Ustroń, 8 September 2008

Electron pair current through the correlated quantum dots

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Outline

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★ **Introduction**

/ correlation effects in quantum dots /

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- **The spin vs charge Kondo effect**

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  / signatures of the Dicke-like behavior /

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- **The two-channel model**

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- **Summary**

1. Introduction

Physical situation

Let us consider the quantum dot (QD)

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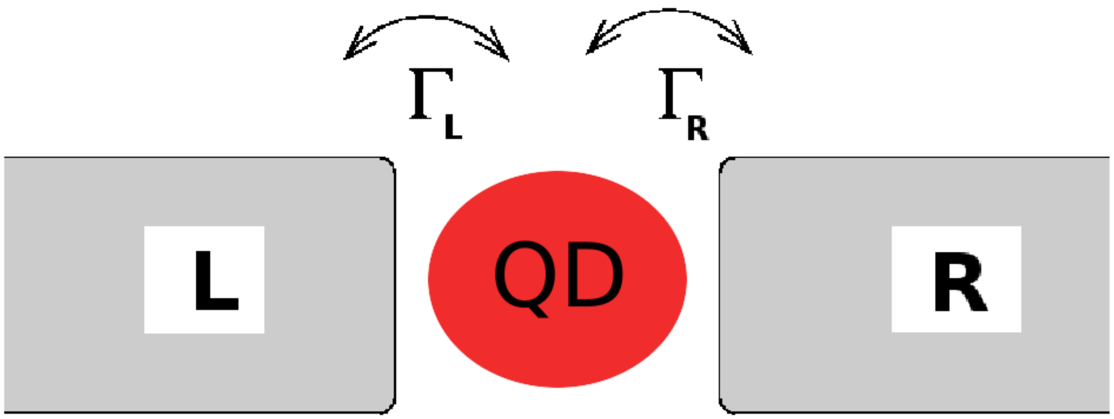

electrode L | QD | electrode R

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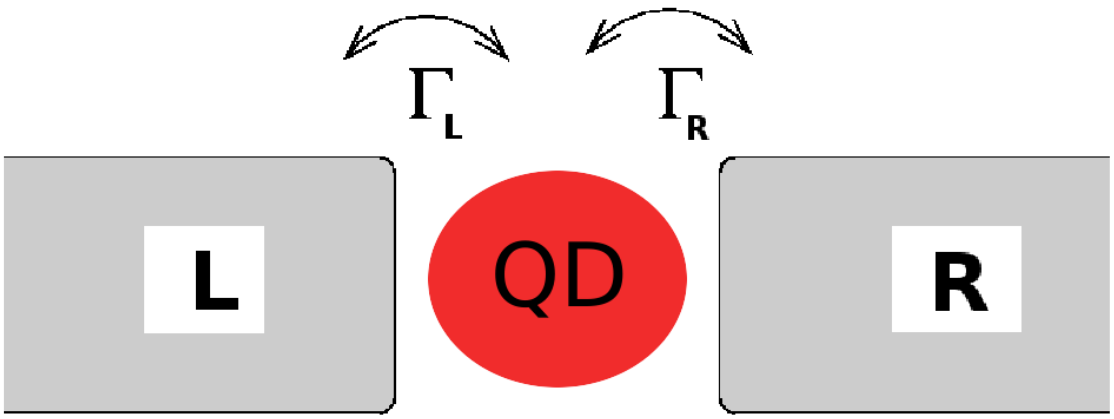

electrode L　　QD　　electrode R

with the metallic (conducting) external leads.

Microscopic model

On-dot correlations

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On-dot correlations

$$\hat{H}_{QD} = \sum_{\sigma} \epsilon_d \, \hat{d}^{\dagger}_{\sigma} \, \hat{d}_{\sigma} + U \, \hat{n}_{d\uparrow} \, \hat{n}_{d\downarrow}$$

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induced by the external voltage $eV = \mu_L - \mu_R$.

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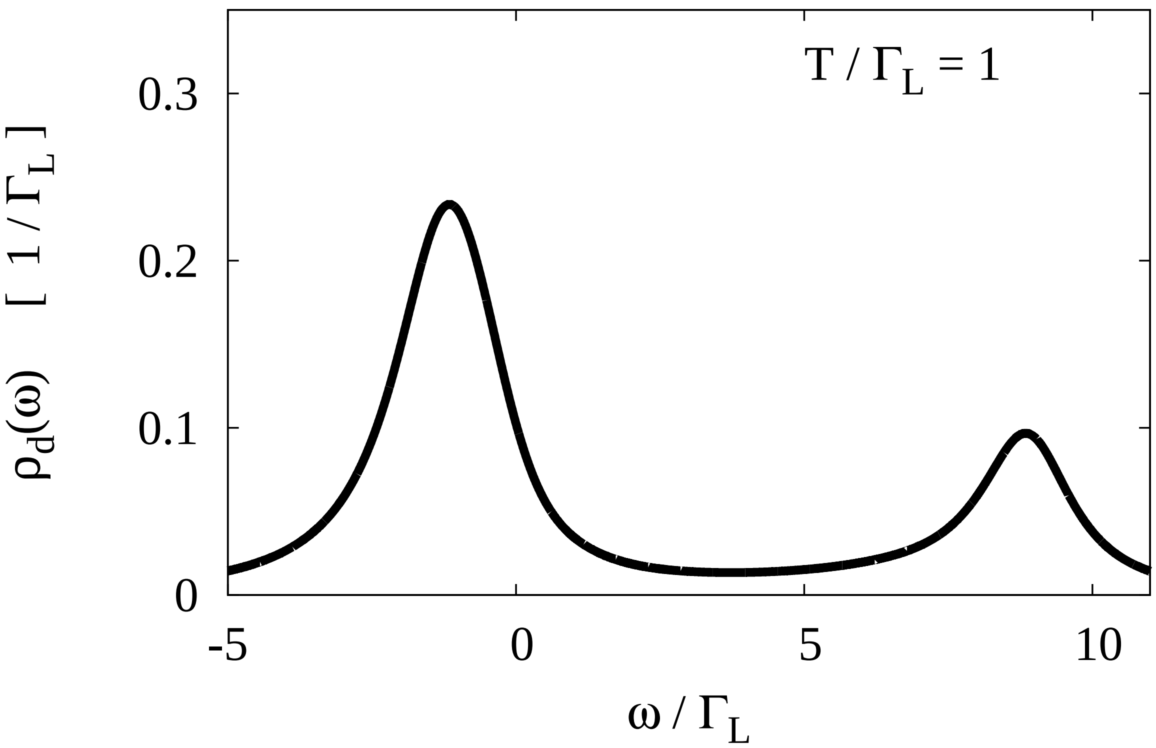

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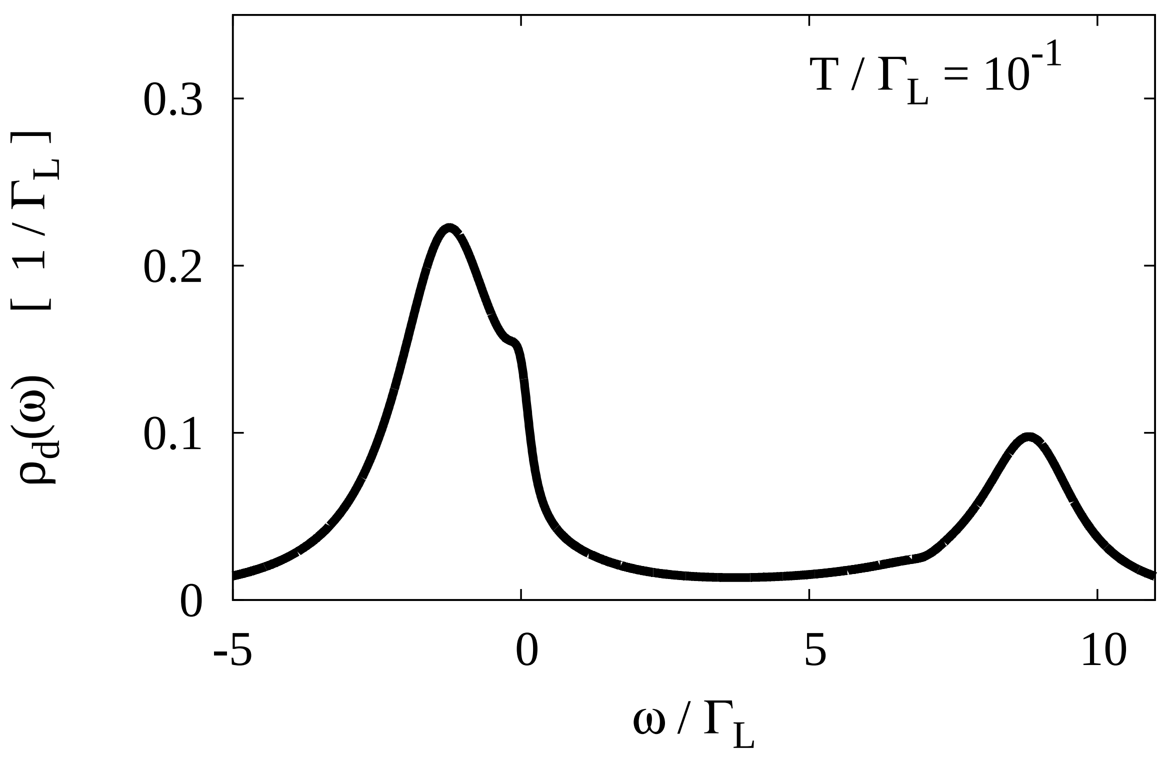

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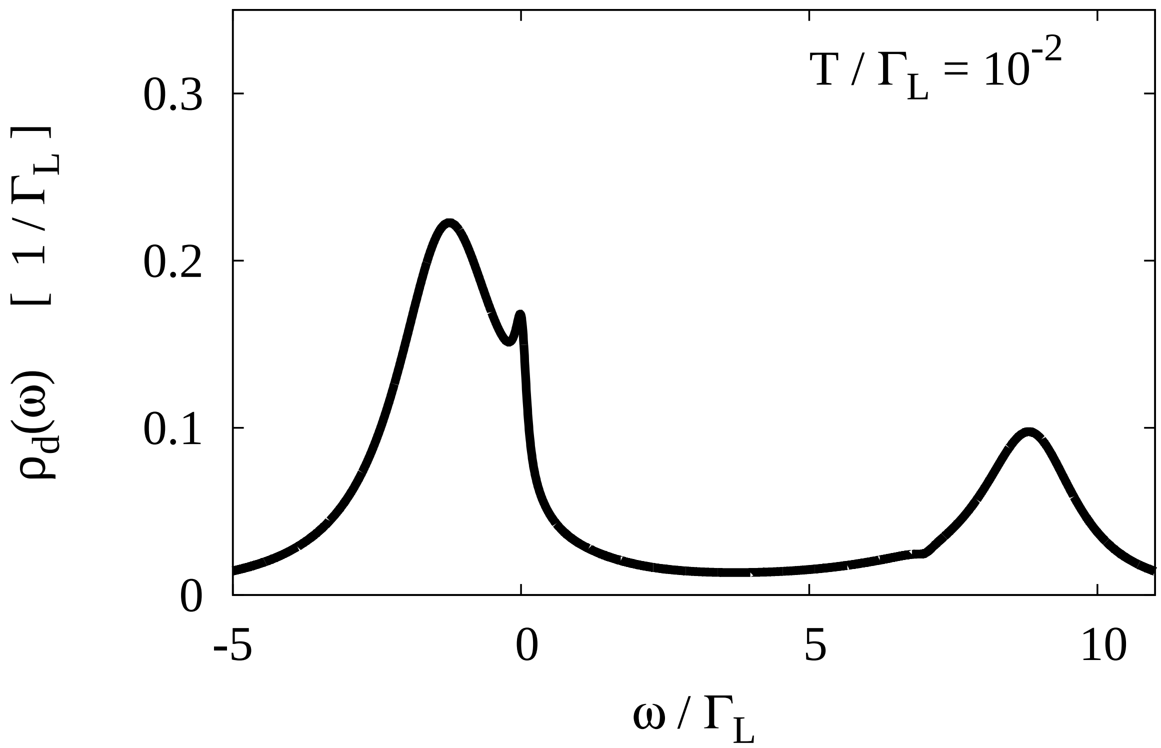

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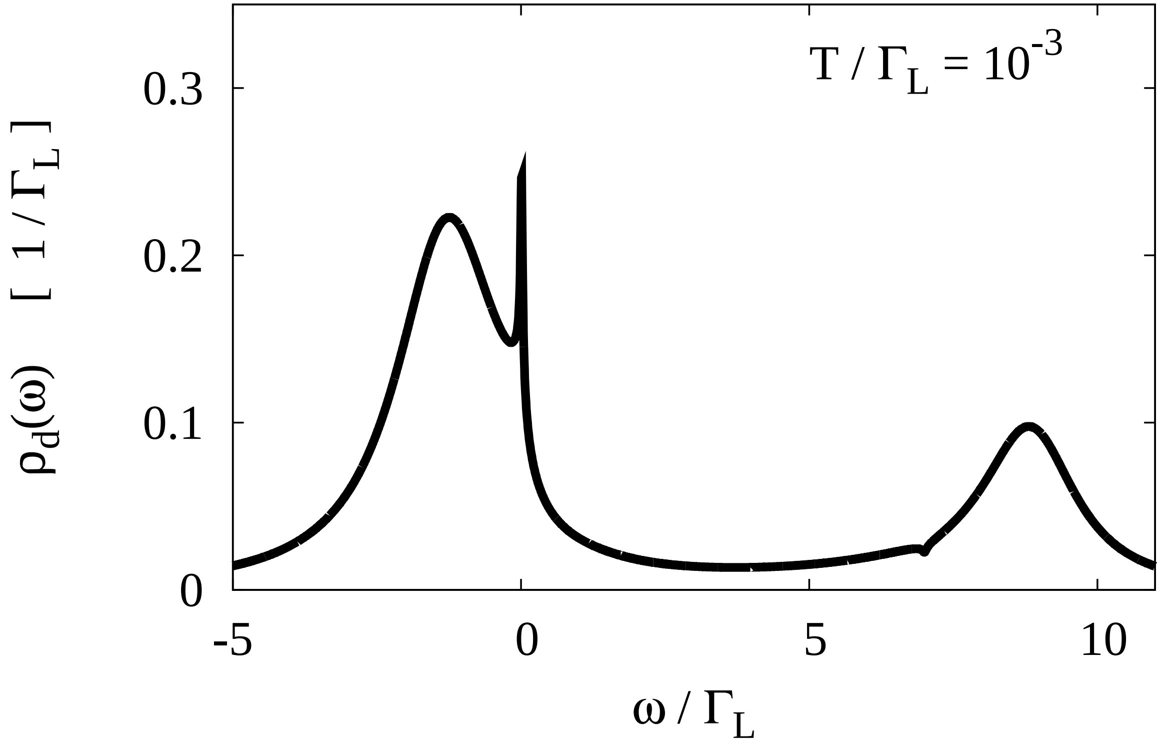

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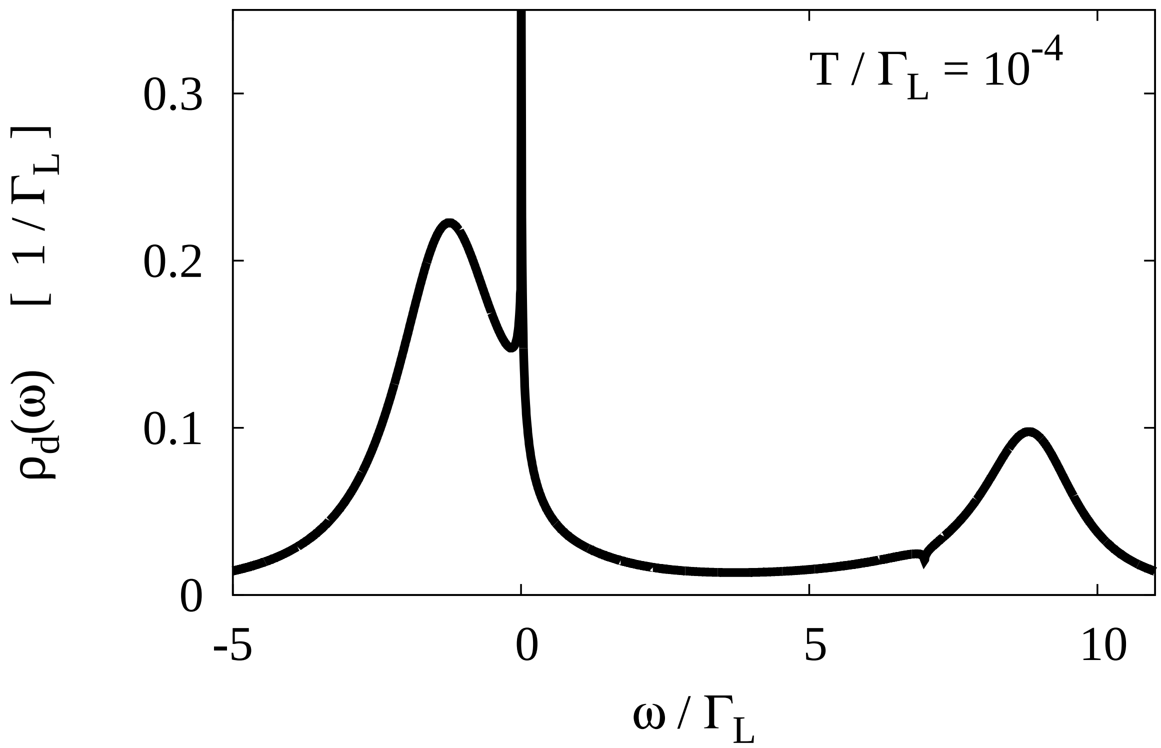

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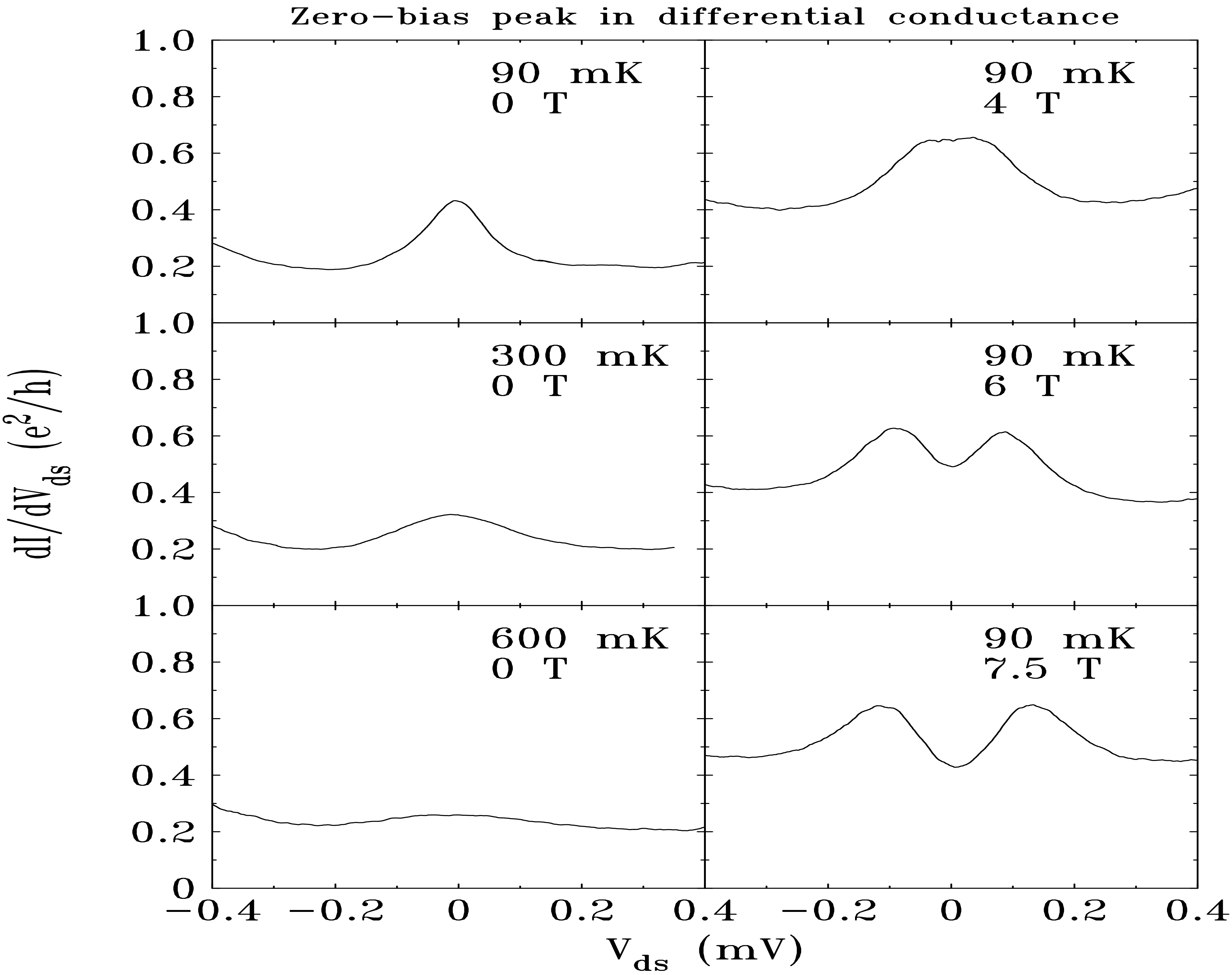
depends on the correlations through the QD spectral function

$$\rho_{d,\sigma}(\omega) = -\frac{1}{\pi} \mathrm{Imag} \left\{ G_{d,\sigma}(\omega + i0^+) \right\}$$

Thu Jul 24 00:19 1997



David Goldhaber-Gordon on (hbar): /data/users/davidg/kastner_backups/0797/11/ivmovie.56A.54

2. The spin vs Kondo effect

Effective interactions: $U > 0$

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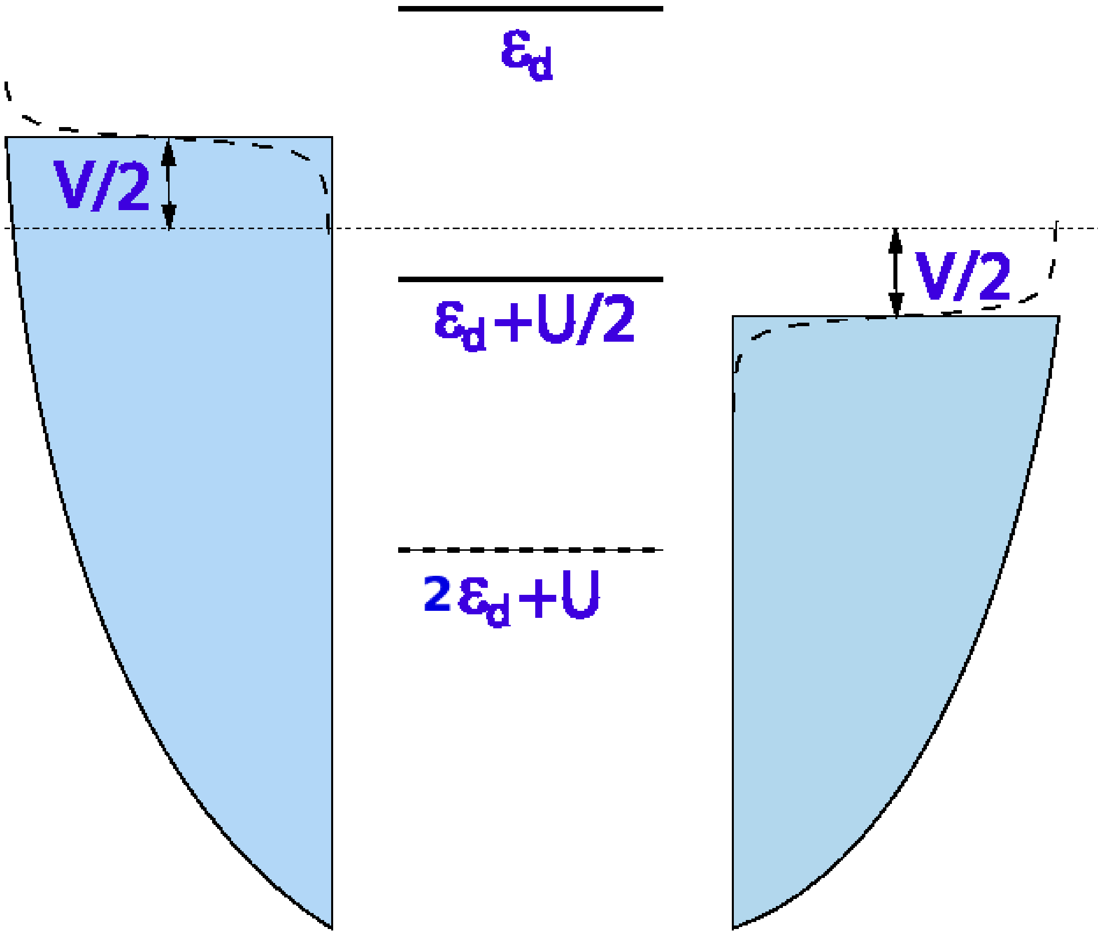
The spin Kondo effect comes from the antiferromagnetic coupling

$$J^{\beta,\beta'}_{\mathbf{k}_F,\mathbf{k}_F} = \frac{U}{\varepsilon_d(\varepsilon_d + U)}\;V_{\mathbf{k}_F\beta}V^{*}_{\mathbf{k}_F\beta'}$$

Situation with the negative U quantum dot



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However, in the present case the empty/double occupied sites are more favorable and they give rise to **the pair-hopping**

$$\sum_{\mathbf{k},\mathbf{q},\beta,\sigma,\sigma'} J_{\mathbf{k},\mathbf{q}}^{\beta,\beta'} \; \hat{d}_{\sigma}^{\dagger} \hat{d}_{-\sigma}^{\dagger} \hat{c}_{\mathbf{k}\beta-\sigma'} \hat{c}_{\mathbf{q}\beta'\sigma'} + \text{h.c.}$$

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The low energy physics is effectively described by

$$\hat{\tilde{H}}^{Kondo}_{charge} = \sum_{\mathbf{k},\beta,\sigma} \xi_{\mathbf{k}\beta}\hat{c}^{+}_{\mathbf{k}\beta\sigma}\hat{c}_{\mathbf{k}\beta\sigma} + 2\sum_{\mathbf{k},\mathbf{q},\beta,\beta'} J^{\beta,\beta'}_{\mathbf{k},\mathbf{q}} \; \hat{\vec{T}}_{d}\cdot\hat{\vec{T}}_{\mathbf{k}\beta,\mathbf{q}\beta'}$$

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$$\hat{\mathcal{T}}_{d}^{+} \hat{d}_{\uparrow}^{\dagger} \; \hat{d}_{\downarrow}^{\dagger} \; \hat{\mathcal{T}}_{d}^{-} = \hat{d}_{\downarrow} \hat{d}_{\uparrow} \; , \; \hat{\mathcal{T}}_{d}^{z} = \frac{1}{2} (\hat{d}_{\uparrow}^{\dagger} \; \hat{d}_{\uparrow} + \hat{d}_{\downarrow}^{\dagger} \hat{d}_{\downarrow} - 1)$$

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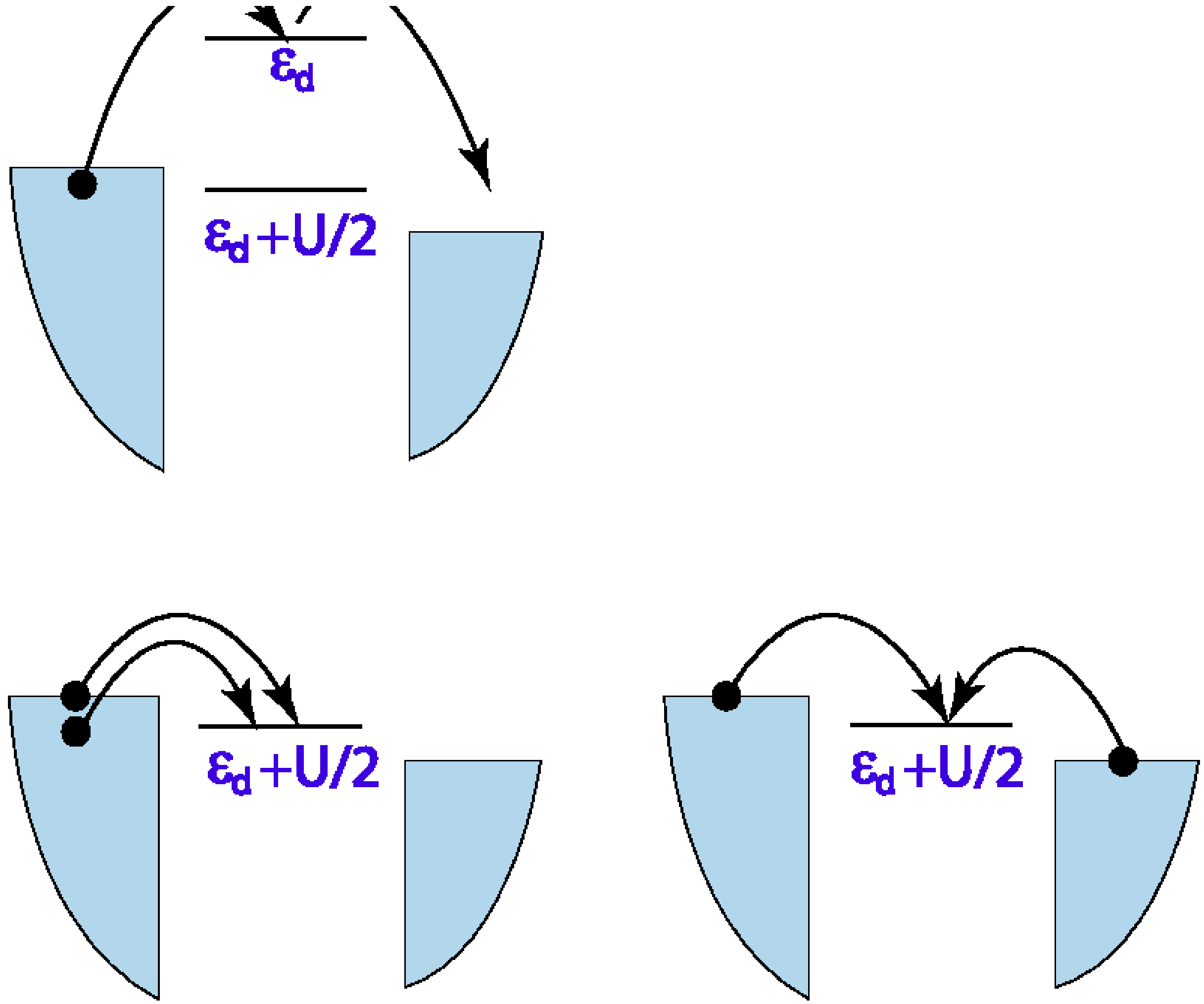
thus the Kondo effect can be formed in the pseudospin channel.

A. Taraphder and P. Coleman, Phys. Rev. Lett. **66**, 2814 (1991).

Charge tunneling through $U < 0$ QD



J. Koch, M.E. Raikh, and F. von Oppen, PRL **96**, 056803 (2006).

Pair tunneling

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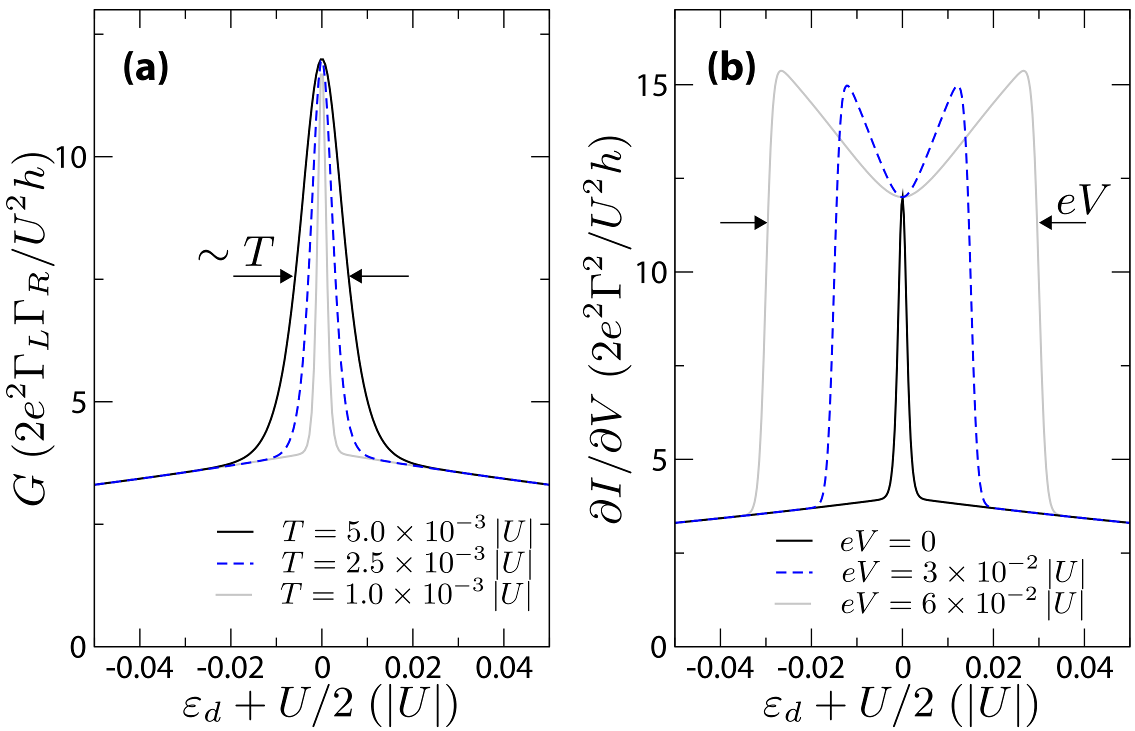

J. Koch, M.E. Raikh, and F. von Oppen, PRL **96**, 056803 (2006).

Pair tunneling

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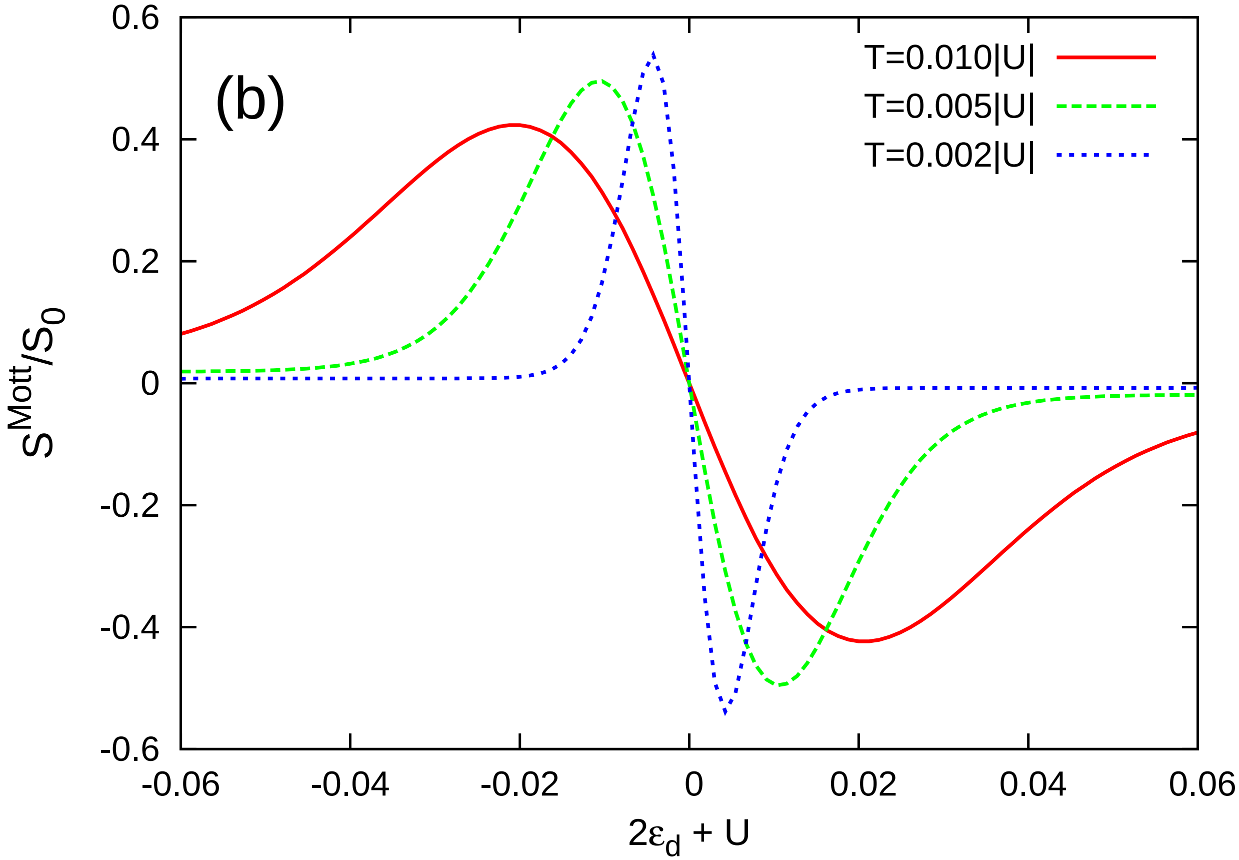

M. Gierczak, K.I. Wysokiński, J.Phys.Conf.Ser. **104**, 012005 (2008).

3. The two-channel model

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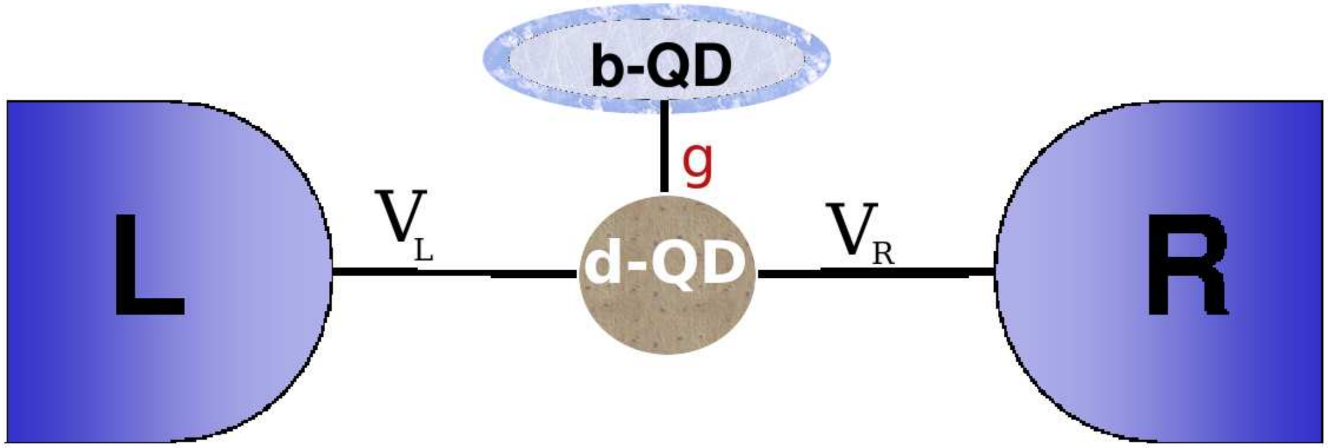

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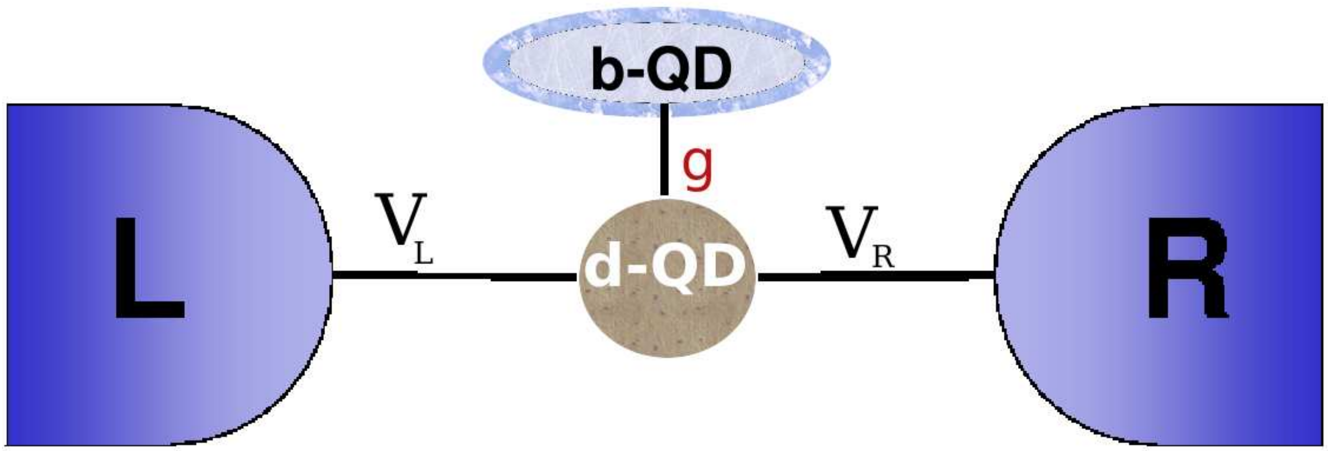

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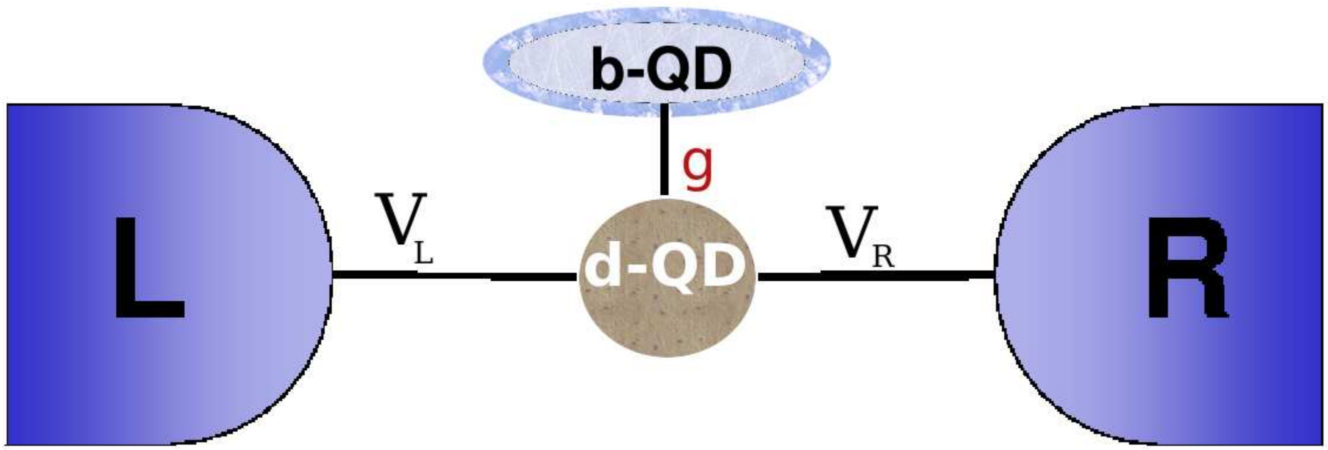

$$\hat{H}_L + \hat{V}_L + \hat{H}_{mQD} + \hat{V}_R + \hat{H}_R$$

$$\hat{H}_{mQD} = \sum_\sigma E_d\, \hat{d}^\dagger_\sigma \hat{d}_\sigma + E_{pair}\, \hat{b}^\dagger \hat{b} + g\left(\hat{b}^\dagger\, \hat{d}_\downarrow \hat{d}_\uparrow + \hat{d}^\dagger_\uparrow\, \hat{d}^\dagger_\downarrow\, \hat{b}\right)$$

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In the limit $V_{\mathbf{k},\beta} = 0$ the true eigenstates are given by

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\begin{aligned}
|B\rangle &= \sin(\varphi)\ |0\rangle_d \otimes |1)_b + \cos(\varphi)\ |\uparrow\downarrow\rangle_d \otimes |0)_b \\
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and the d-QD Green's function has a three-pole structure

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\mathcal{G}_d^{V_{\mathbf{k}\beta}=0}(\omega) = \frac{\mathcal{Z}}{\omega - E_d} + (1-\mathcal{Z})\left[\frac{u^2}{\omega - E_B} + \frac{v^2}{\omega - E_A}\right]
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T. Domański, Eur. Phys. J. B **33**, *41 (2003).*

Quantum fluctuations (c.d.)

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where

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and $\mathcal{Z}$ is a strongly temperature-dependent coefficient.

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\begin{aligned}
E_A, E_B &= \frac{1}{2}\left[E_{pair} \mp \gamma(2E_d - E_{pair})\right] \\
v^2, u^2 &= \frac{1}{2}\left(1 \mp \frac{1}{\gamma}\right) \\
\gamma^2 &= 1 + \left(\frac{2g}{2E_d - E_{pair}}\right)^2
\end{aligned}
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and $\mathcal{Z}$ is a strongly temperature-dependent coefficient.

To account for a finite hybridization we employ the **Ansatz**

Quantum fluctuations (c.d.)

where

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$$\mathcal{G}_d(\omega)^{-1} = \mathcal{G}_d^0(\omega)^{-1} - \sum_{\mathbf{k},\beta} \frac{|V_{\mathbf{k}\beta}|^2}{\omega - \xi_{\mathbf{k}\beta}}$$

Spectrum of the d-QD

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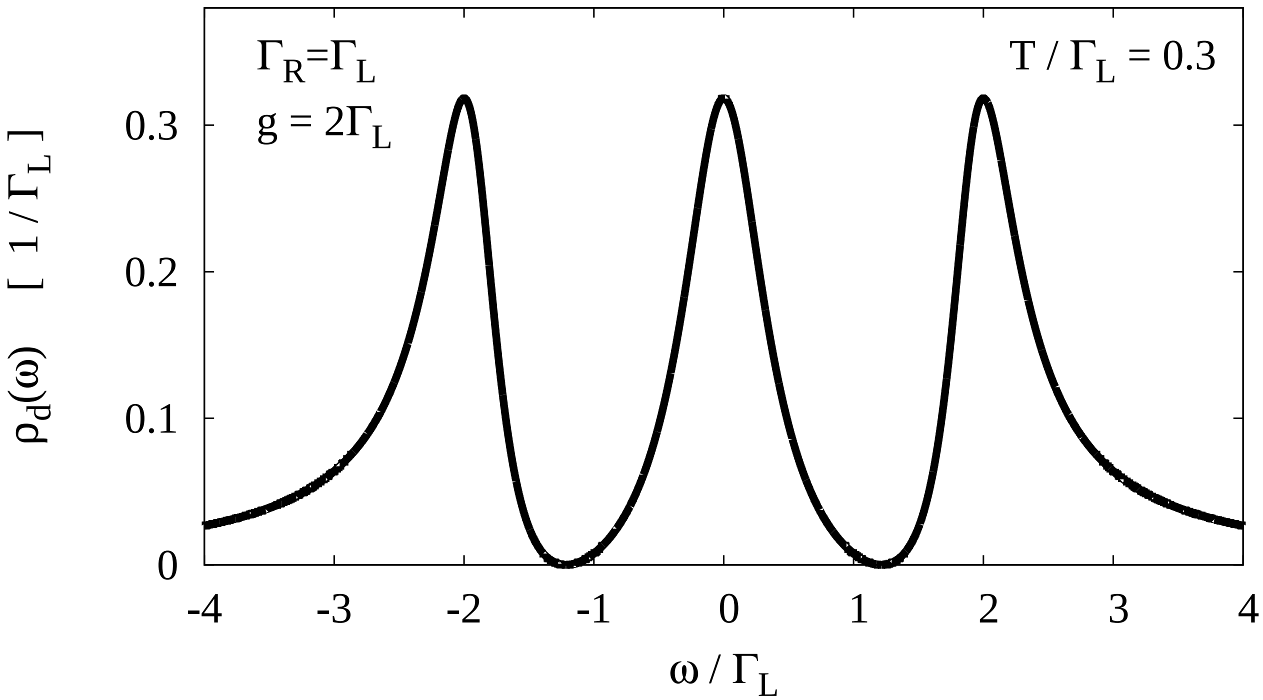

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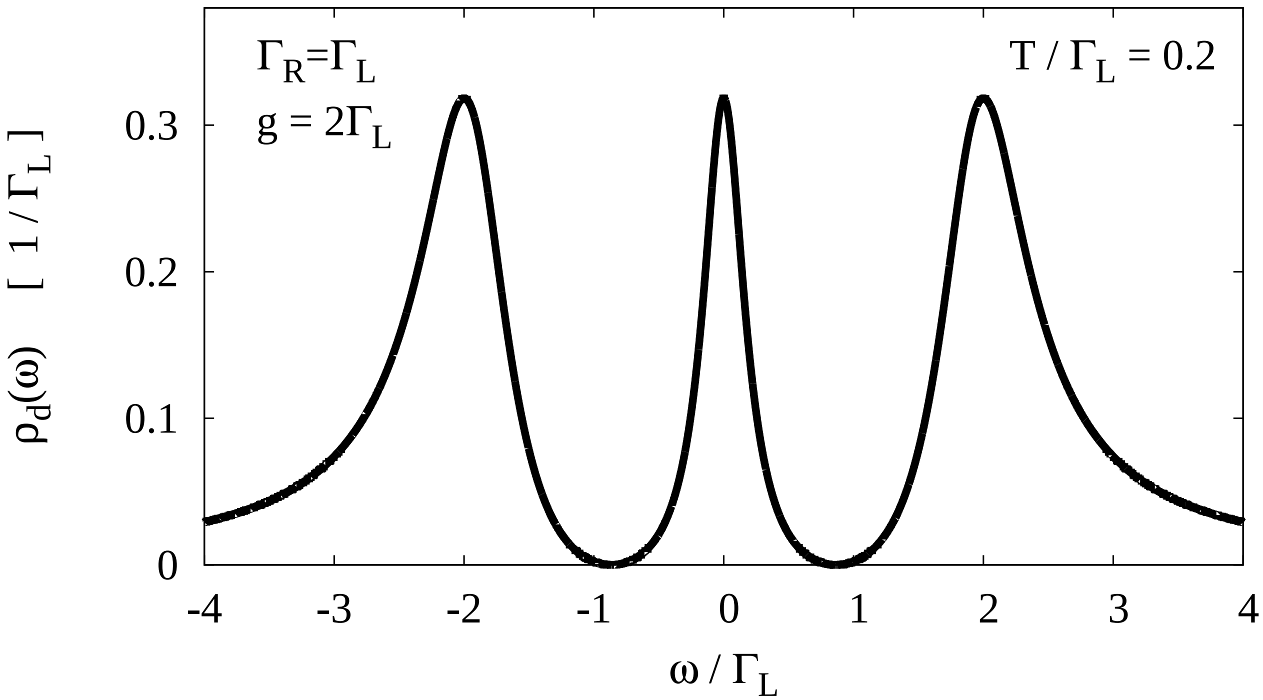

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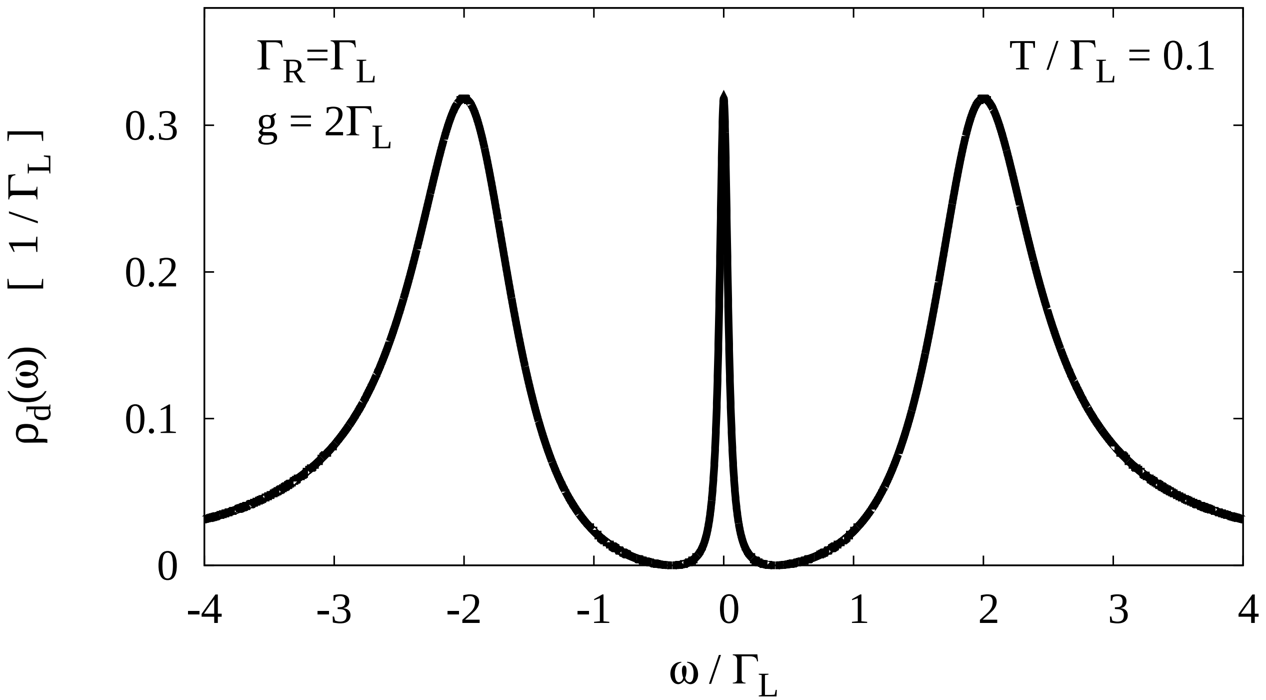
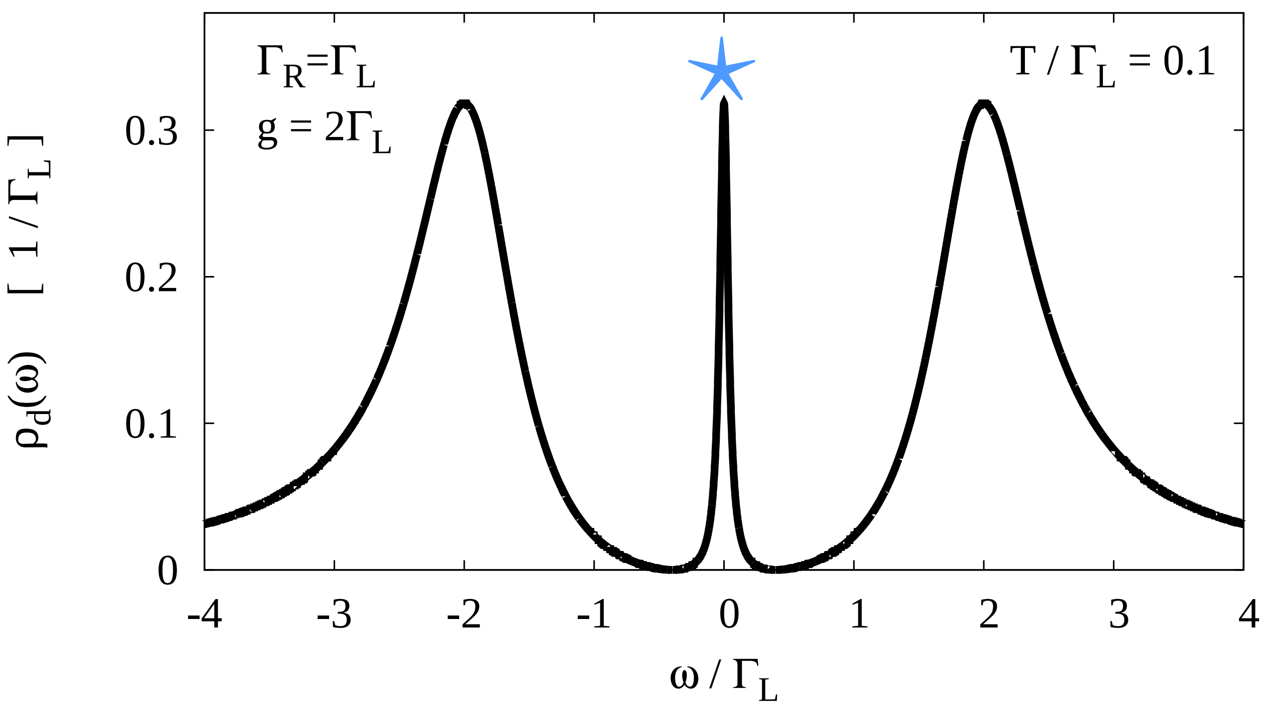
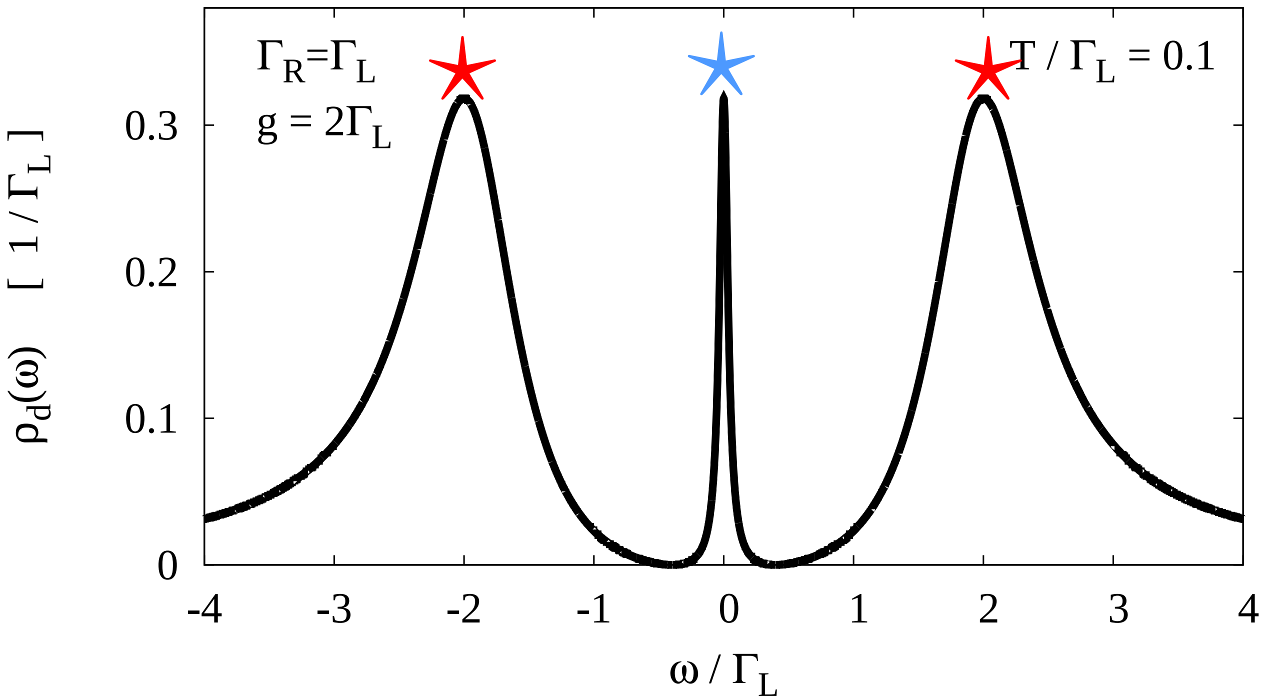


Spectrum of the d-QD



★ the middle peak: superradiant state,

Spectrum of the d-QD

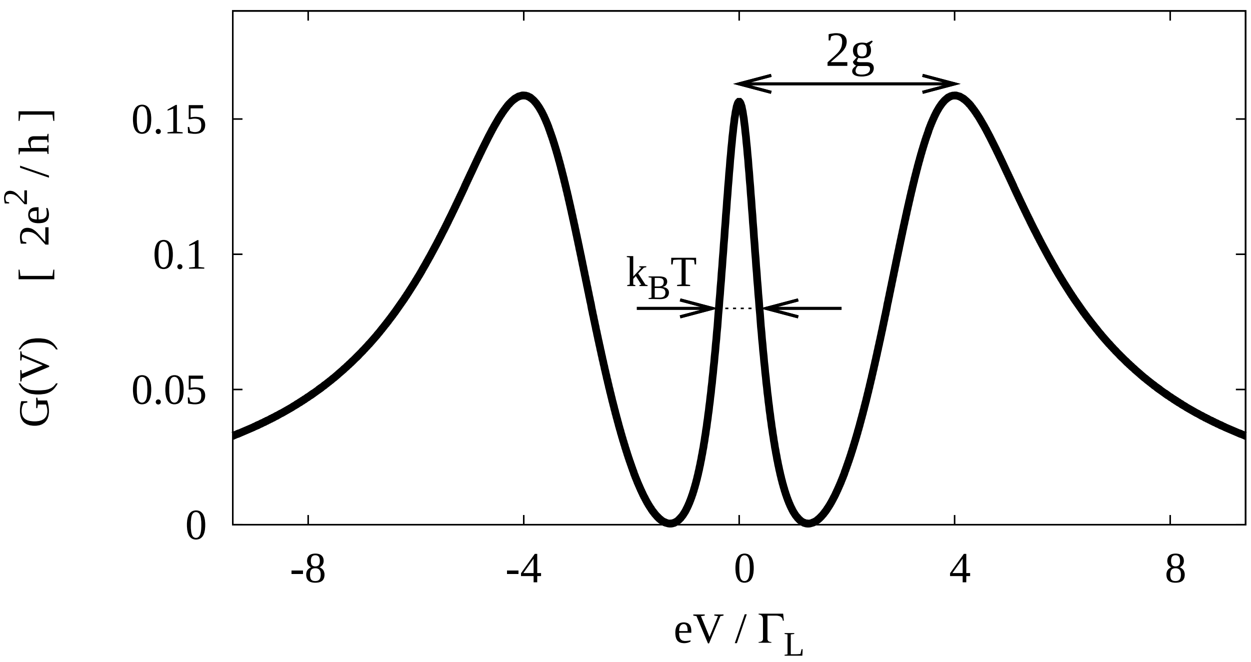


★ the middle peak: superradiant state,

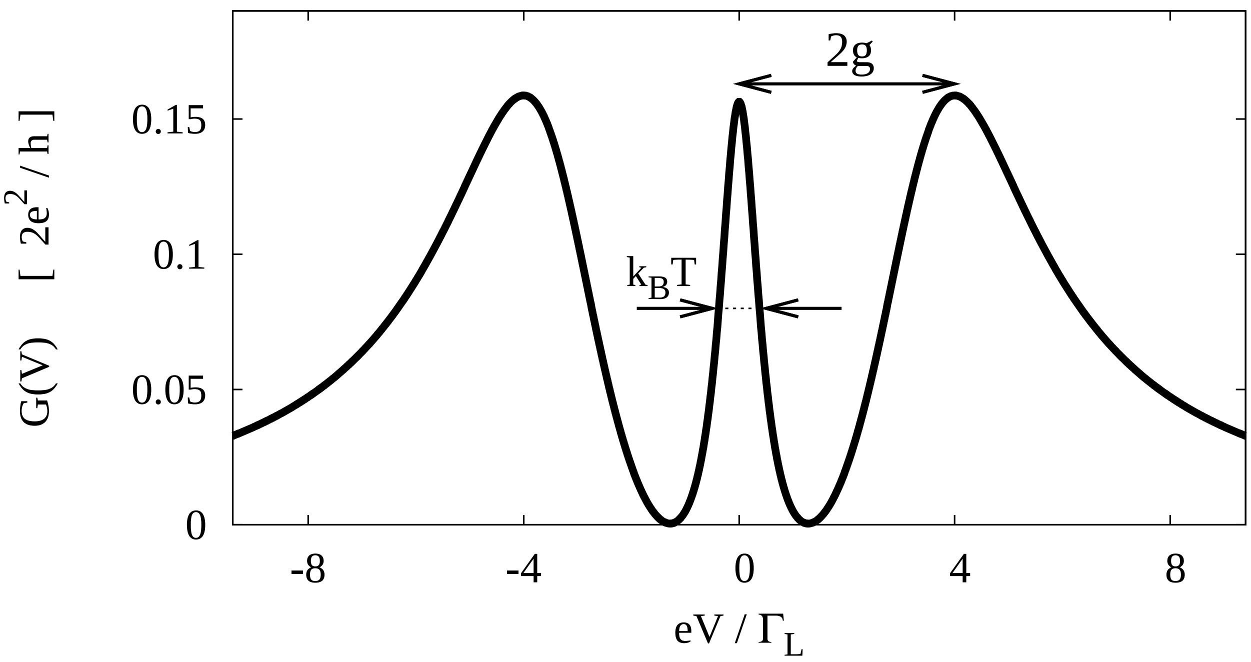
★ the side peaks: subradiant states.

Differential conductance

Differential conductance



Differential conductance

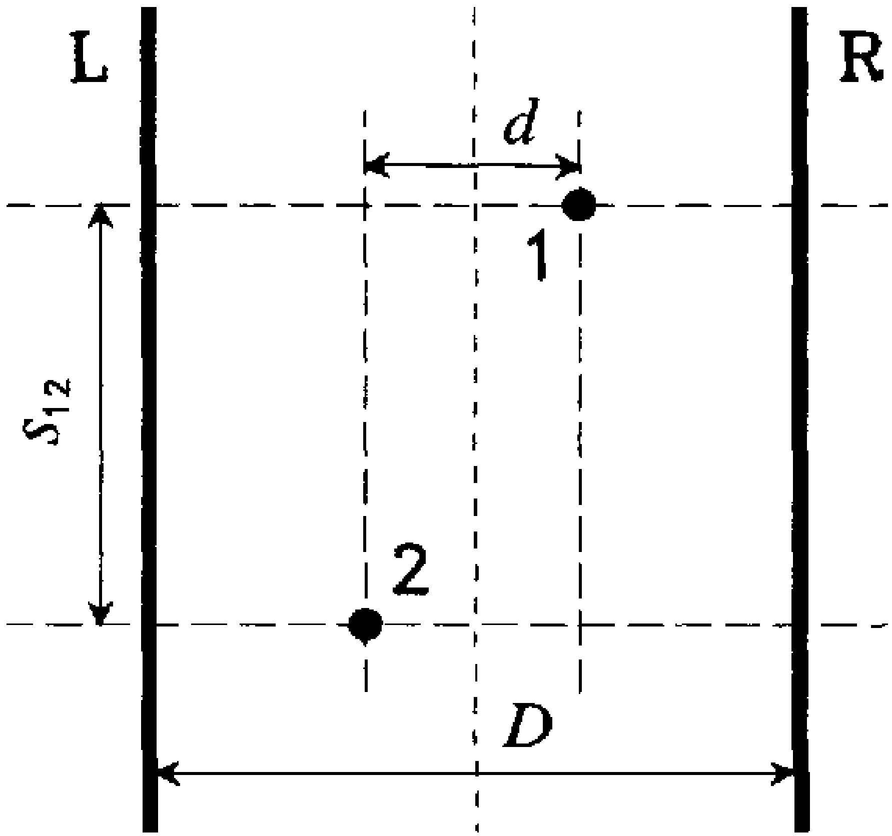


Superradiant line broadening is proportional to T !

Dicke effect in mesoscopic physics

Dicke effect in mesoscopic physics

1 tunneling via two quantum dots



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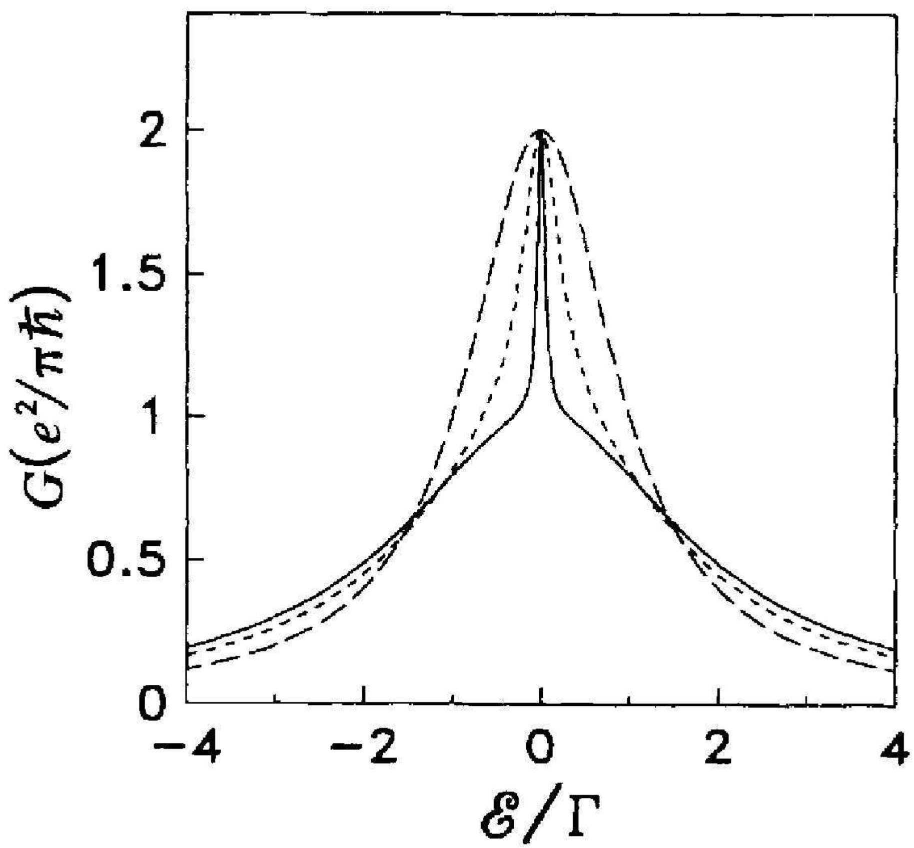
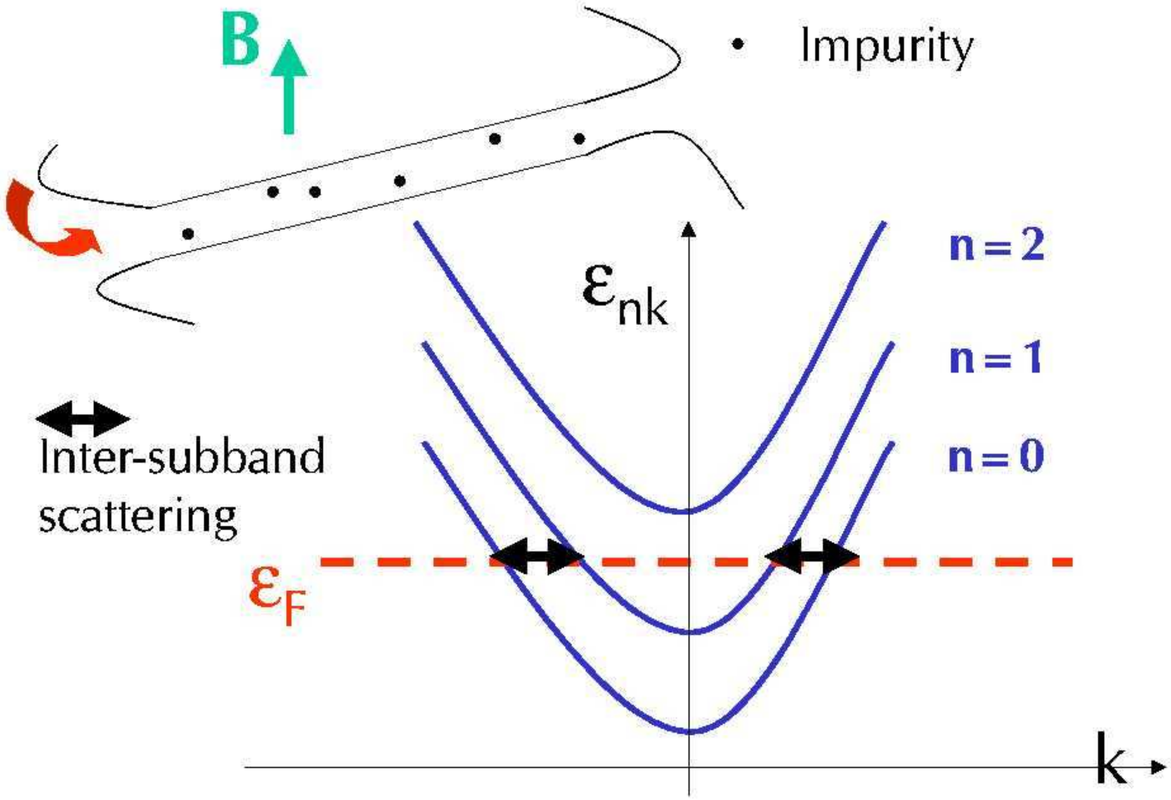


T.V. Shahbazyan and M.E. Raikh, PRB **49**, 17123 (1994).

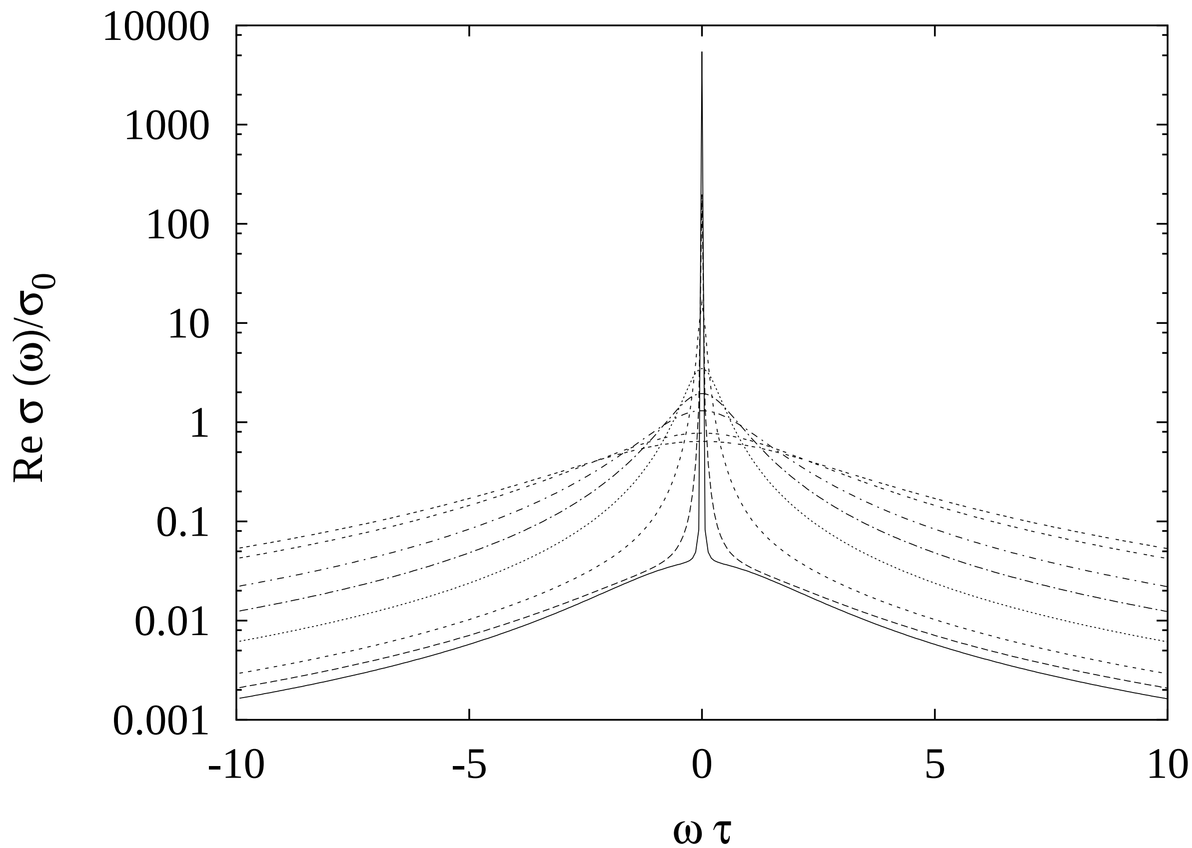
Dicke effect in mesoscopic physics

\# 2 tunneling via the quantum wire + magnetic field



Dicke effect in mesoscopic physics

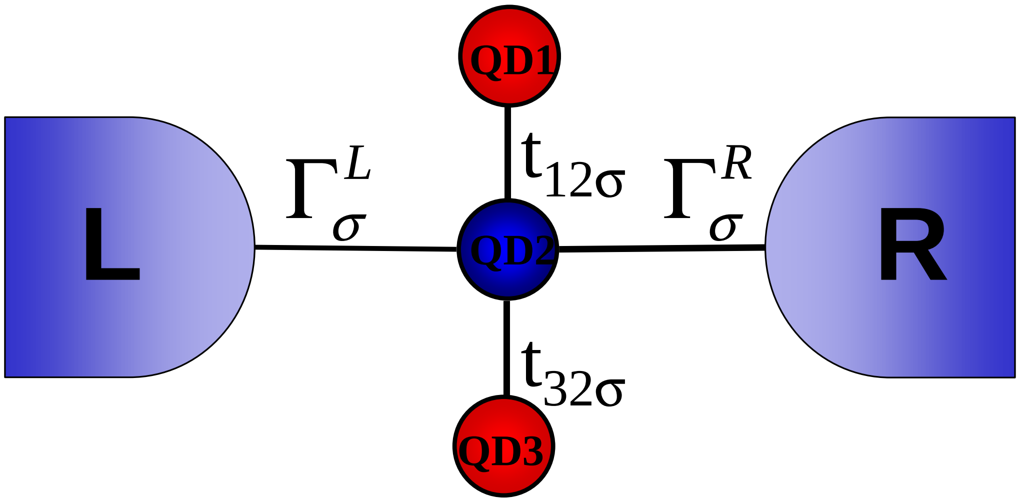
2 tunneling via the quantum wire + magnetic field



T. Brandes, Phys. Rep. **408**, 315 (2005).

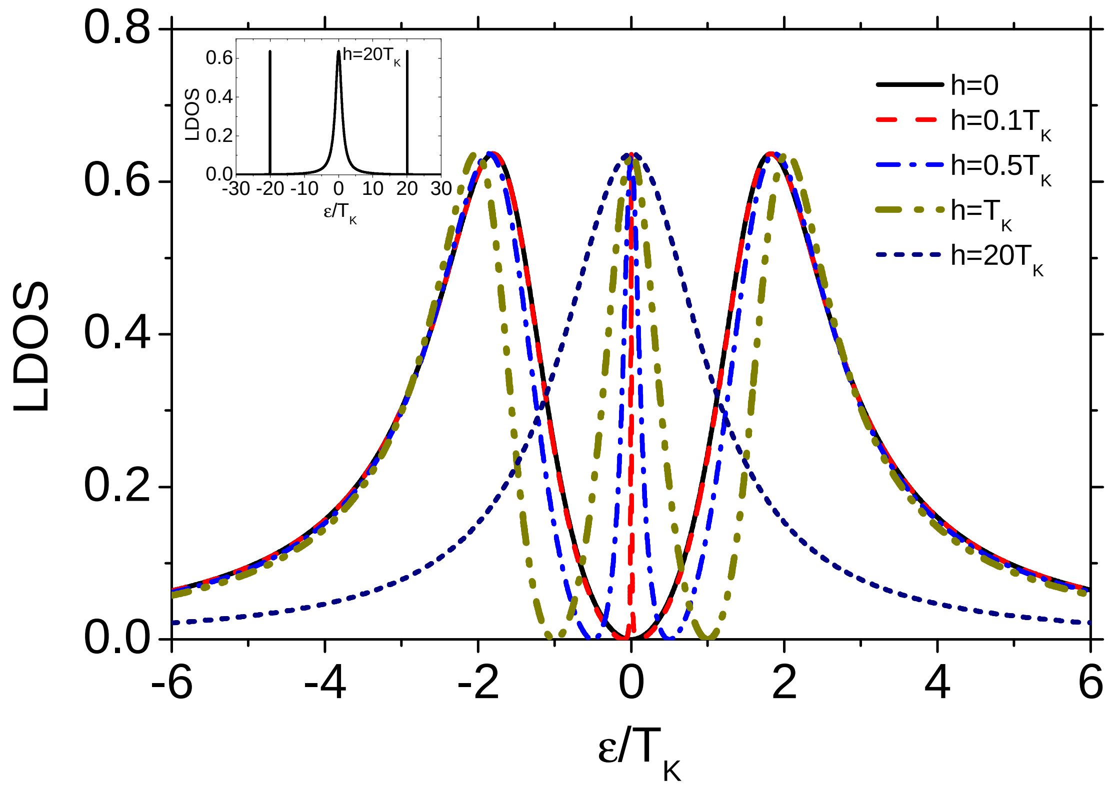
Dicke effect in mesoscopic physics

3 tunneling via three quantum dots



Dicke effect in mesoscopic physics

3 tunneling via three quantum dots



P. Trocha and J. Barnaś, PRB **78**, 075242 (2008).

4. Summary

Summary:

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http://kft.umcs.lublin.pl/doman