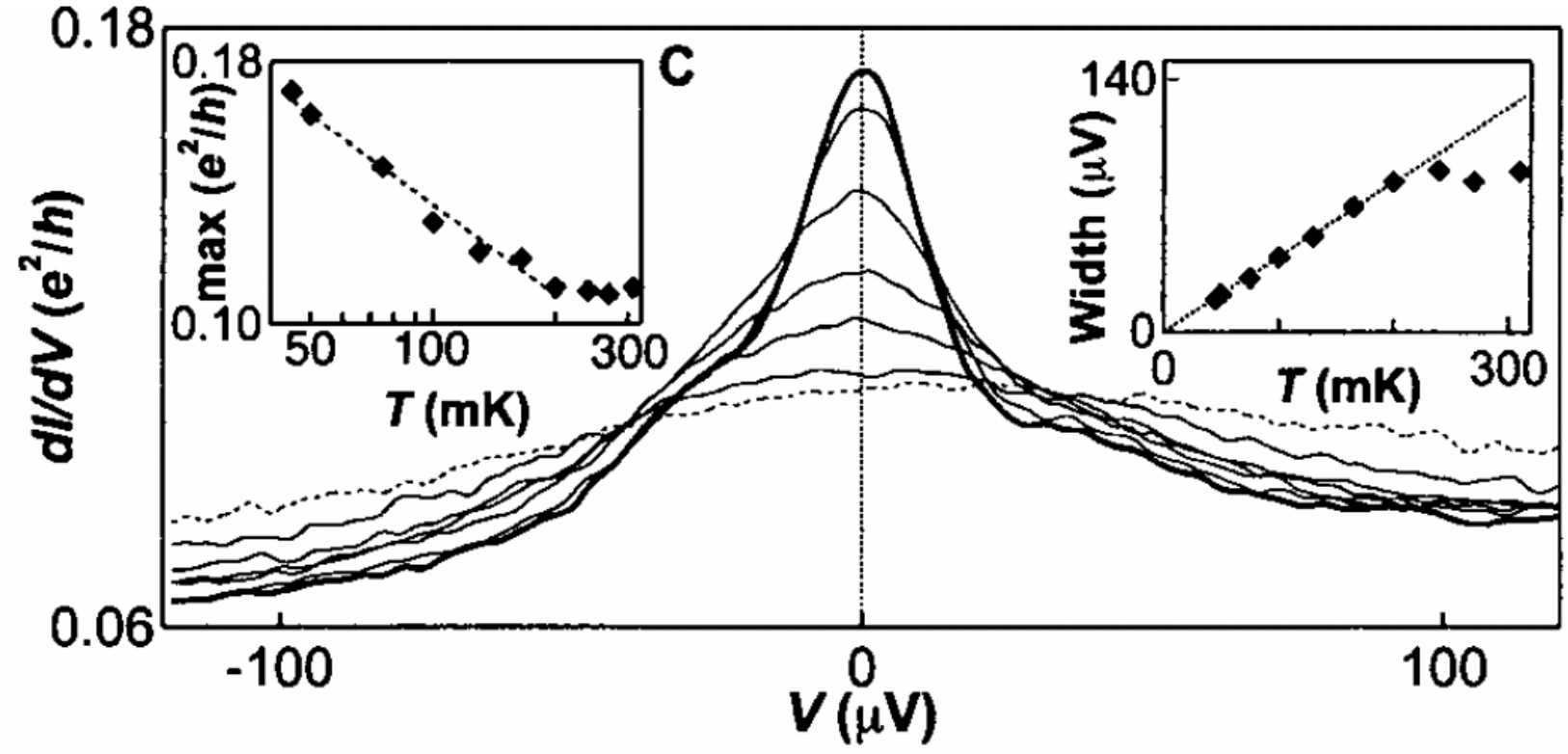
Goldhaber-Gordon et al., Nature **391**, 156 (1998)

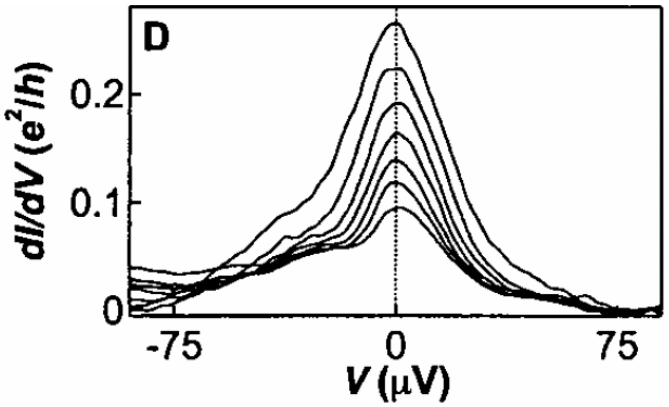
Kondo Effect in Quantum Dots: Experiments



Cronenwett et al., Science **281**, 540 (1998)

Kondo Effect in Quantum Dots: Experiments

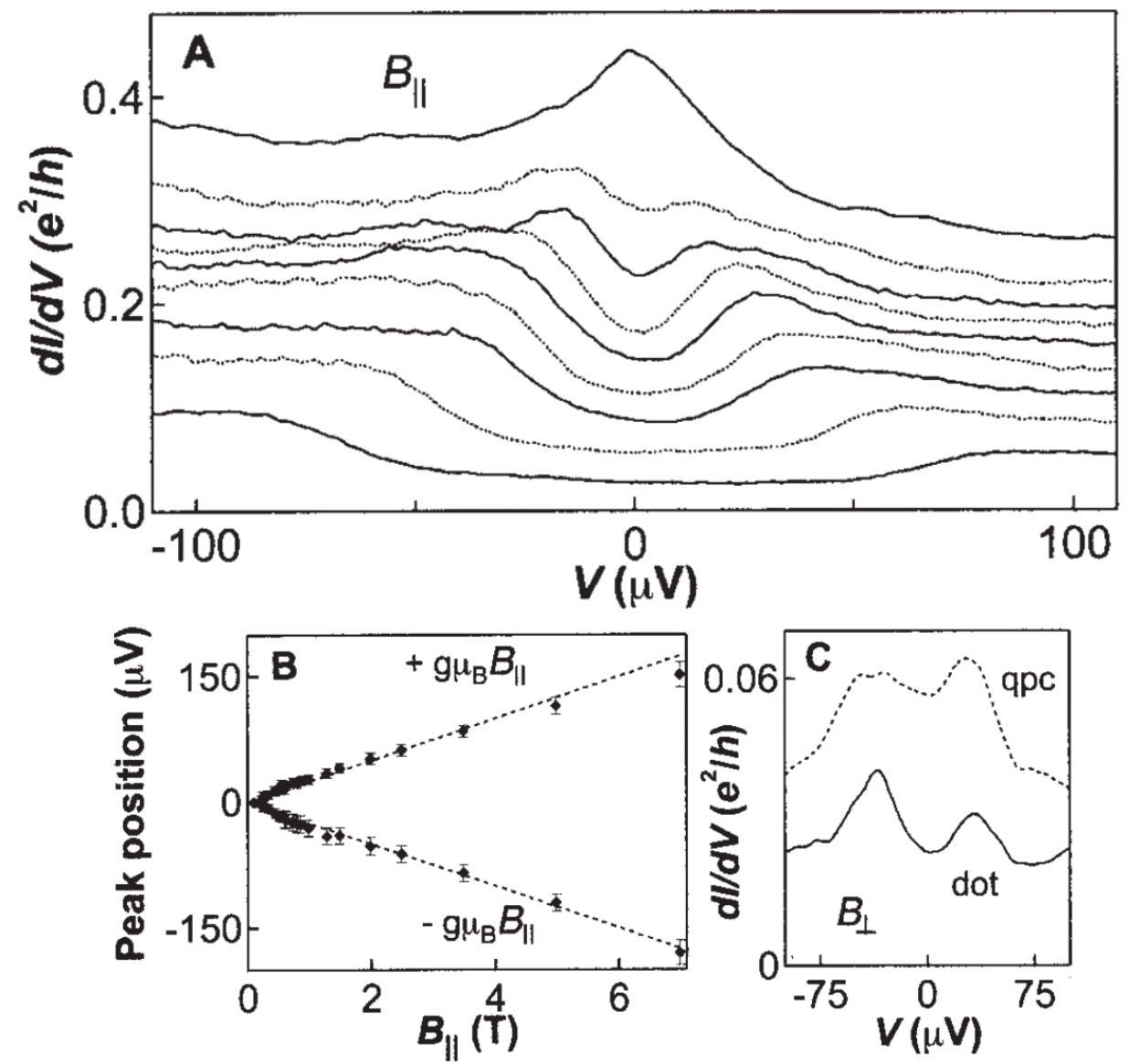




gate voltages
into odd valley

Cronenwett et al., Science **281**, 540 (1998)

Kondo Effect in Quantum Dots: Experiments



Cronenwett et al., Science **281**, 540 (1998)

Kondo Effect in Quantum Dots: Experiments