LT lab nano

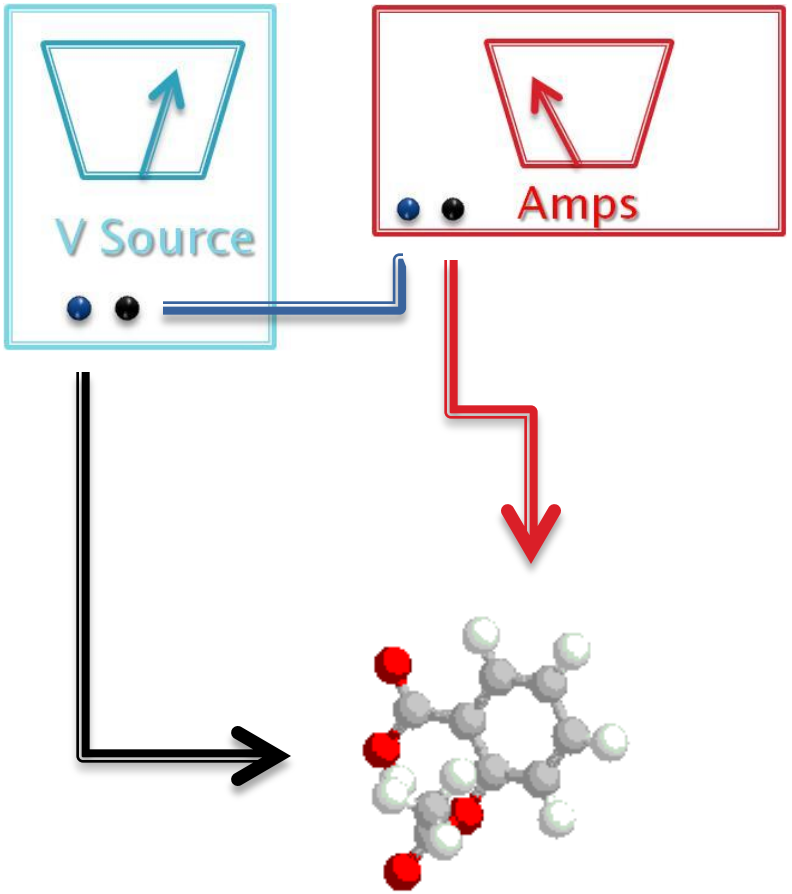
Universitat d'Alacant
Universidad de Alicante

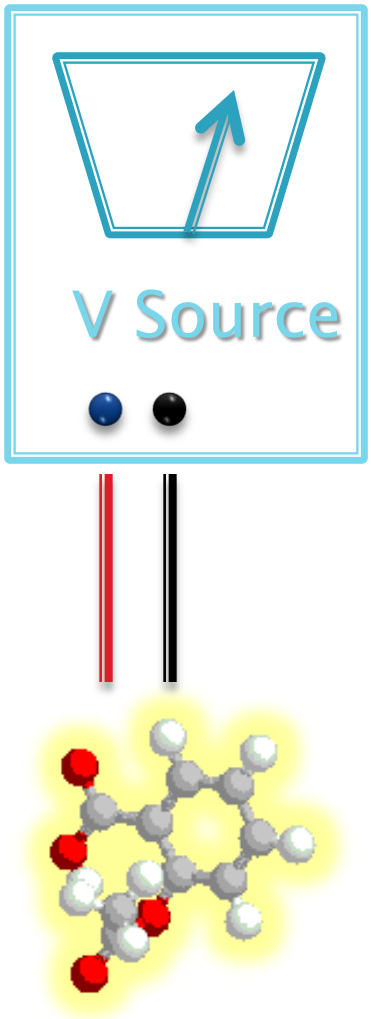
Kondo Effect in a One-Atom Contact of a Ferromagnetic Material

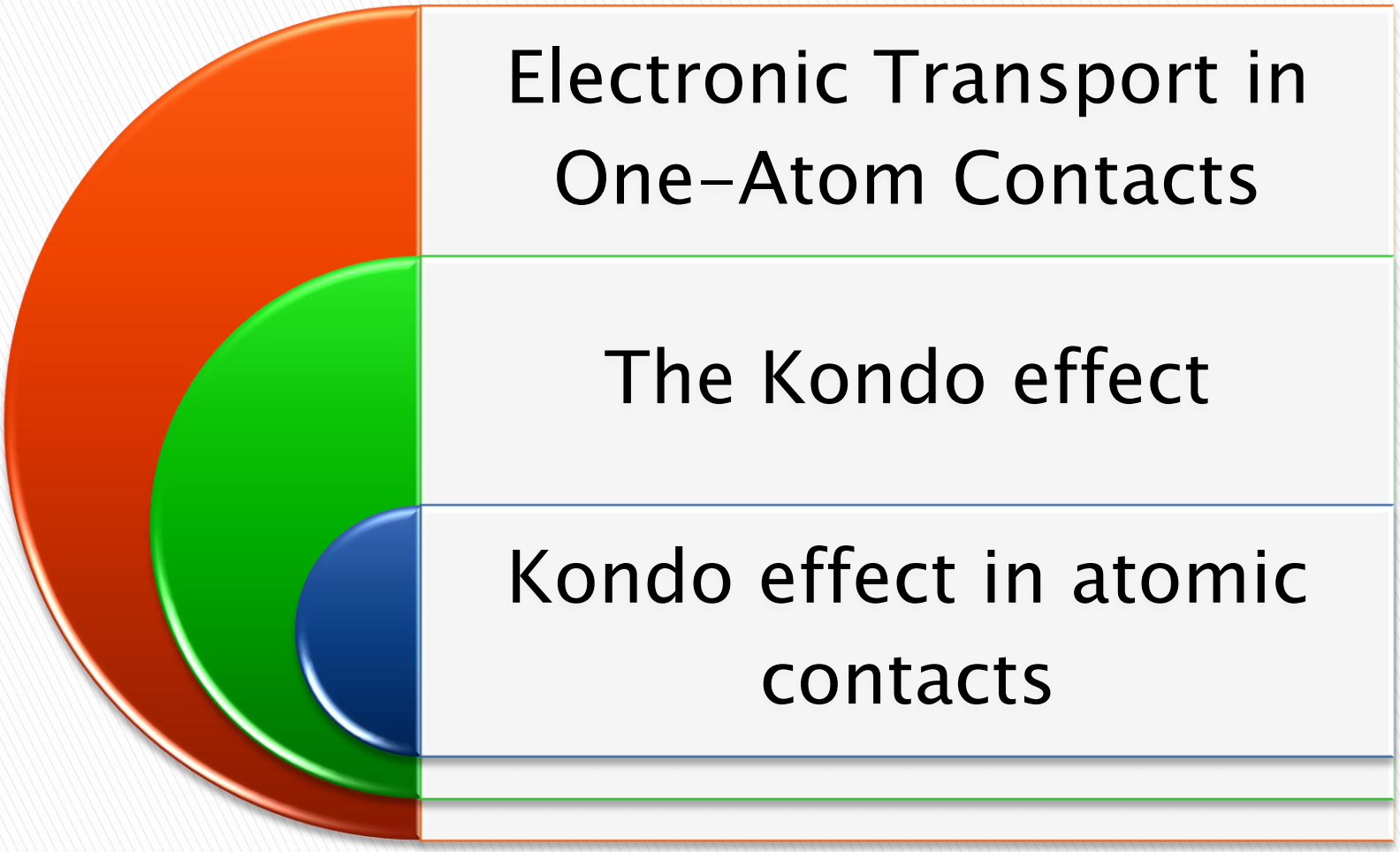
Carlos Untiedt

WS10-ETOLDs

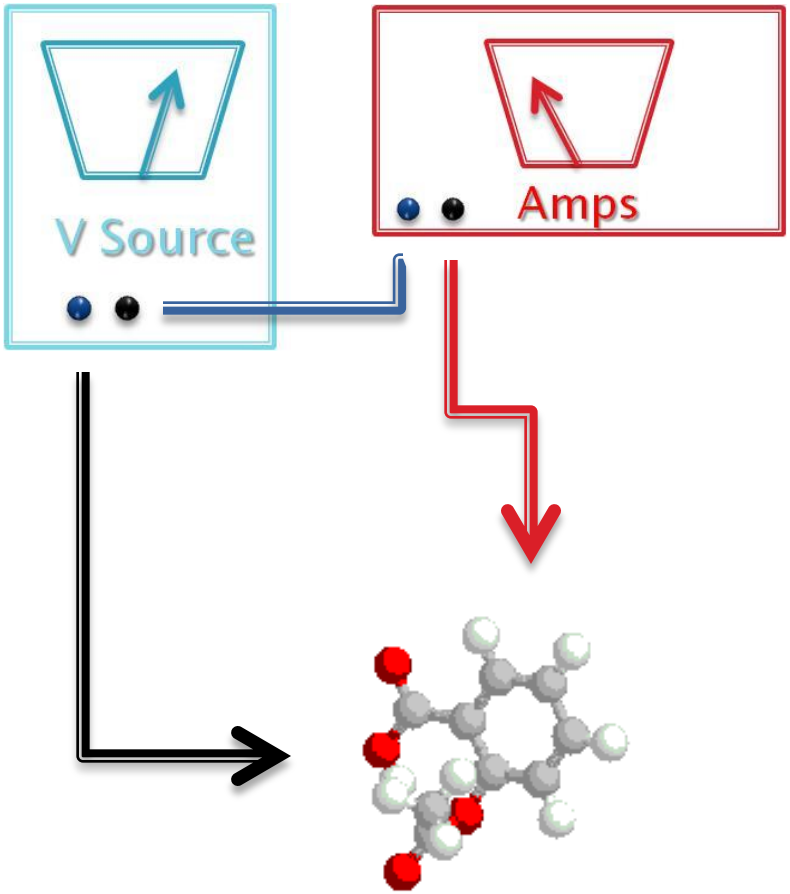
Electronic transport of low-dimensional systems

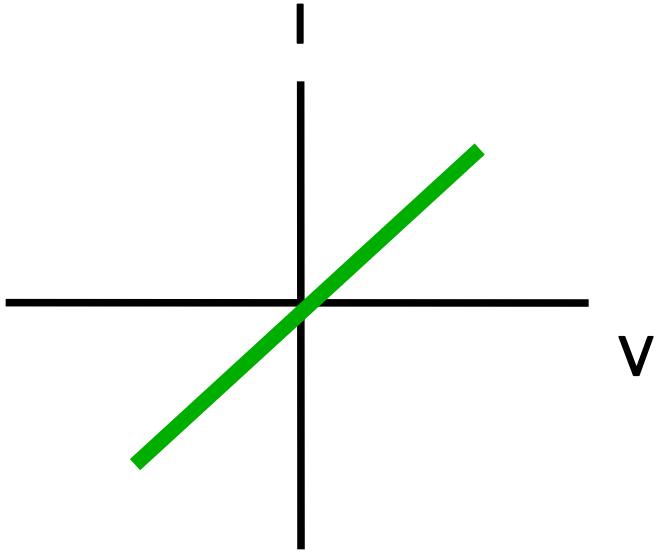


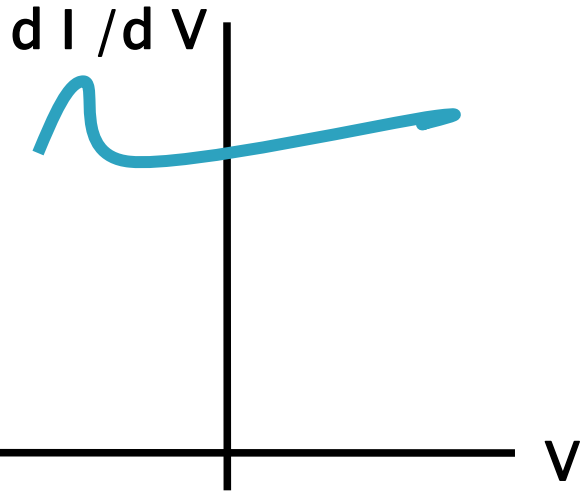



Electronic Transport in One-Atom Contacts
The Kondo effect
Kondo effect in atomic contacts

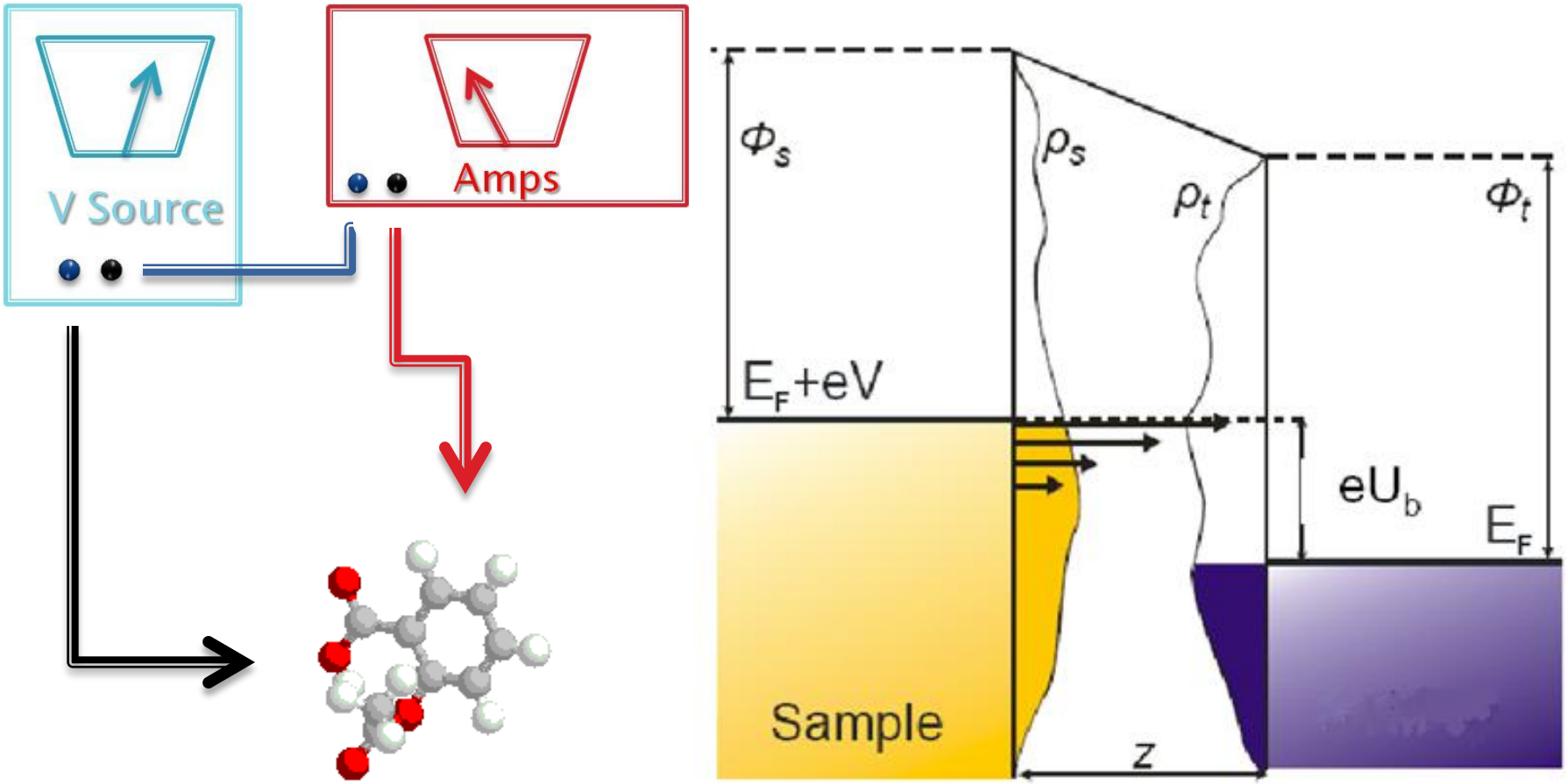
d I / d V characteristics

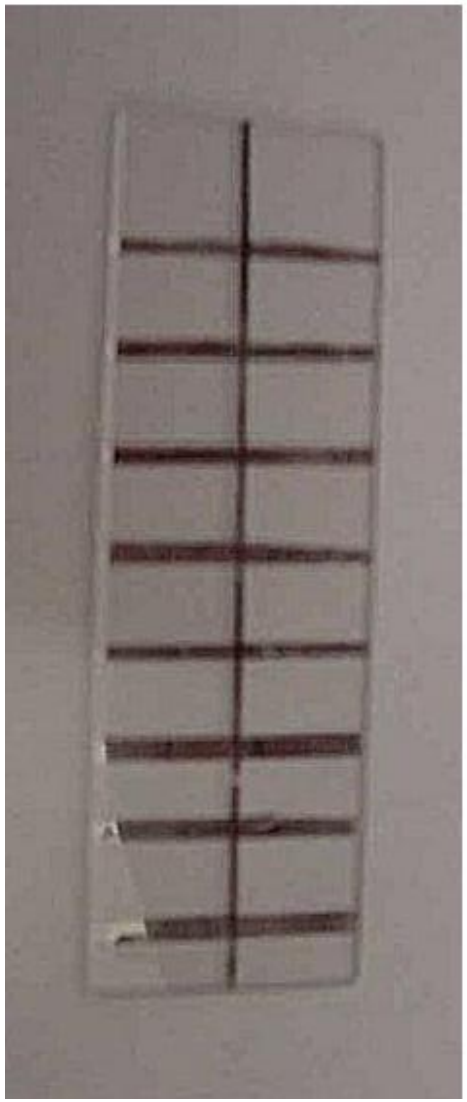


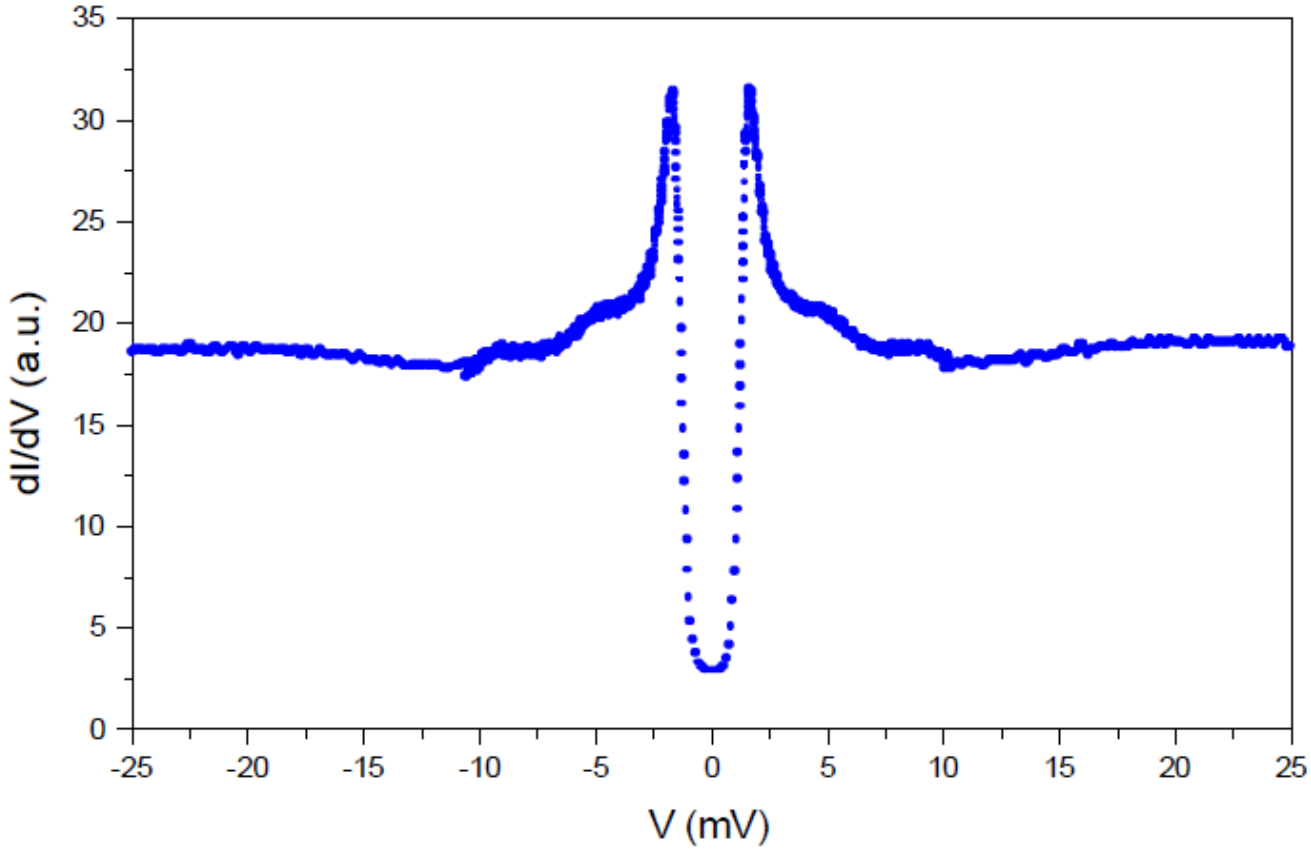




d I /d V and the DOS

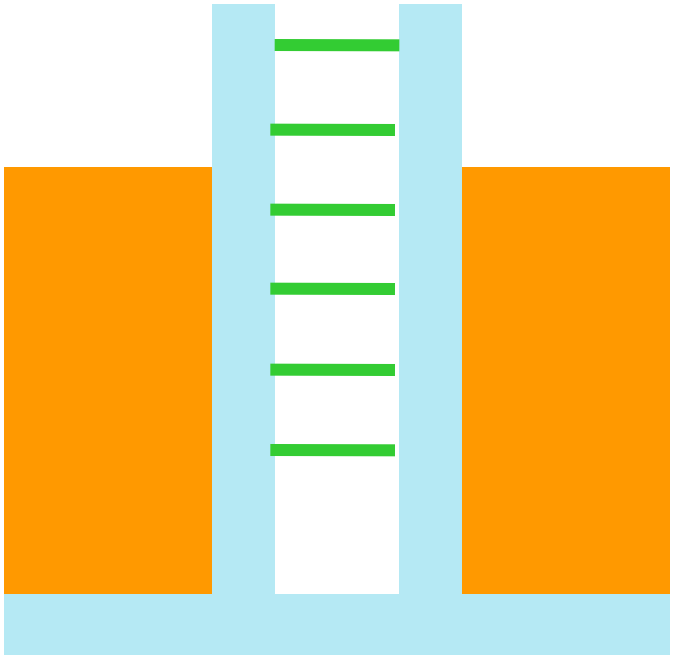


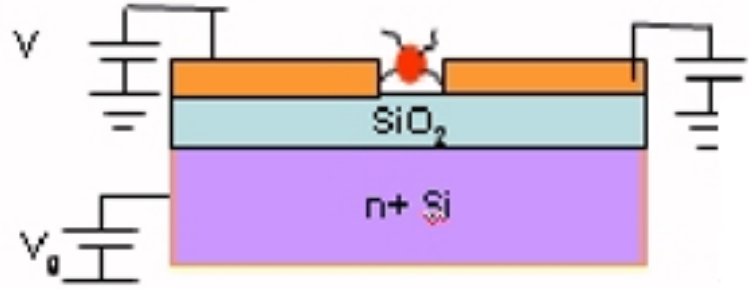


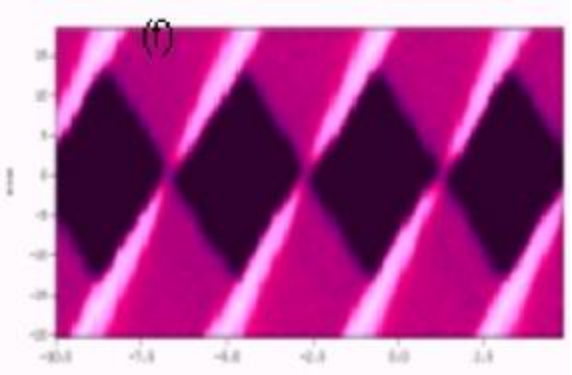


Ivar Giaever 1959

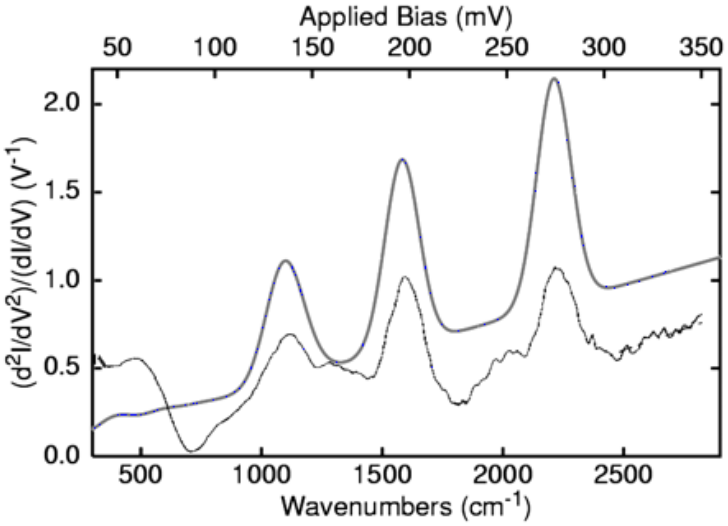
Spetroscopy in atomic/molecular systems

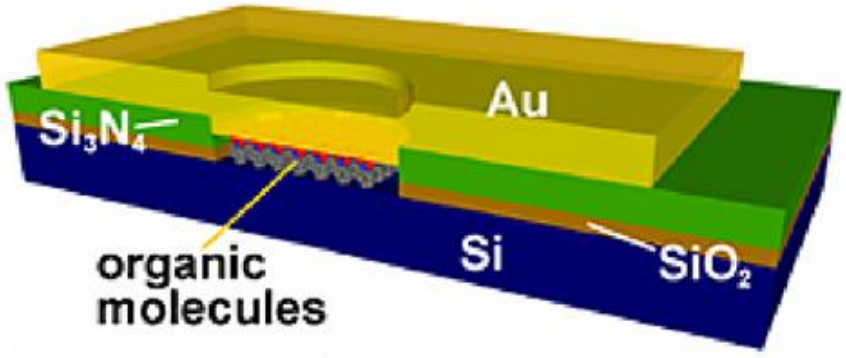


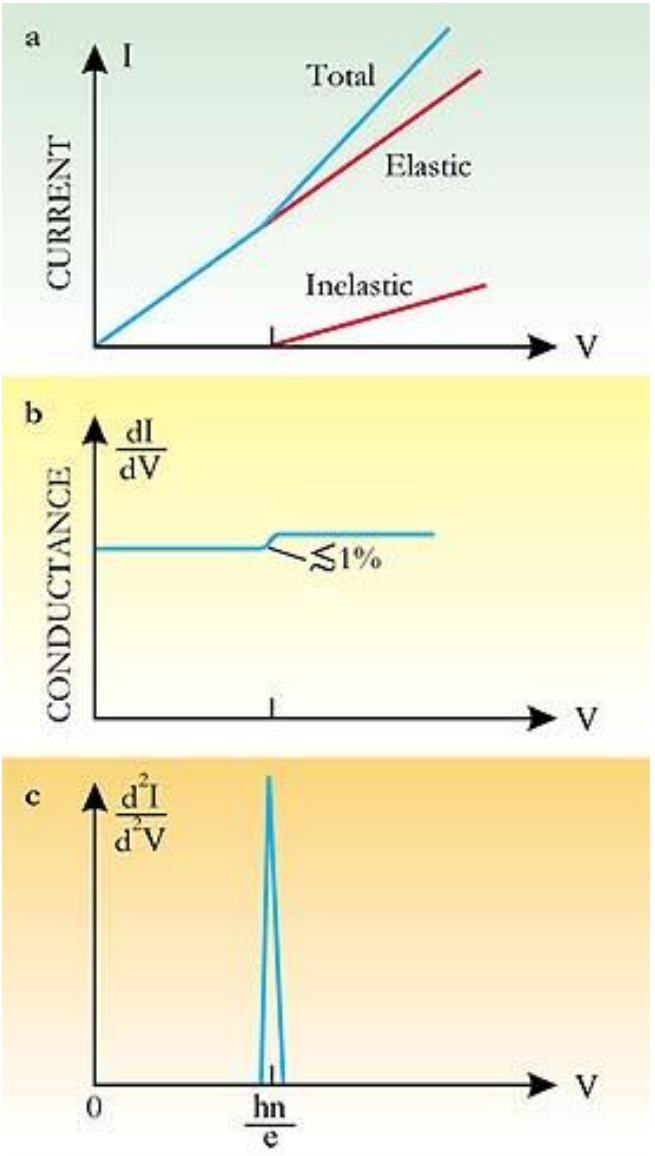




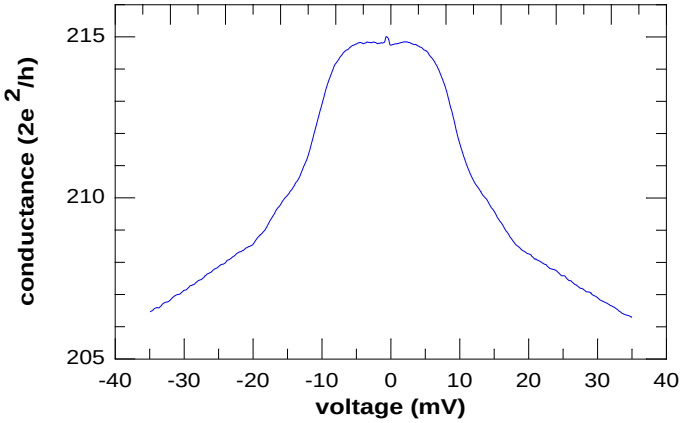
Inelastic effects

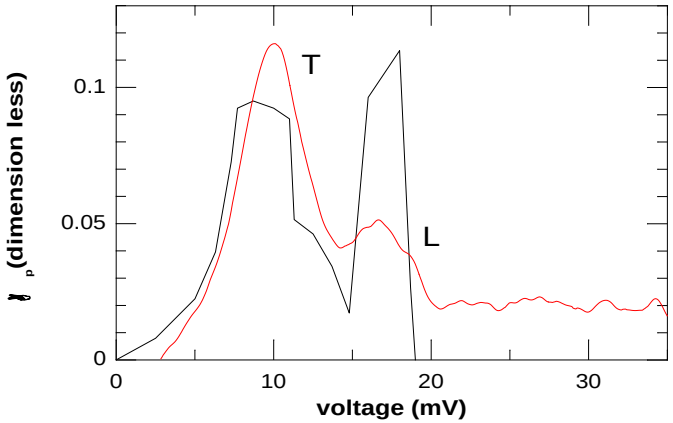


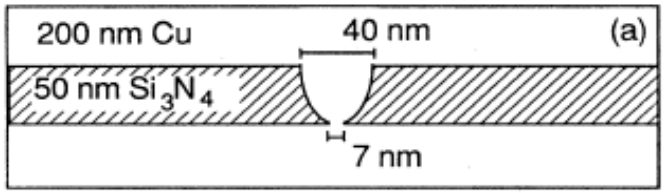


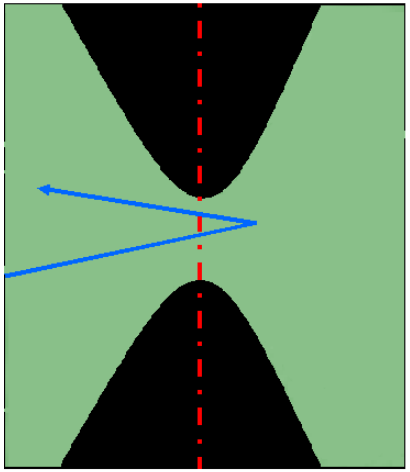


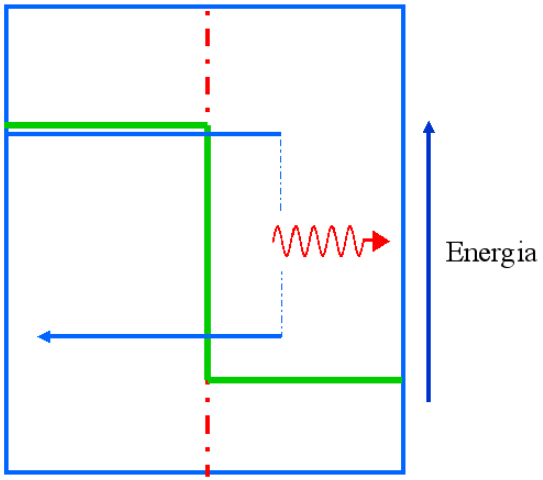
Point Contact Spectroscopy







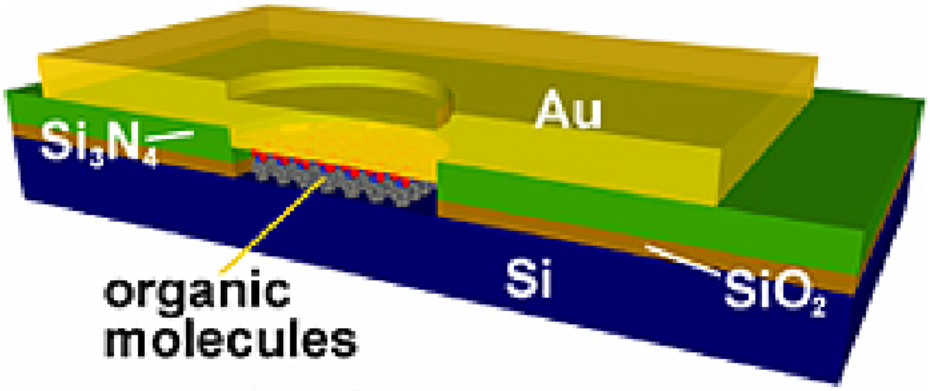


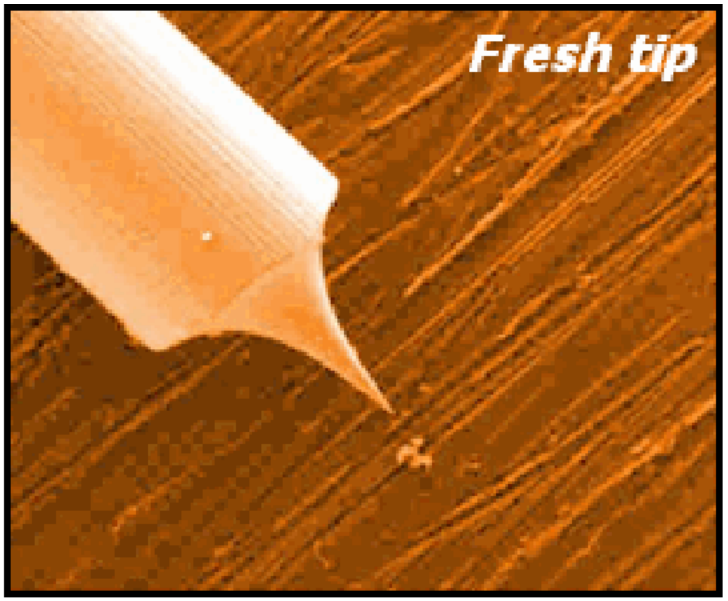


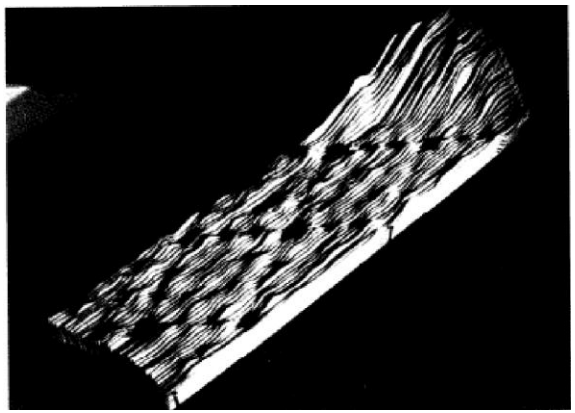
I. K. Yanson Zh. Eksp. Teor. Fiz. **66**, 1035 (1974)

STM by Binig & Rohrer

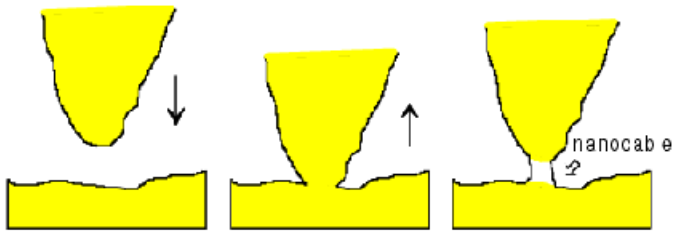
(1982)

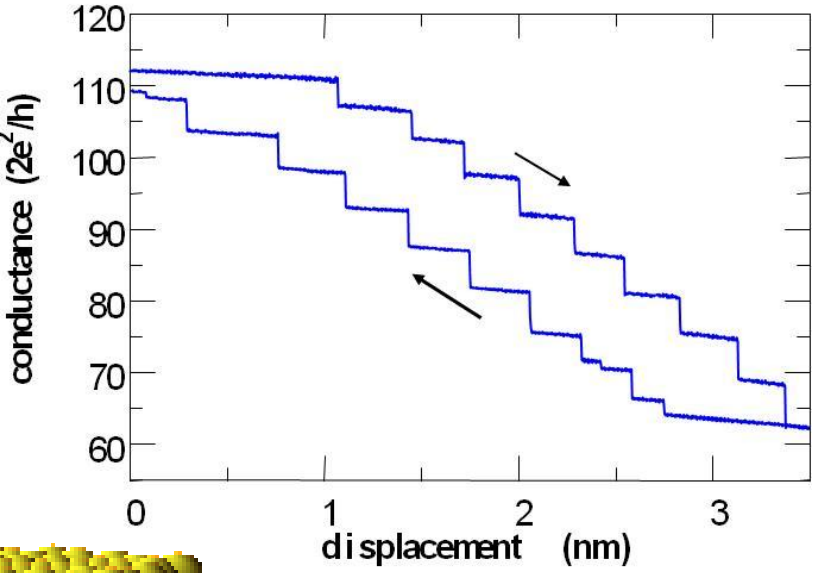


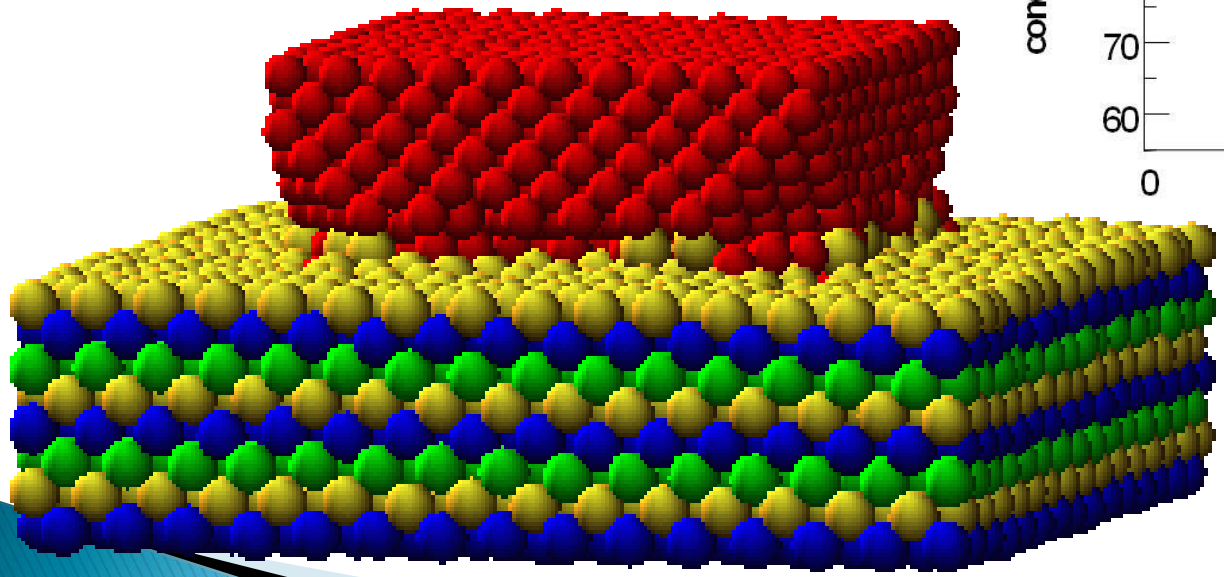




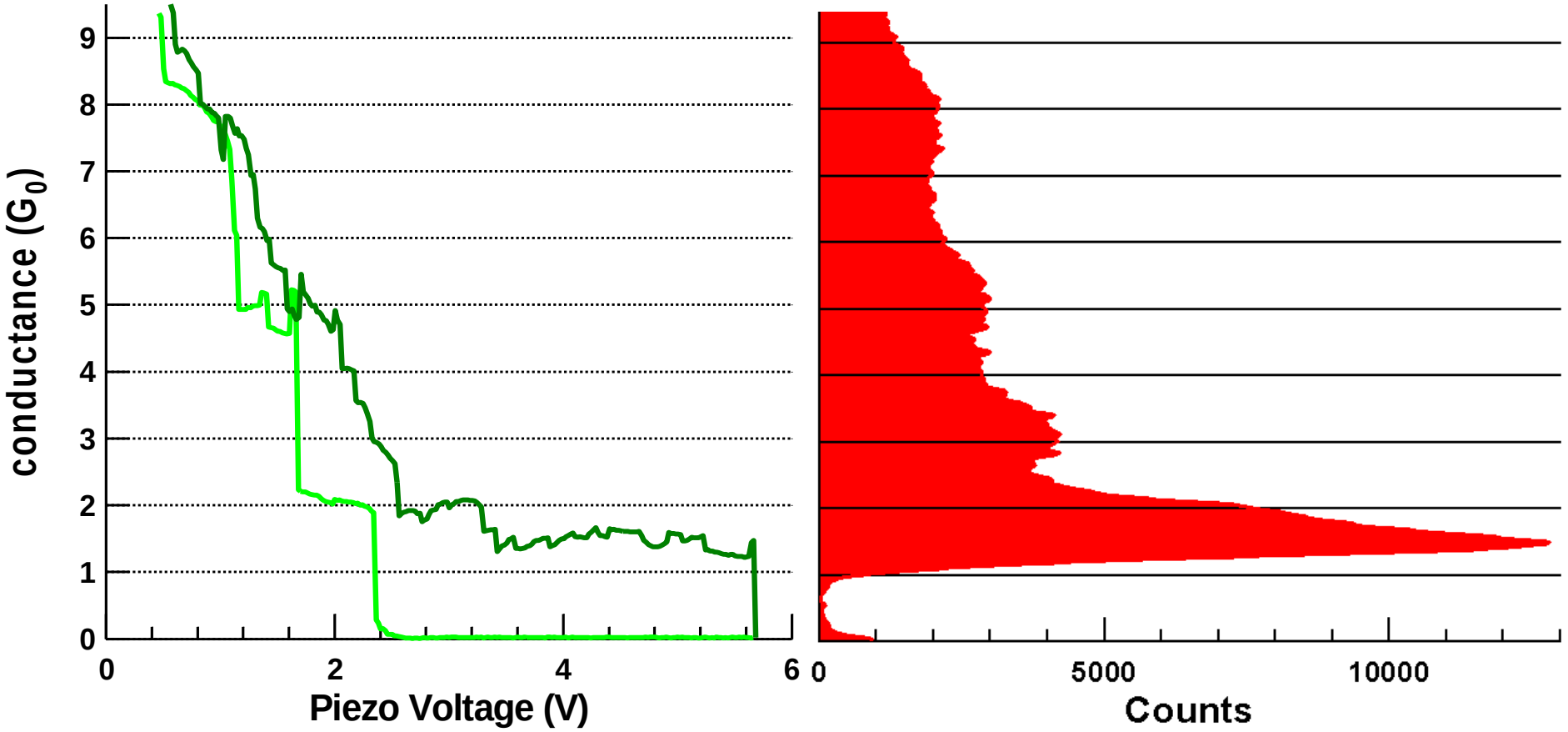
Atomic Contacts



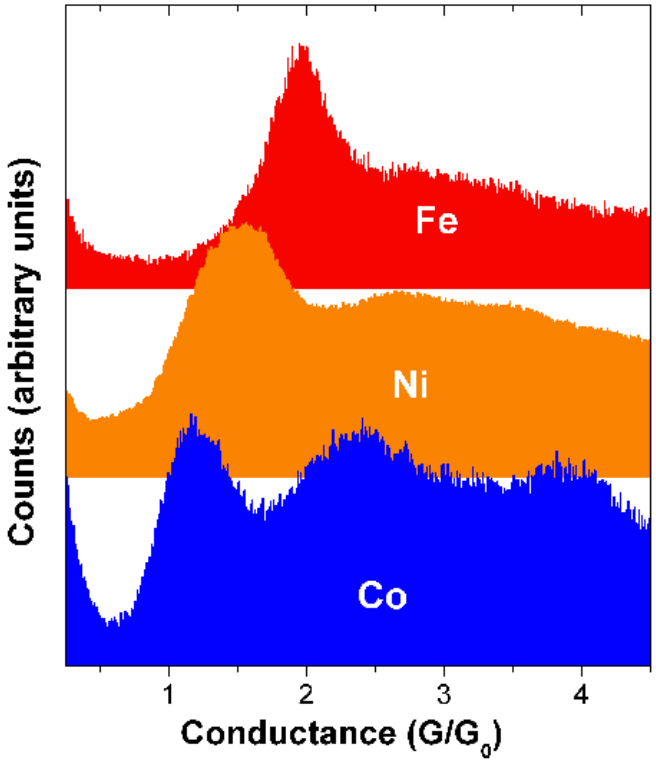




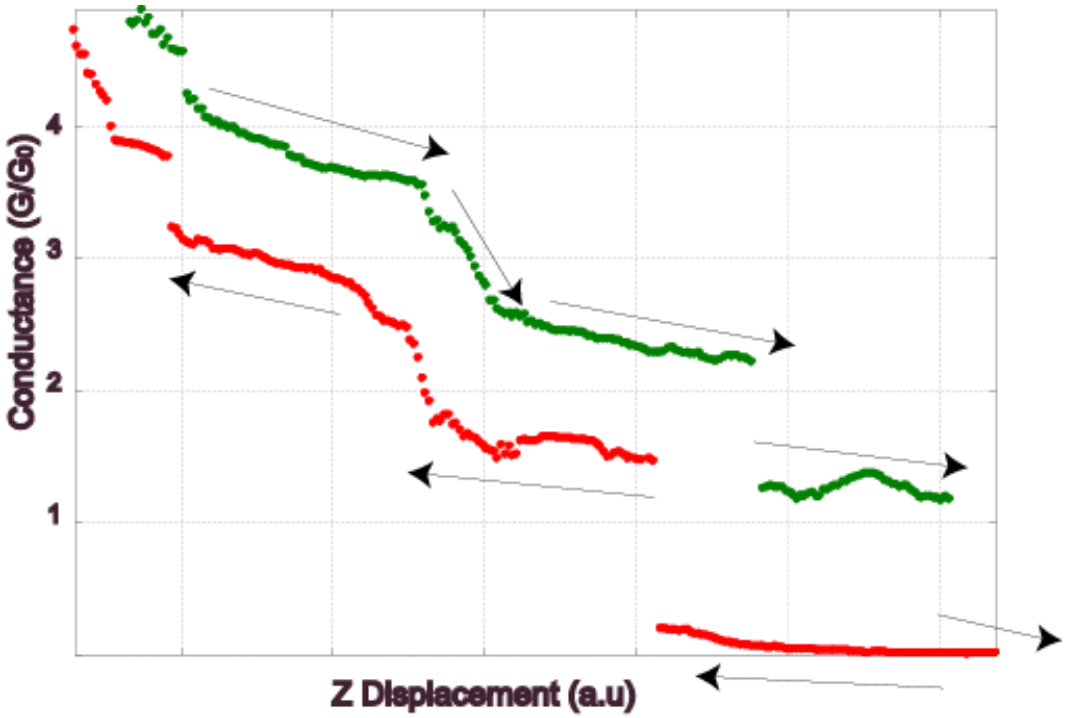
Conductance of a Pt contact

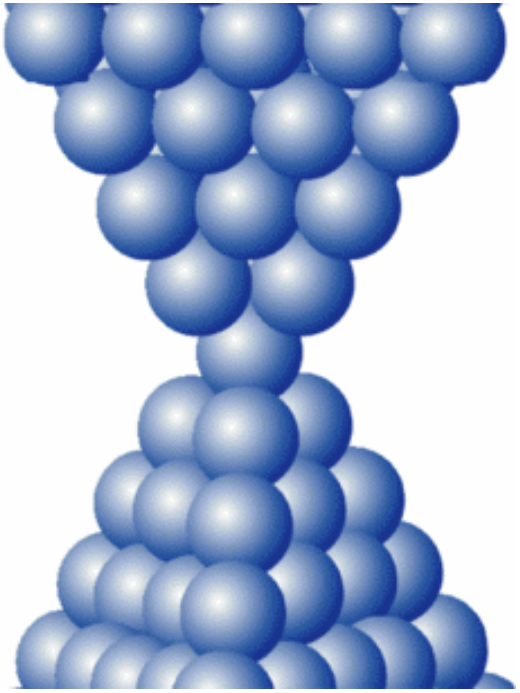


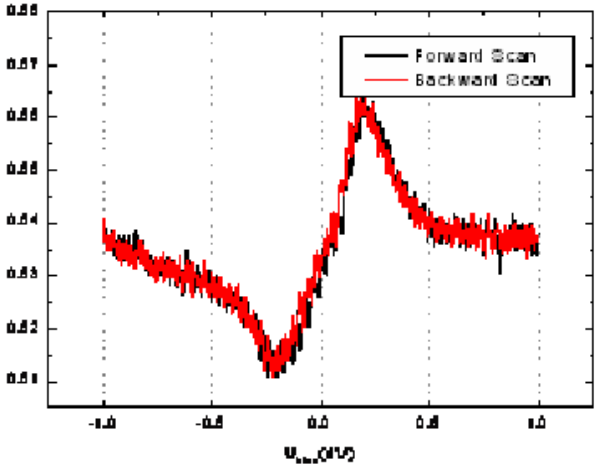
Magnetic Materials Fe, Co, and Ni

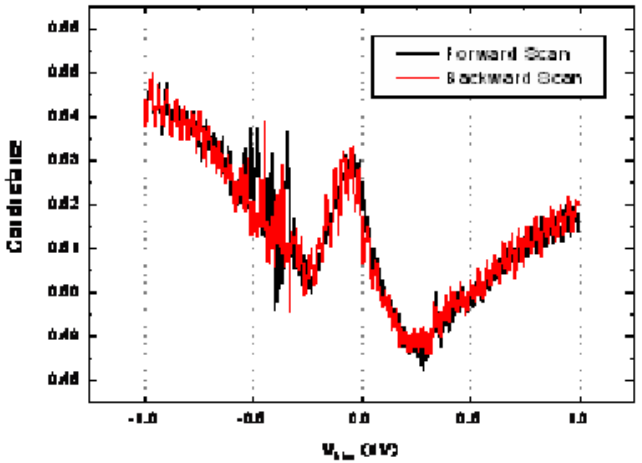


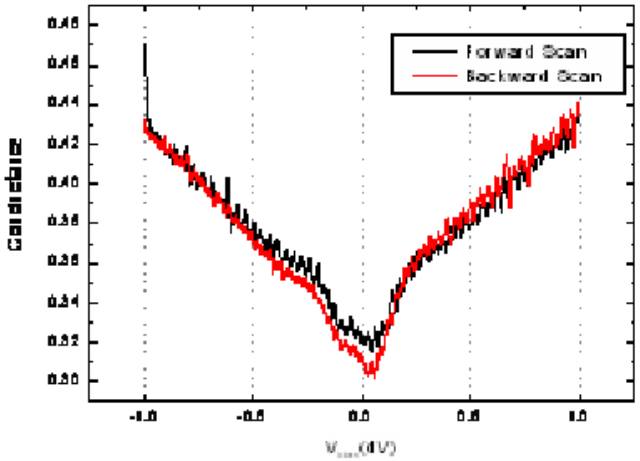
Magnetic Materials Fe, Co, and Ni

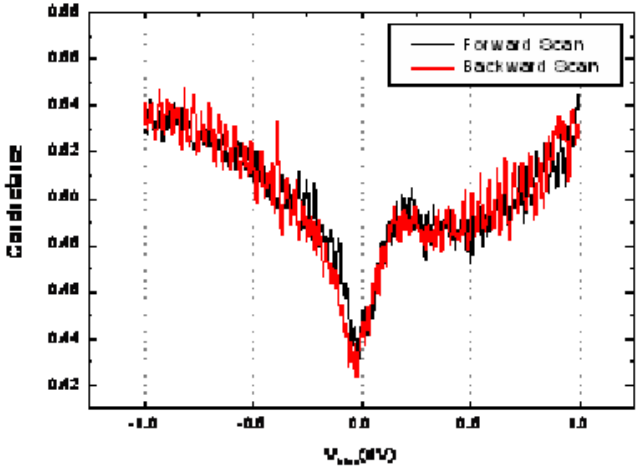





Forward Scan
Backward Scan

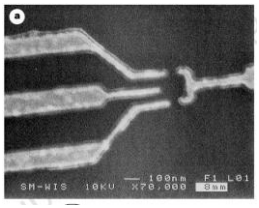

Forward Scan
Backward Scan

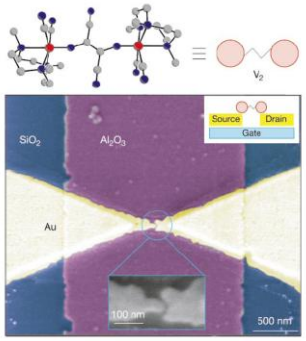

Forward Scan
Backward Scan

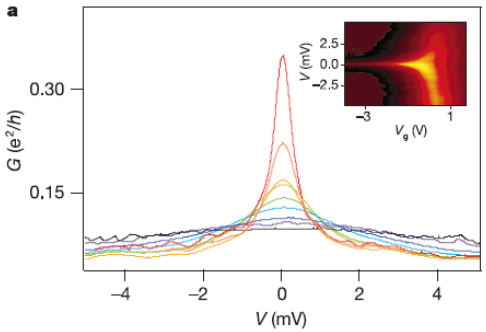

Forward Scan
Backward Scan

Kondo effect in mesoscopic systems

Q-Dots / Molecules





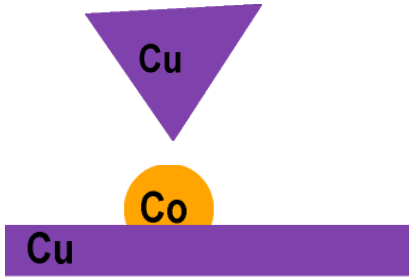


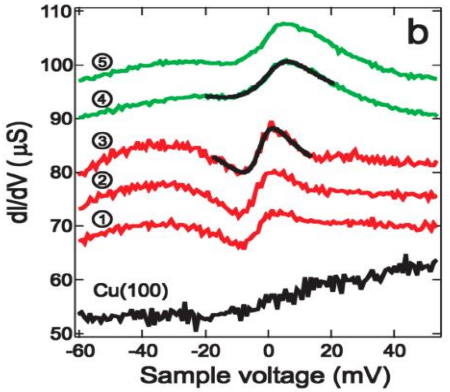
D. Goldhaver-Gordon et al. *Nature.* (1998)
Liang et al. *Nature*. (2002)

Resonance at zero bias in the differential conductance.

Magnetic adatoms

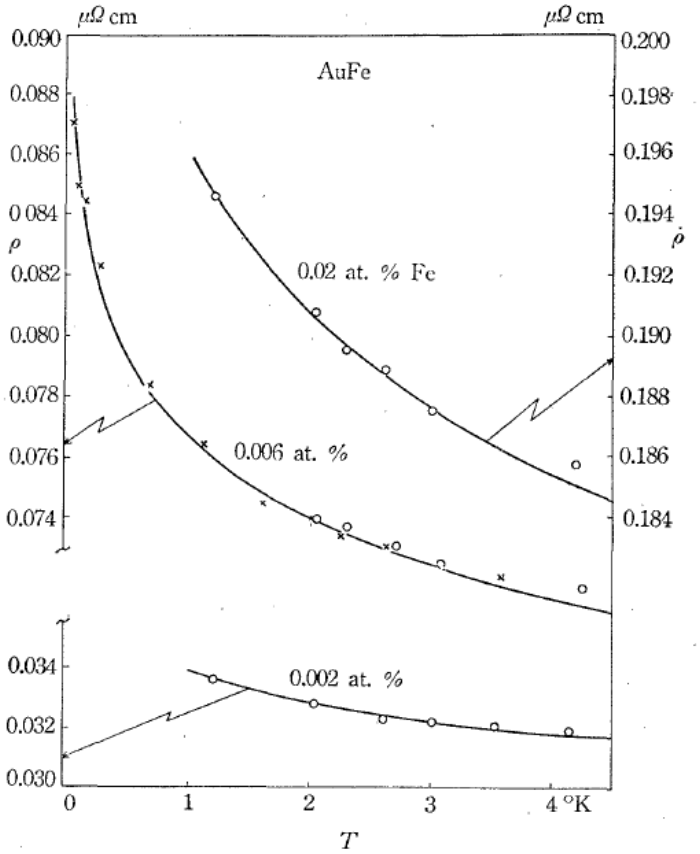
Tunnel/Contact





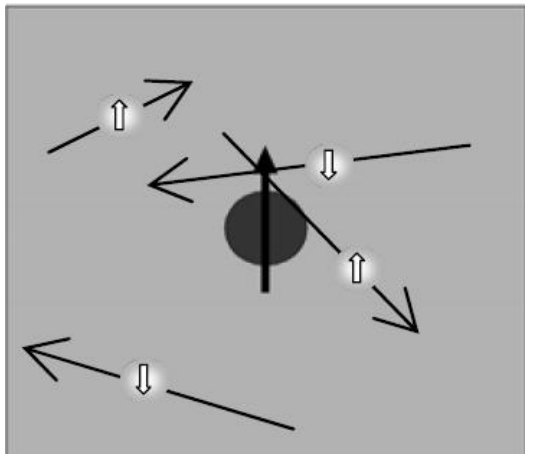
Interference
Zero bias anomaly
Fano lineshape

- Unexpected increase of the resistance at low temperatures in metals containing magnetic impurities..

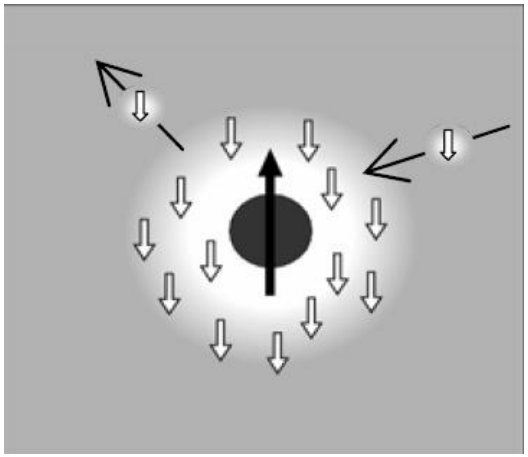


J. Kondo. *Prog. Theor. Phys.* (1964)

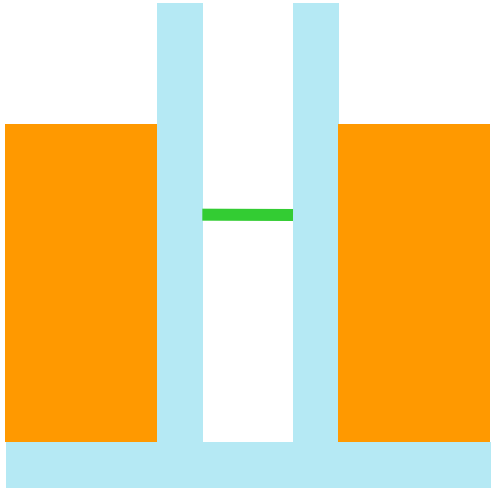
$T >> T_k$



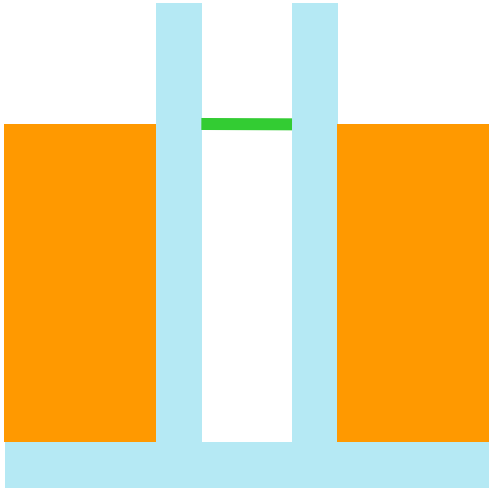
$T < T_k$



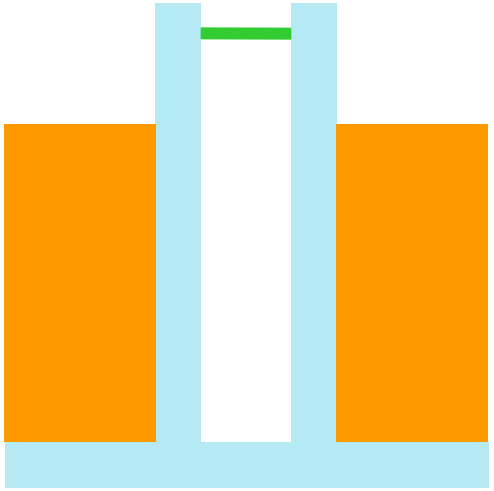
Kondo effect in mesoscopic systems



Level below Ef
No conduction

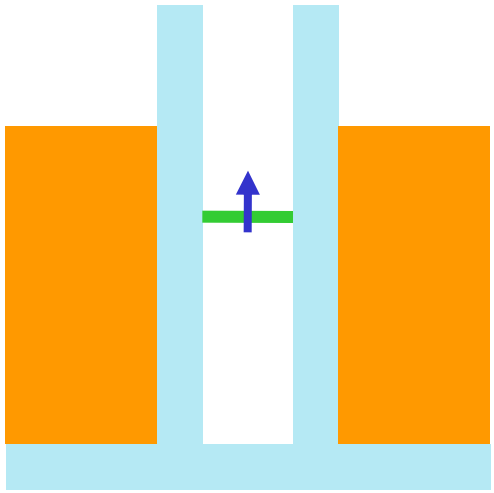


Level at Ef
Conduction

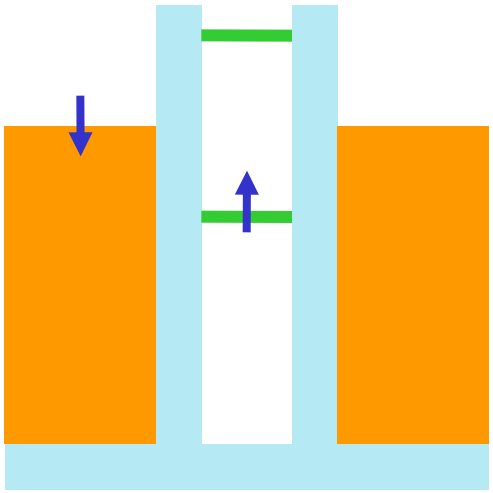


Level above Ef
No conduction

Kondo effect in mesoscopic systems



Level below Ef
No conduction



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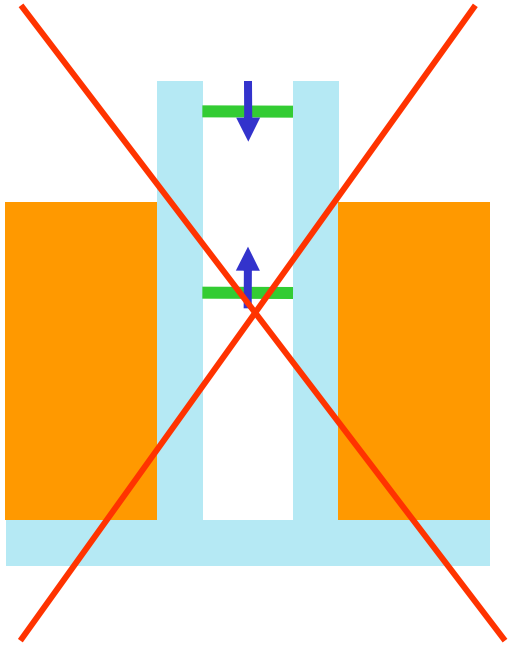

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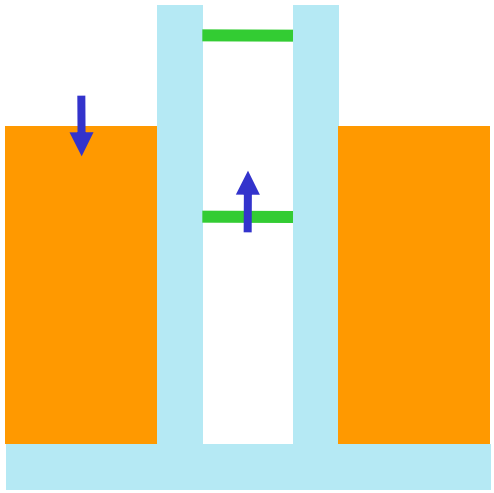
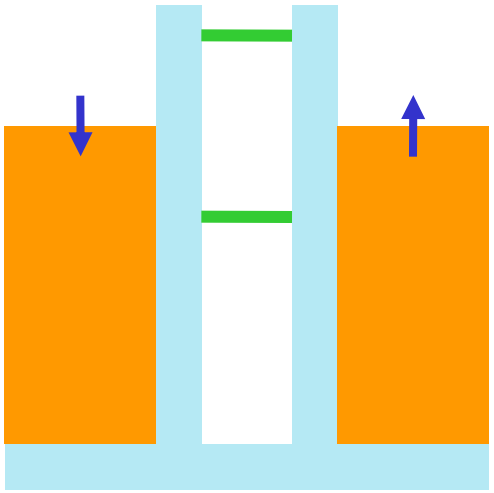
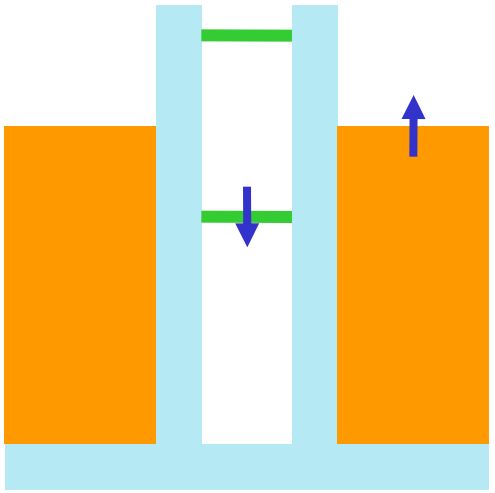


Initial state



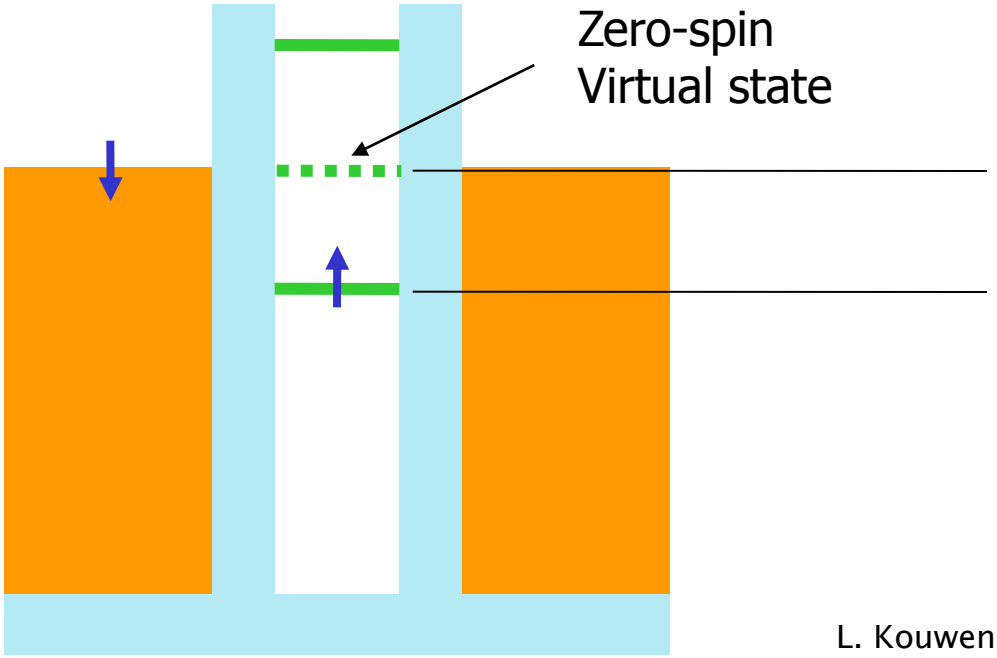
Virtual state

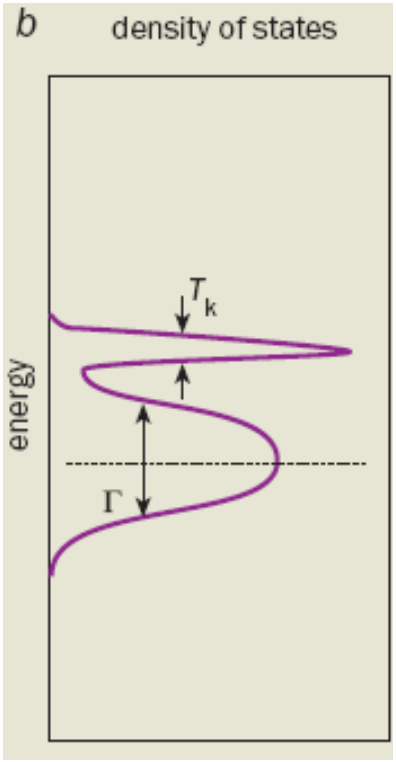


Final state

KONDO EFFECT

Kondo effect in mesoscopic systems





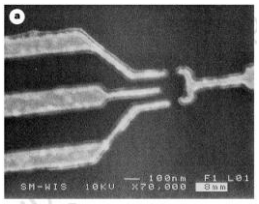
L. Kouwenhoven and L. Glazman. *Physics world.* (2001

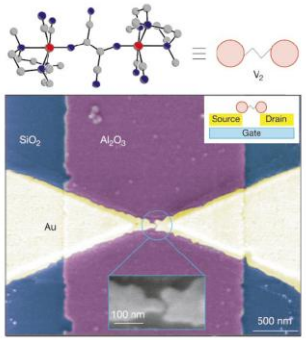
-Conduction electrons interact with a localized spin state.

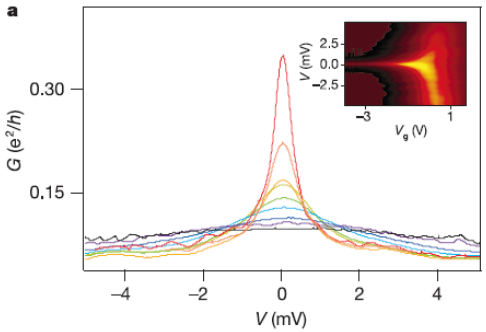
- **Resonance at Fermi level in the Density of States.**

Kondo effect in mesoscopic systems

Q-Dots / Molecules







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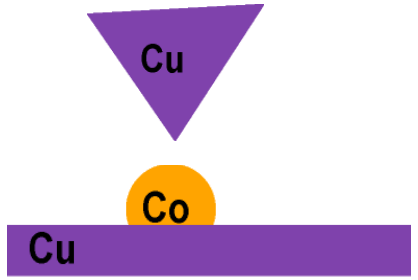

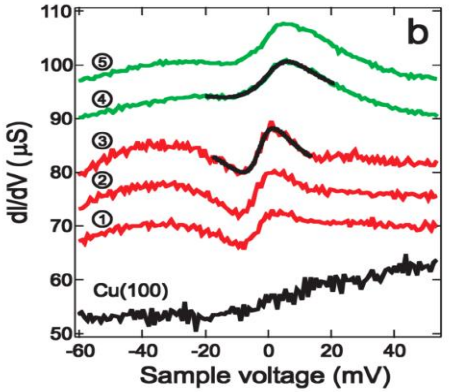

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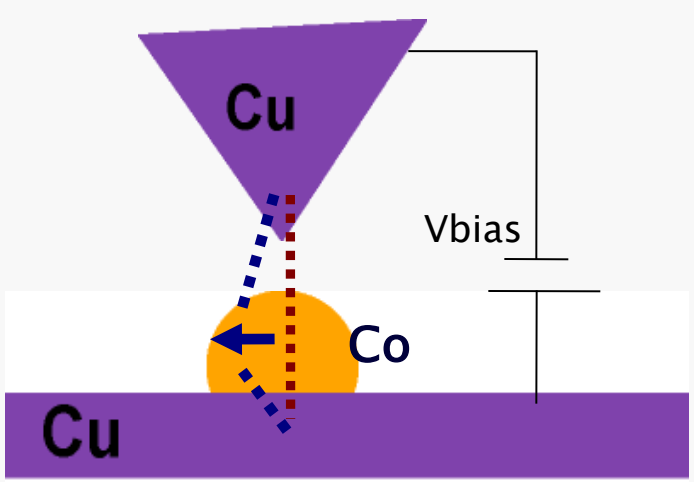
Zero bias anomaly
Fano lineshape



- spin degenerated tunneling

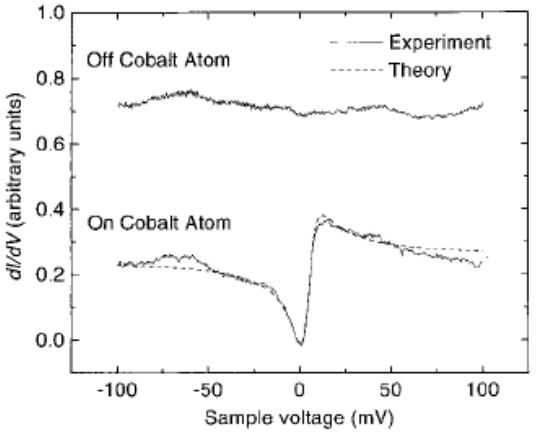
+

- transport through localized spin state (Kondo)

↓

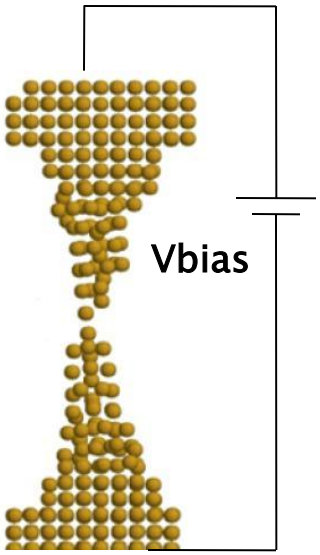
Interference
Zero bias anomaly
Fano lineshape

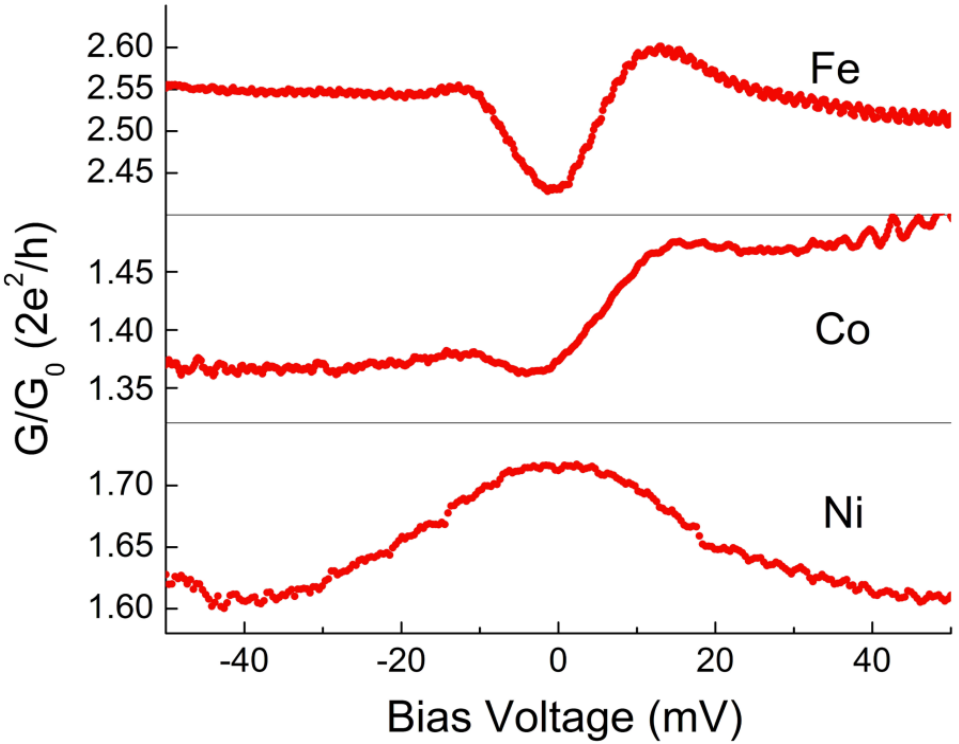
Madhavan et al. *Science* (1998)



Spectroscopy

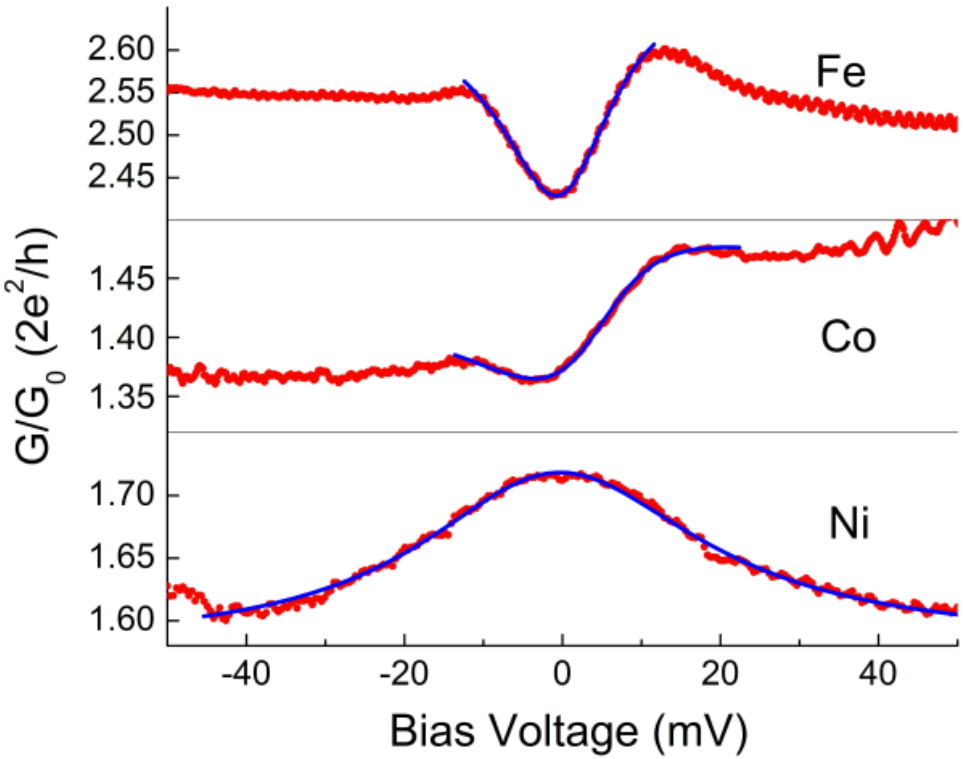
Spectroscopy: Differential conductance vs Bias voltage





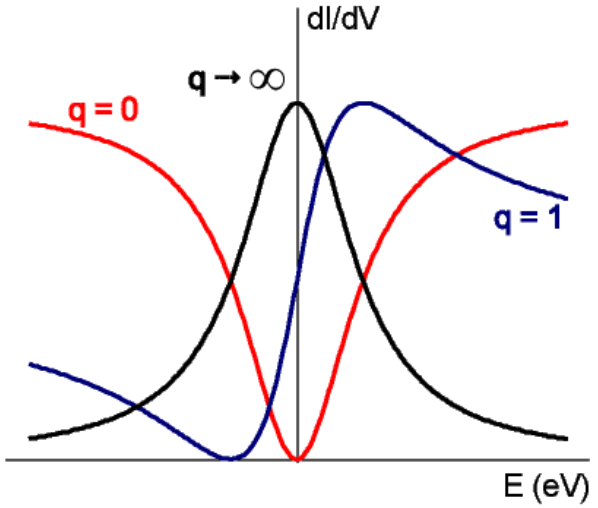
80 % of curves show ZBA
Amplitude 10 %

Spectroscopy

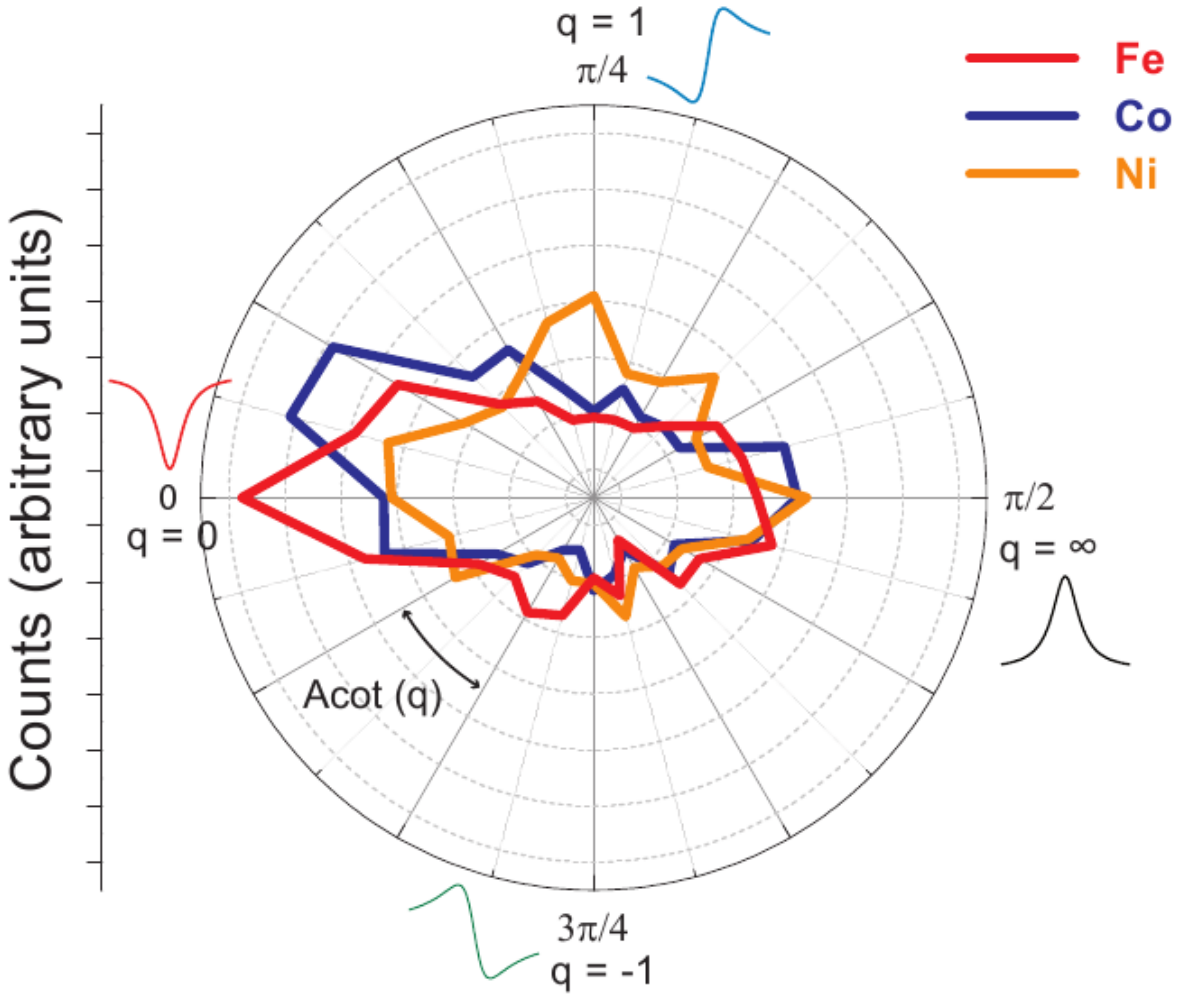


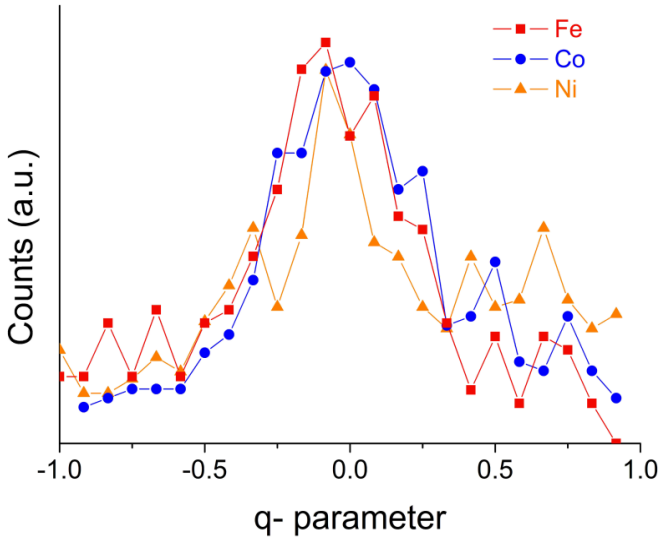
$$\frac{dI}{dV} \alpha \frac{(q+\varepsilon)^2}{(1+\varepsilon^2)}$$

q : Fano parameter

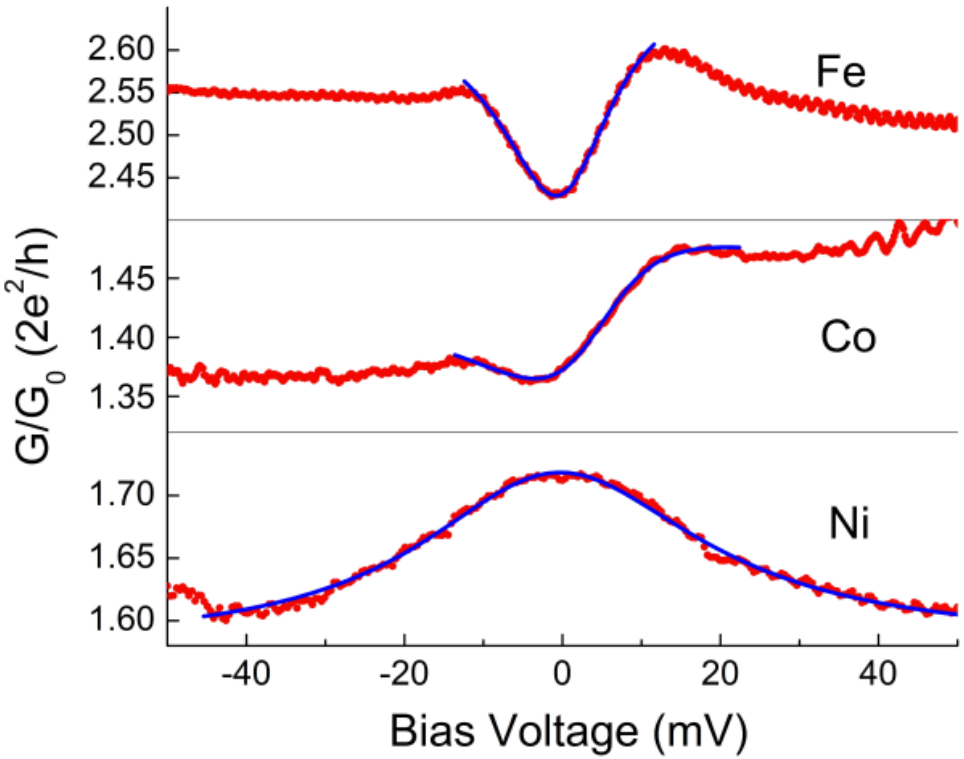


Spectroscopy



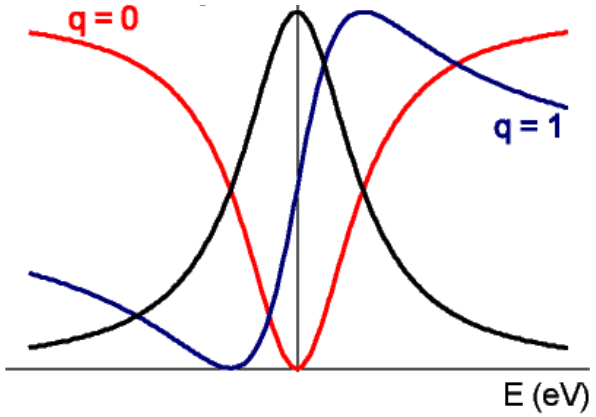


Kondo Temperature

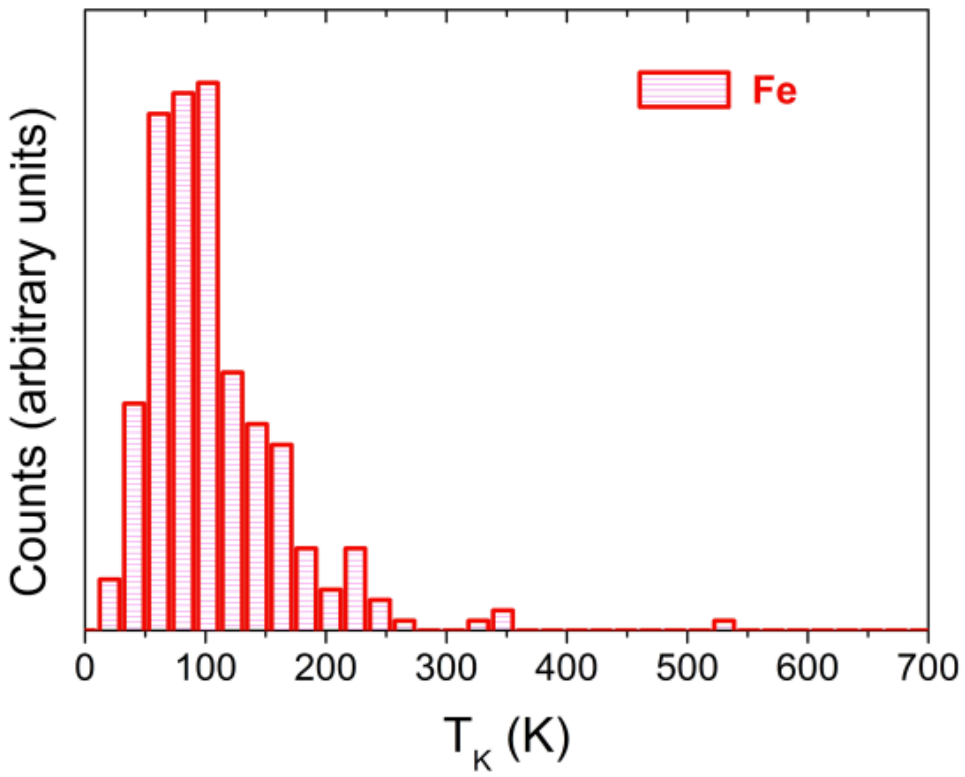


$$\frac{dI}{dV} \alpha \frac{(q+\varepsilon)^2}{(1+\varepsilon^2)}$$

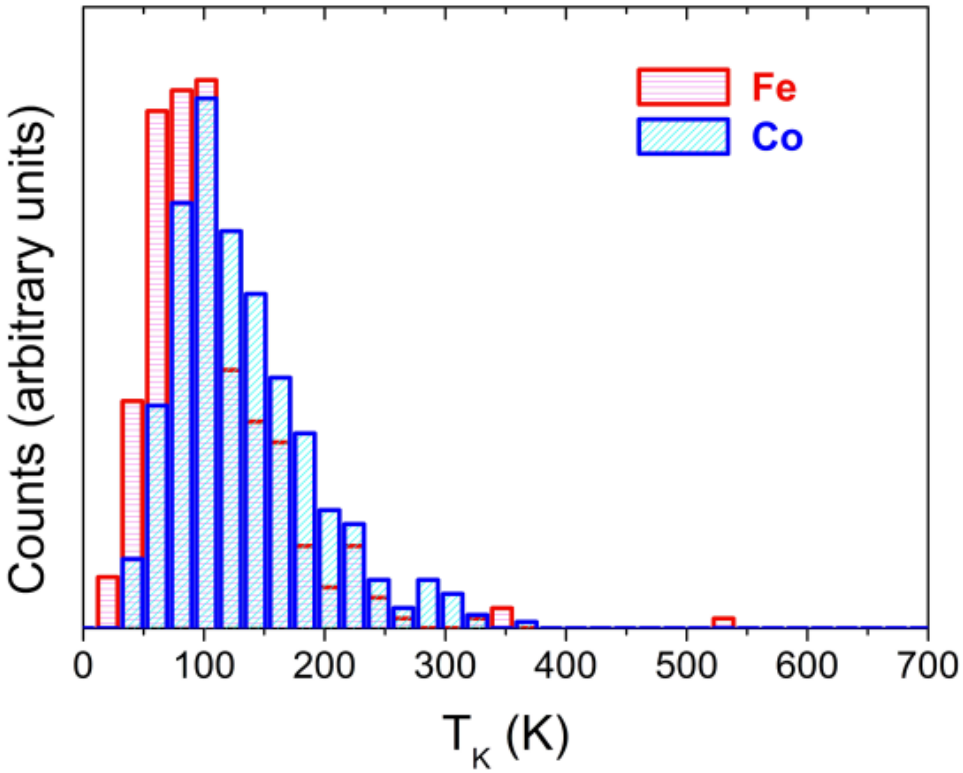
$$\varepsilon = \frac{eV - \varepsilon_K}{k_B T_K}$$



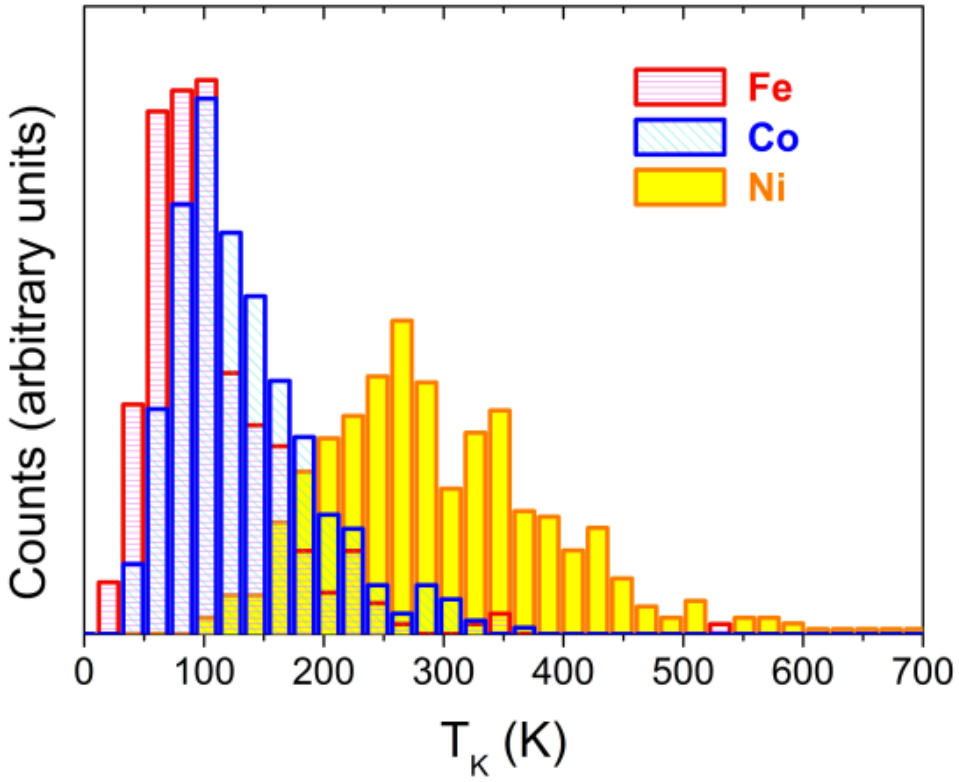
Statistics of Kondo Temperatures



Statistics of Kondo Temperatures



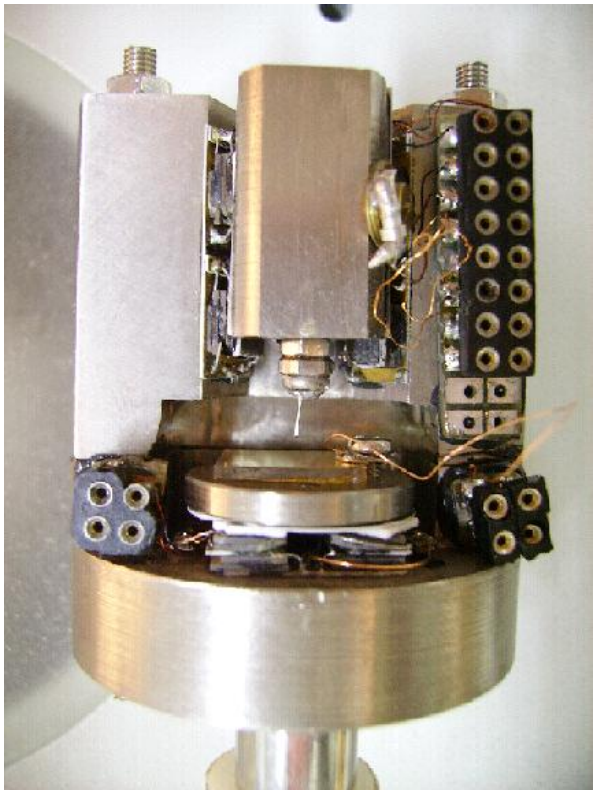
Statistics of Kondo Temperatures

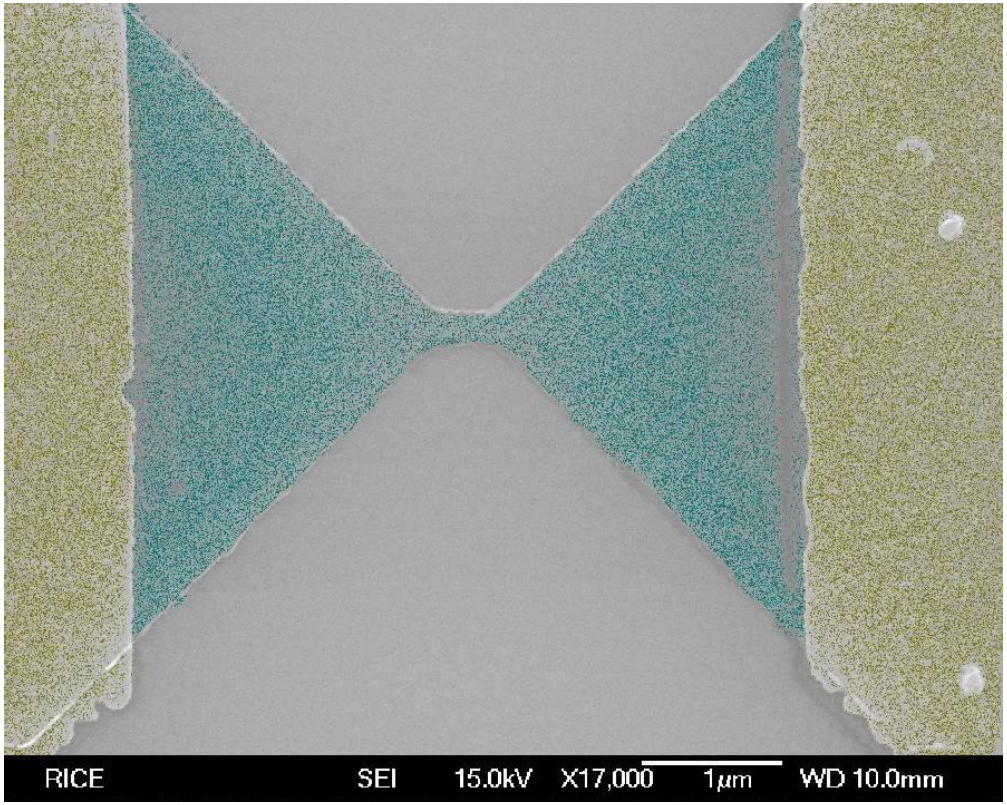


$$T_K \alpha e^{-\frac{J\rho_0}{2}}$$

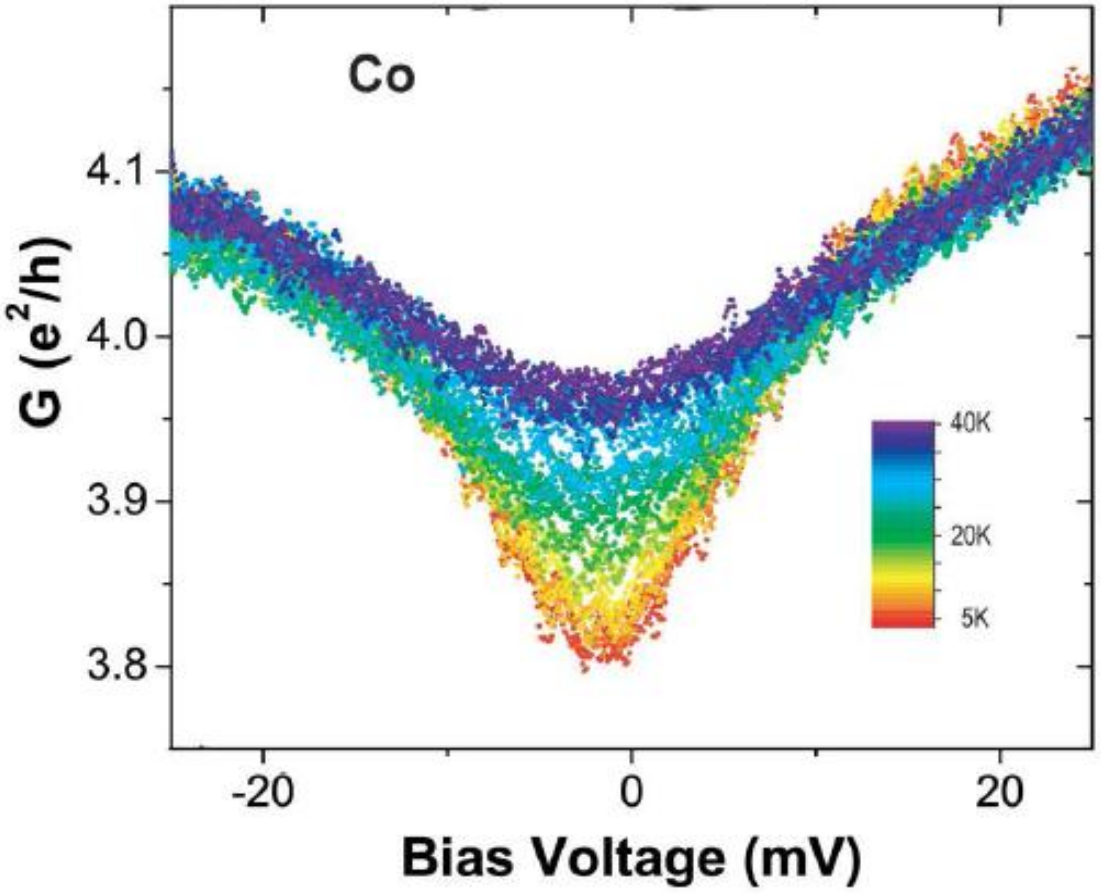
	Fe	Co	Ni
T_K (K)	**94**	**121**	**283**

Evolution with Temperature

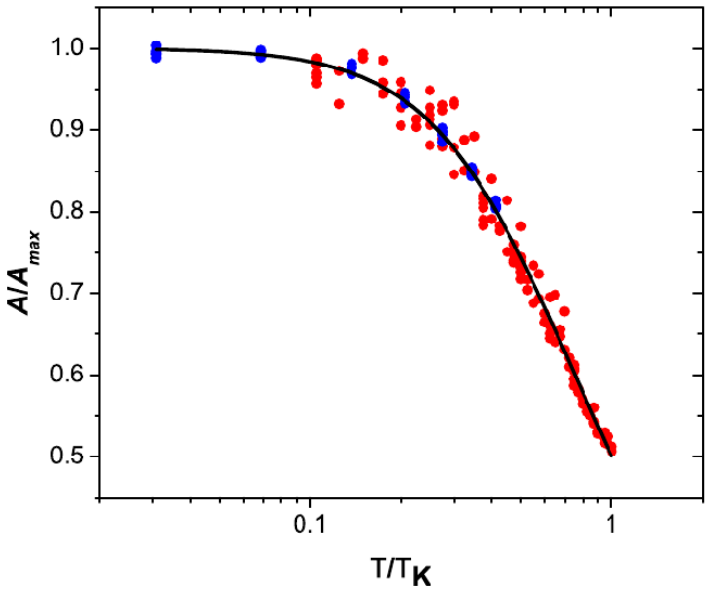




Evolution with Temperature



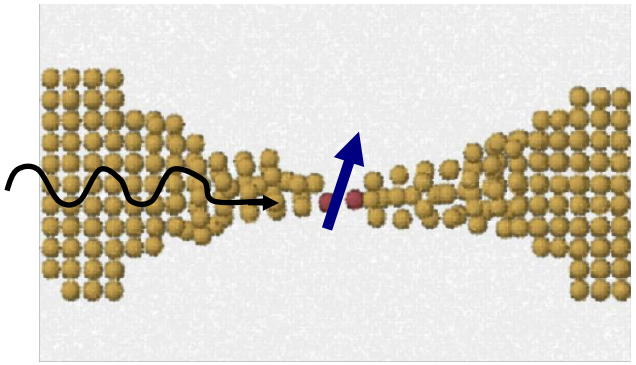
Co



$$G(T) = G_{off} + A_{max}\left(\frac{T_K'^2}{T^2 + T_K'^2}\right)^s$$

Interpretation:

- Low coordination results in localized spin (d-orbitals).
- Conduction electrons (s-band) (degenerated in spin) interacts:
  Kondo effect



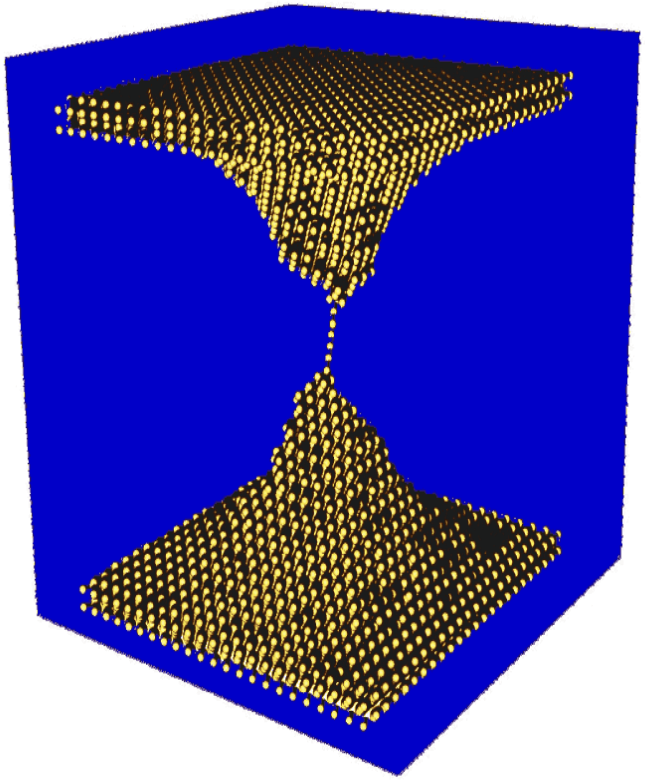
We report the existence of Kondo effect in a system:

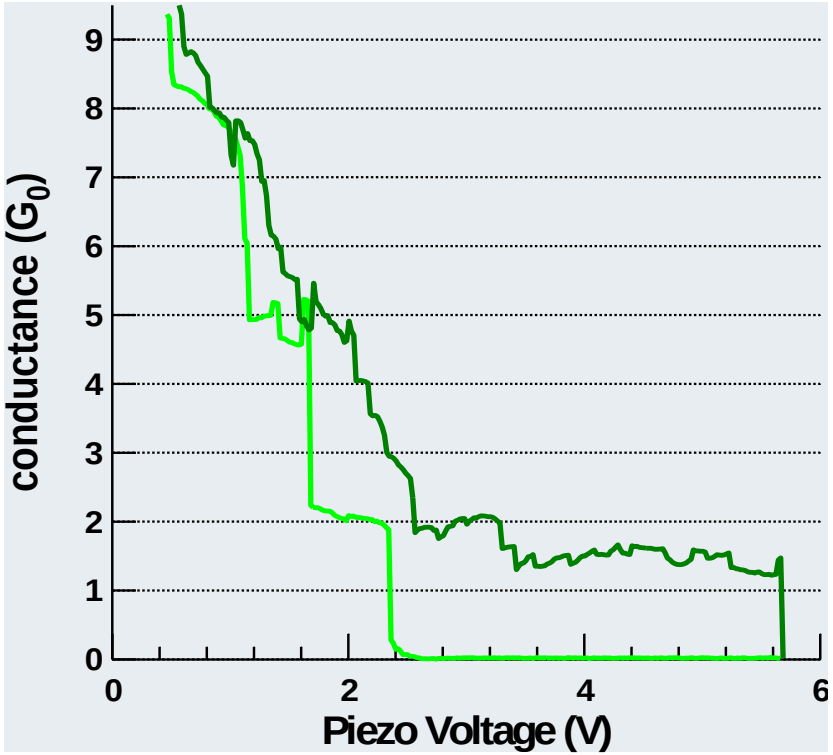
- homogeneous (chemically pure)
- ferromagnetic

Screening of magnetism in magnetic materials with low coordination

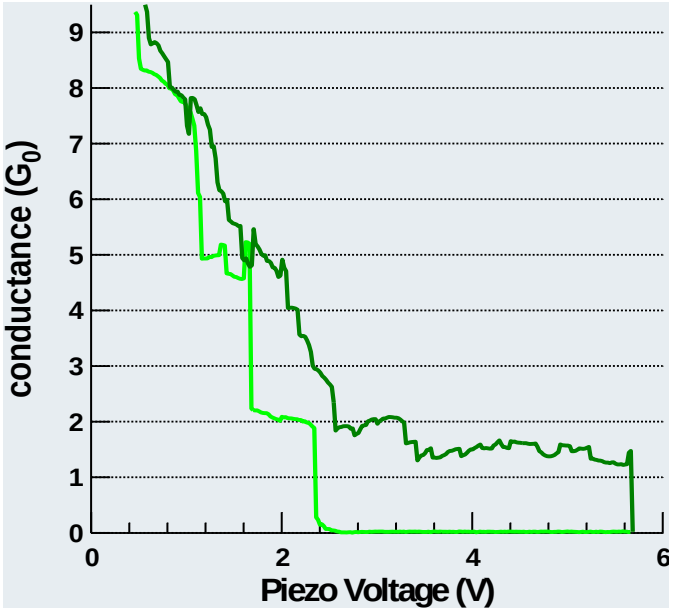
M.R. Calvo, et al. Nature **458**, 1150 (2009)

An other system: Pt chains

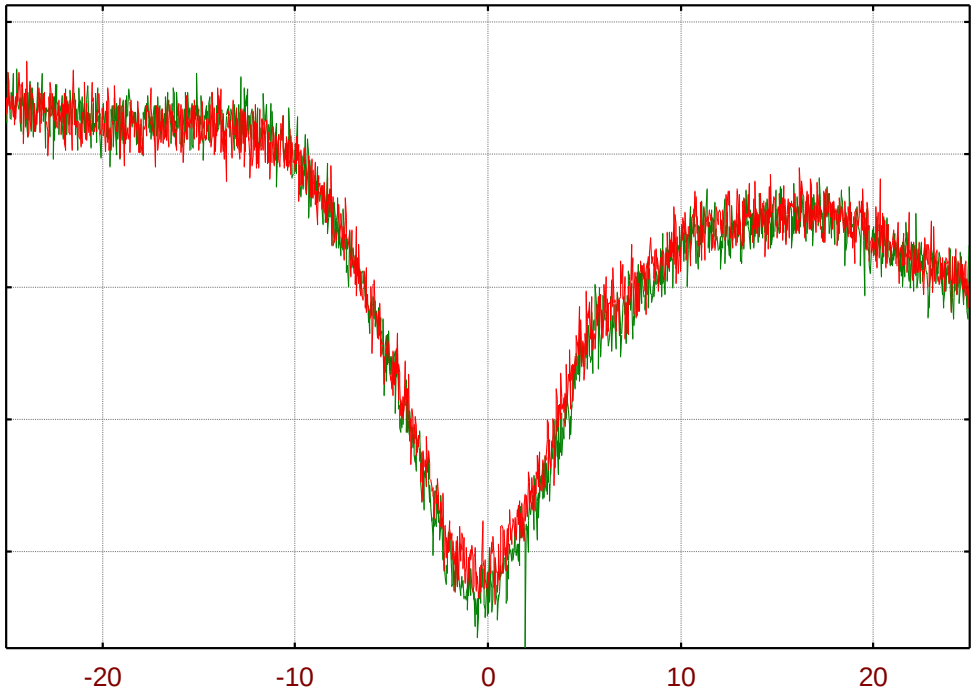




An other system: Pt chains



Pt



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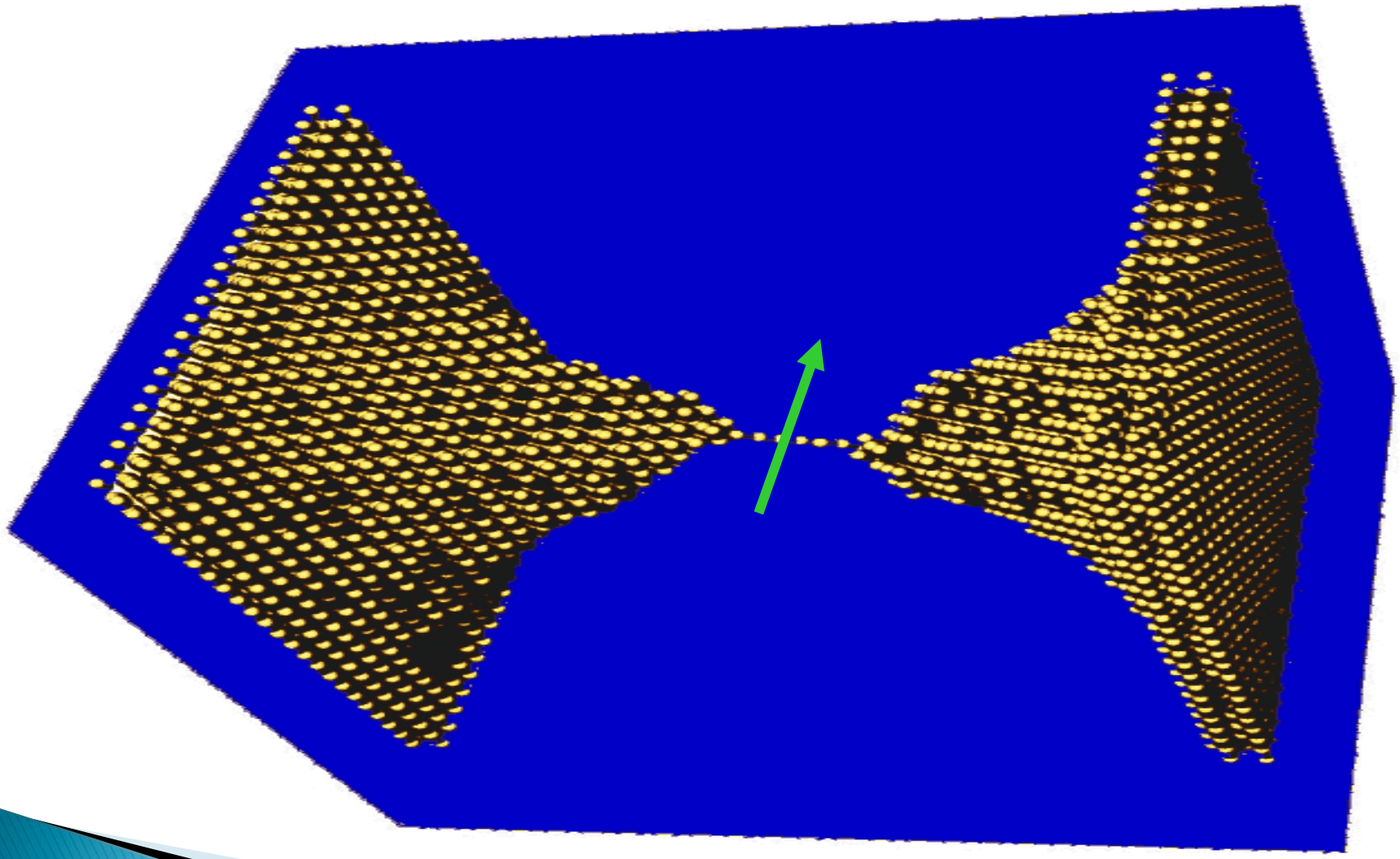
An other system: Pt chains



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An other system: Pt chains

PHYSICAL REVIEW B **72**, 224418 (2005)

Transport in magnetically ordered Pt nanocontacts

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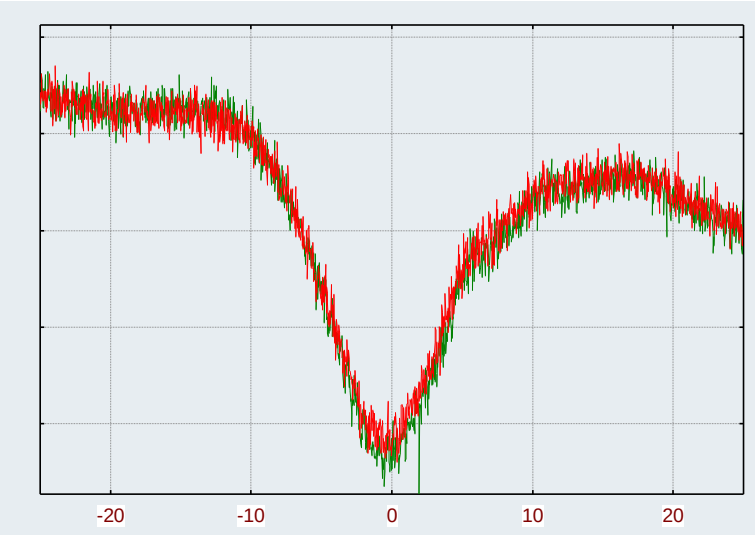
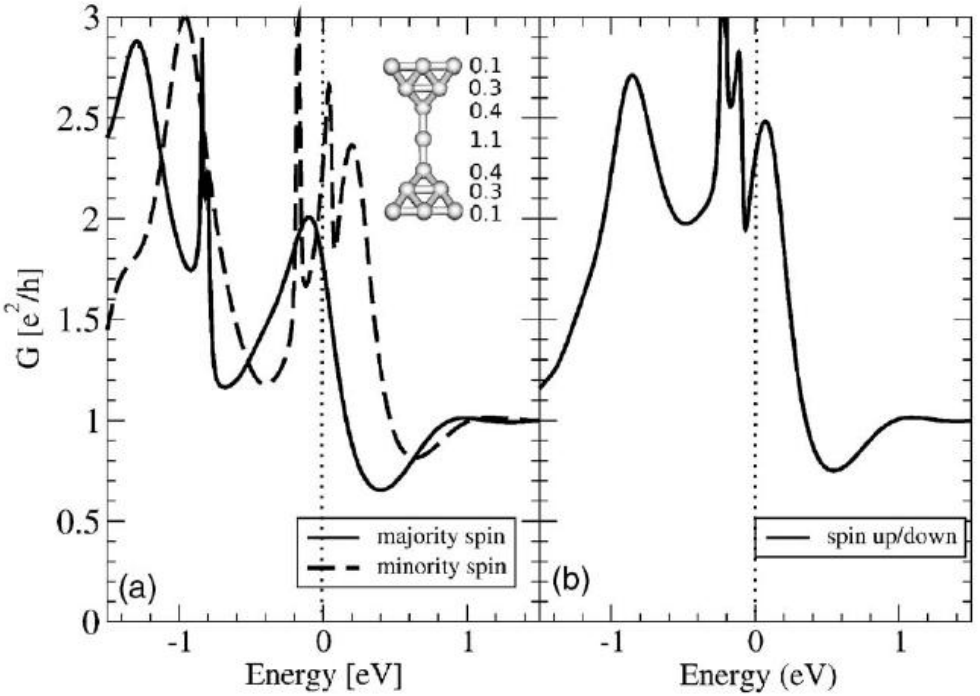
Departamento de Física Aplicada and Instituto Universitario de Materiales de Alicante (IUMA), Universidad de Alicante, San Vicente del Raspeig, 03690 Alicante, Spain





- Reyes Calvo

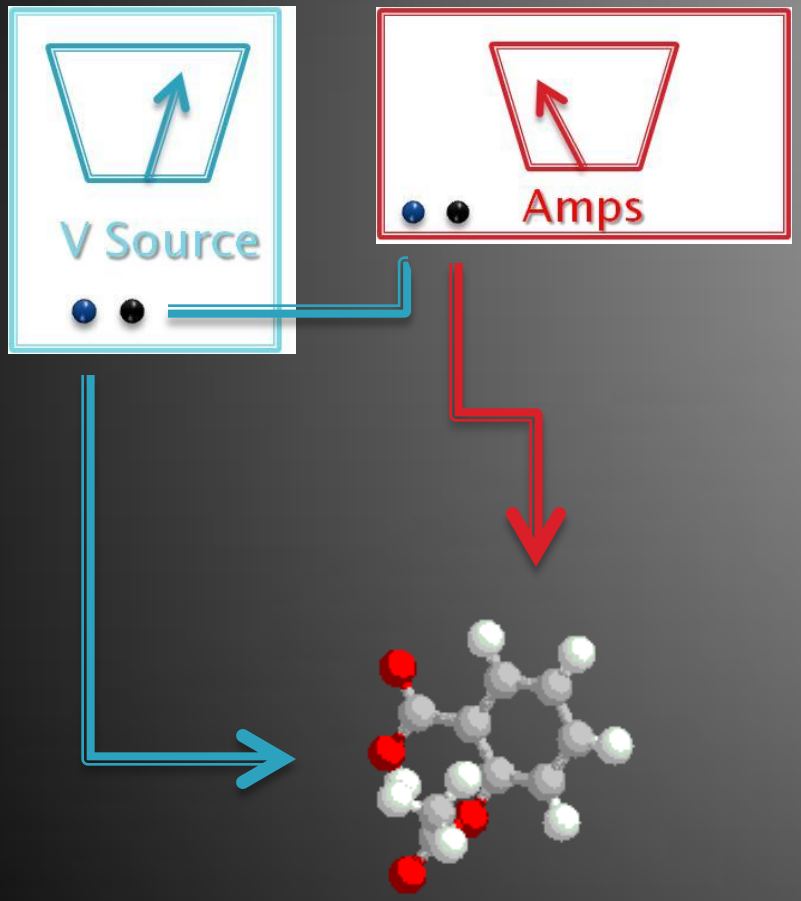
- Juan José Palacios

- Joaquín Fernandez

- Douglas Natelson

- David Jacob

Sumary



Electronic transport measurements on atomic contacts of ferromagnets show:

- Kondo screening : electronicc screening of the magnetic moment

This is due to:

- Localization of a magnetic moment on the contacts because of the low coordination
- Antiferromagnetic coupling with the s-band

We can learn about:

- Interband coupling in atomic-contacts
- The magnetic moment of the atoms
- Correlation effects in atomic and molecular conductors
- Presence of magnetism in other systemns (Pt)