Heat transport and spin torques in strongly correlated spin valves

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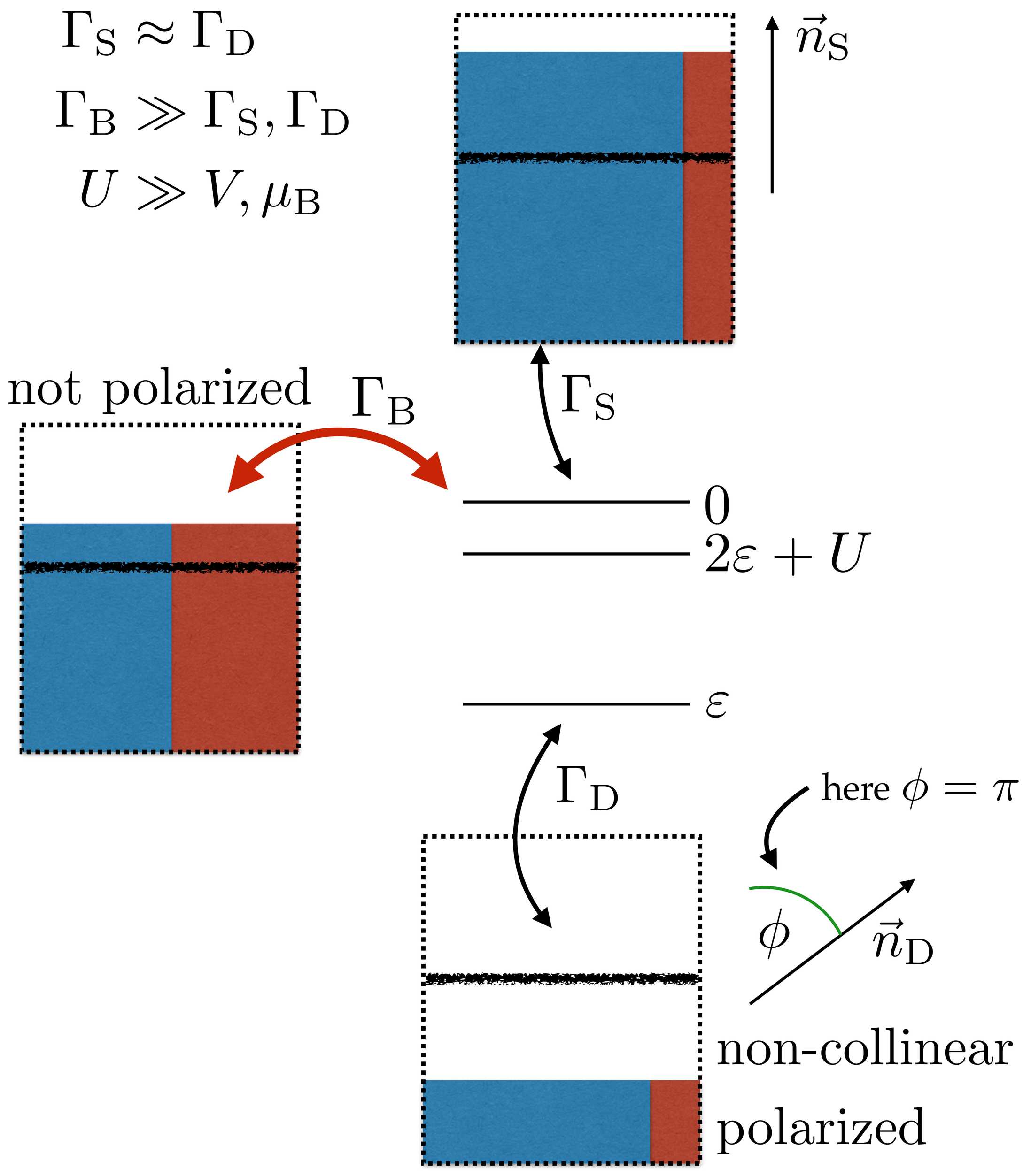
1. Three-reservoir quantum-dot setup

$\Gamma_{\mathrm{S}} \approx \Gamma_{\mathrm{D}}$
$\Gamma_{\mathrm{B}} \gg \Gamma_{\mathrm{S}}, \Gamma_{\mathrm{D}}$
$U \gg V, \mu_{\mathrm{B}}$



The considered model reservoirs are at grandcanonical equilibrium and have a wideband-limit DOS.

Dynamic magnetic field

The angle between the reservoir polarisation directions than generates an effective magnetic field on the dot system [1,2]:

$$H_{\mathrm{dot}} = \sum_{\sigma=\uparrow,\downarrow} \varepsilon n_\sigma + U n_\uparrow n_\downarrow$$

$$H_{\mathrm{tun}} = \sum_{k,\sigma\sigma'\alpha} c^\dagger_{k\sigma\alpha} R^\alpha_{\sigma\sigma'} d_{\sigma'} + \mathrm{h.c.}$$

independent of unpolarised μ_{B}

$$B_{\mathrm{ind}} = \frac{\pi}{2} \sum_\alpha t_\alpha^2 \vec{n}_\alpha \mathrm{Re}\left[\Psi\left(\frac{1}{2} + i\frac{\varepsilon - \mu_\alpha}{2\pi T_\alpha}\right) - \Psi\left(\frac{1}{2} + i\frac{\varepsilon + U - \mu_\alpha}{2\pi T_\alpha}\right)\right]$$

$R^\alpha_{\sigma\sigma'}$ is a phase factor that encodes the polarisation direction of the considered reservoir.

2. Perturbation theory in Liouville space

Use Liouville space methods [3,4,5] to apply a perturbation theory in the tunnel couplings, valid for (ρ_0 is reservoir DOS):

$$\boxed{\Gamma/T = 2\pi t^2 \rho_0 / T \ll 1}$$

The time evolution of the system is described by the Liouville-von-Neumann equation which is Laplace transformed to obtain:

$$\frac{\partial}{\partial t}\rho(t) = -i[H,\rho]_- = -iL\rho$$

$$\Rightarrow \rho(z) = -\frac{i}{z-L}\rho(t_0)$$

Tracing out the reservoir degrees of freedom yields for the reduced dot density operator:

$$\rho_{\mathrm{dot}}(z) = -\frac{i}{z - L_{\mathrm{eff}}(z)}\rho_{\mathrm{dot}}(t_0)$$

$$L_{\mathrm{eff}}(z) = L_{\mathrm{dot}} + \Sigma(z)$$

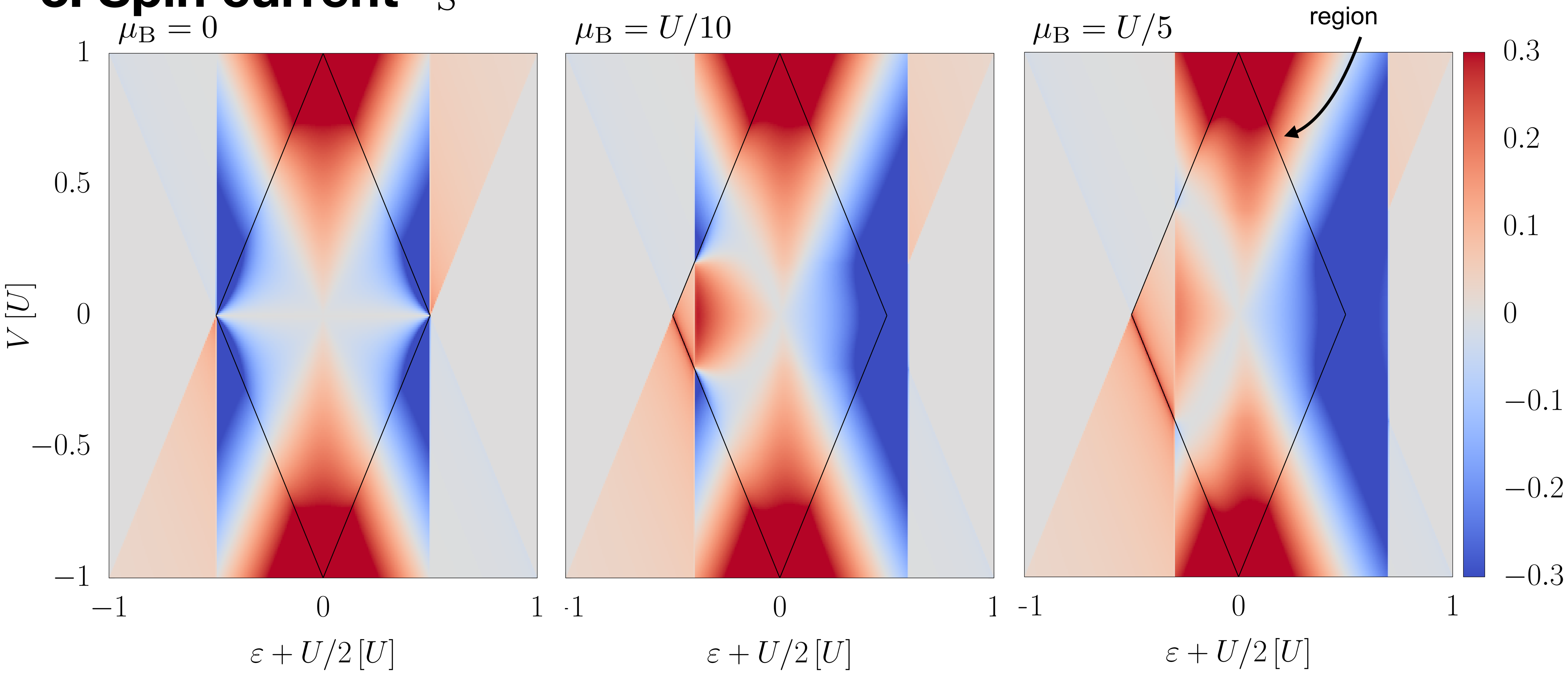
$$L_{\mathrm{dot}}\bullet = [H_{\mathrm{dot}}, \bullet]_-$$

$$\Sigma(z) = \sum_{k=1}^{\infty} \mathop{\mathrm{tr}}_{\mathrm{res}} \left(L_{\mathrm{tun}} \frac{1}{z - (L_{\mathrm{dot}} + L_{\mathrm{res}})}\right)^k L_{\mathrm{tun}} \rho_{\mathrm{res}}\Big|_{\mathrm{irred.}}$$

This is than perturbatively evaluated up to and including order $\mathcal{O}\left(\Gamma^2\right)$.

3. Spin current $I_{\mathrm{S}}^{\vec{n}_{\mathrm{S}} \times \vec{n}_{\mathrm{D}}}$

spin current into drain

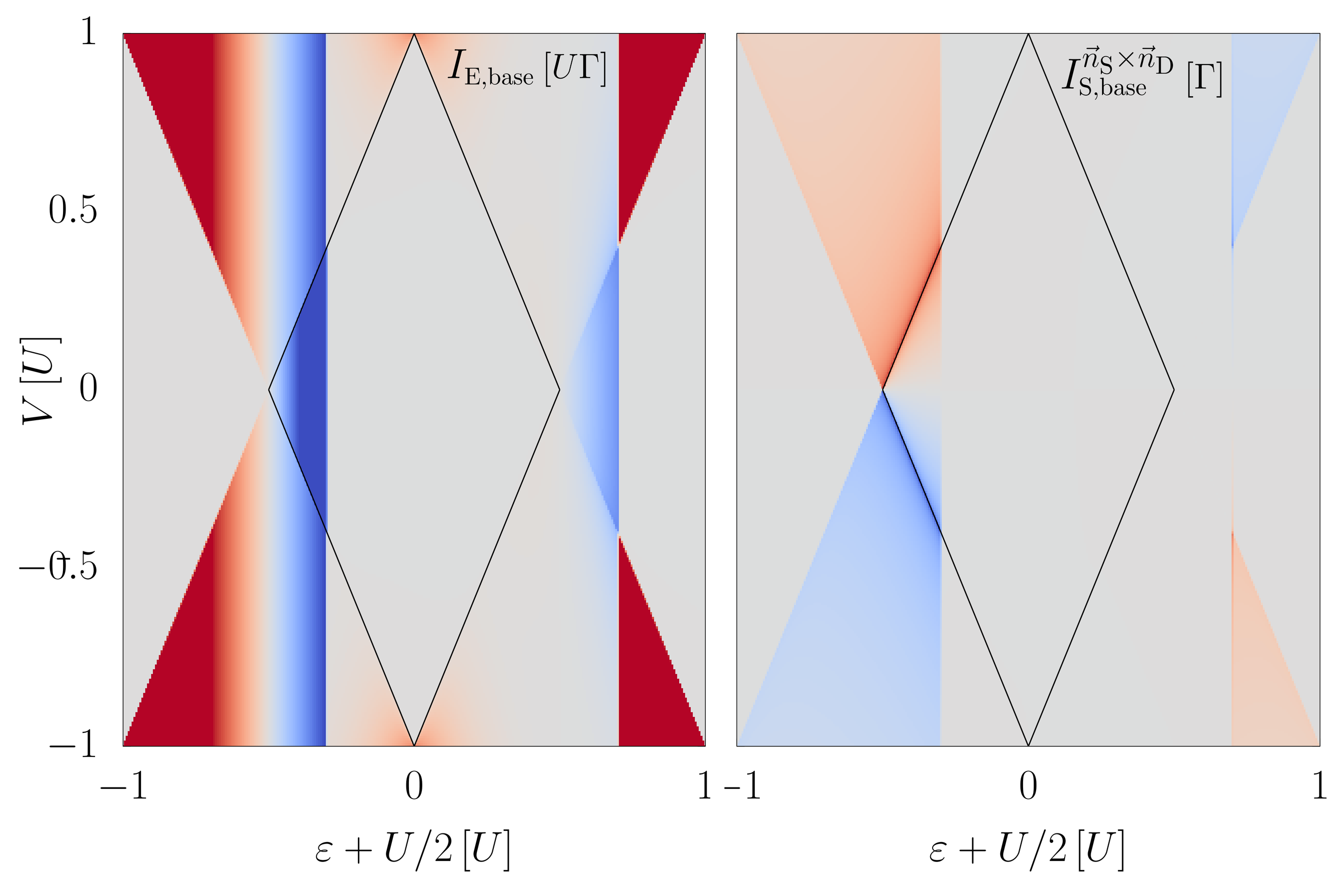


Two main mechanism cause this spin flow orthogonal to the polarisation axis:

1. Transport of spins rotated by the induced magnetic field out of plane.
2. Back-action of the induced magnetic field on the reservoirs. Every spin rotation on the dot has to be compensated by a counter-rotation of spins in the polarised reservoirs (model conserves spin).

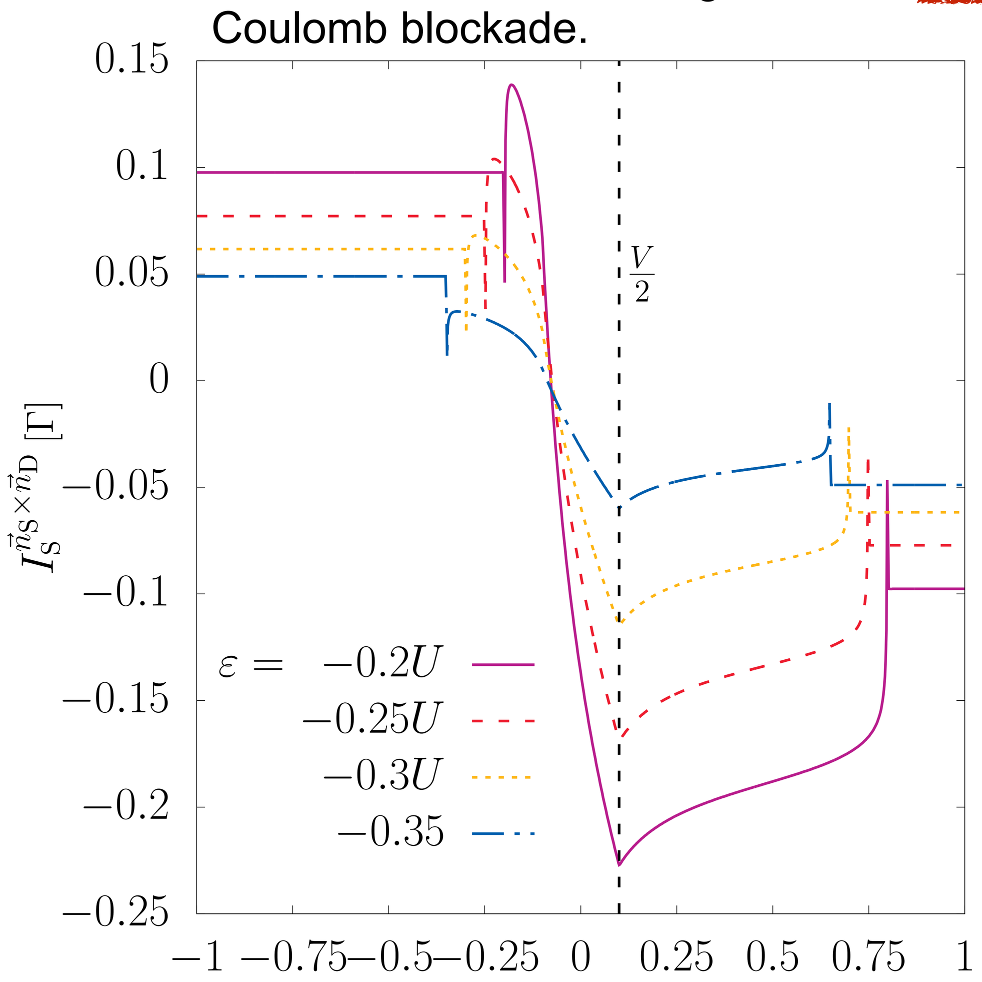
Working assumption: In the Coulomb blockade is mainly mechanism 2 active.

The base reservoir influences the spin flow by offering a relaxation channel without experiences a significant spin, charge or heat flow itself.

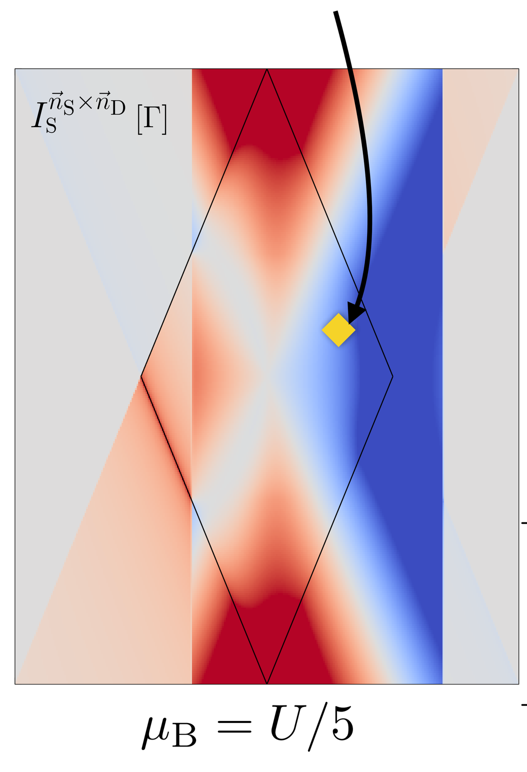


4. Controlling spin flow via the unpolarised reservoir

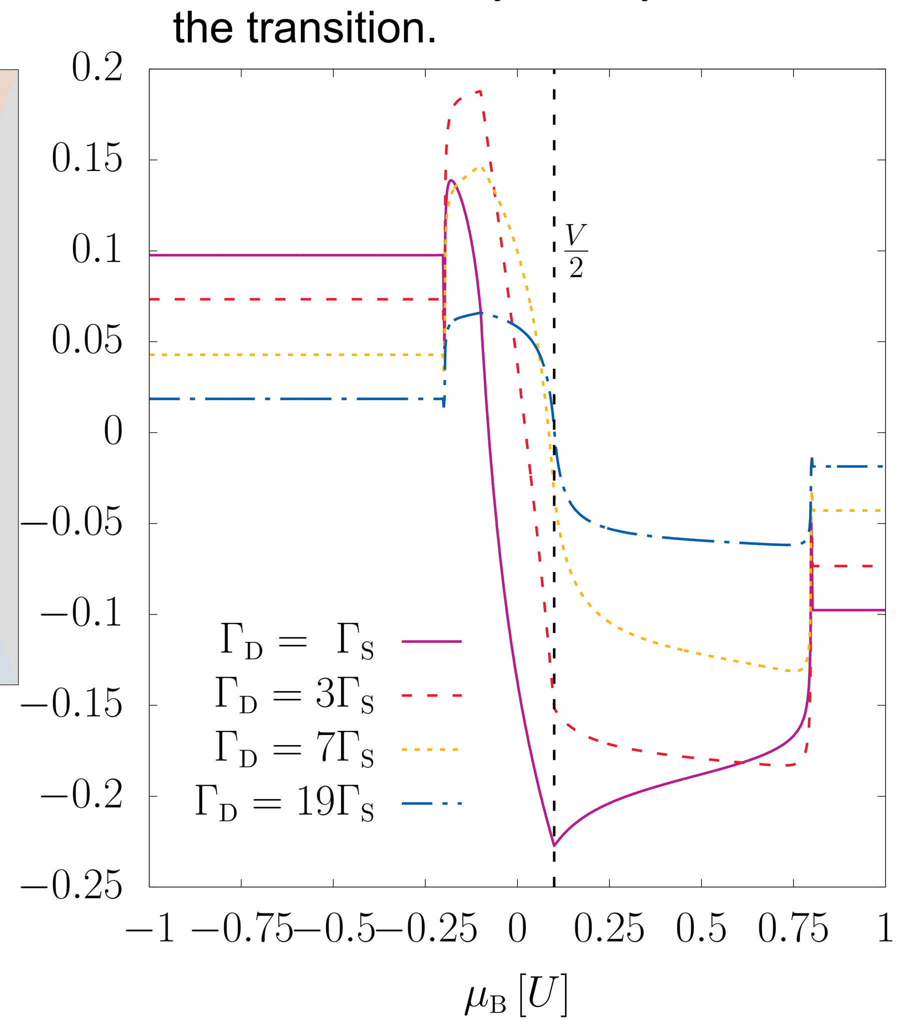
Effect increases at the edges of the Coulomb blockade.

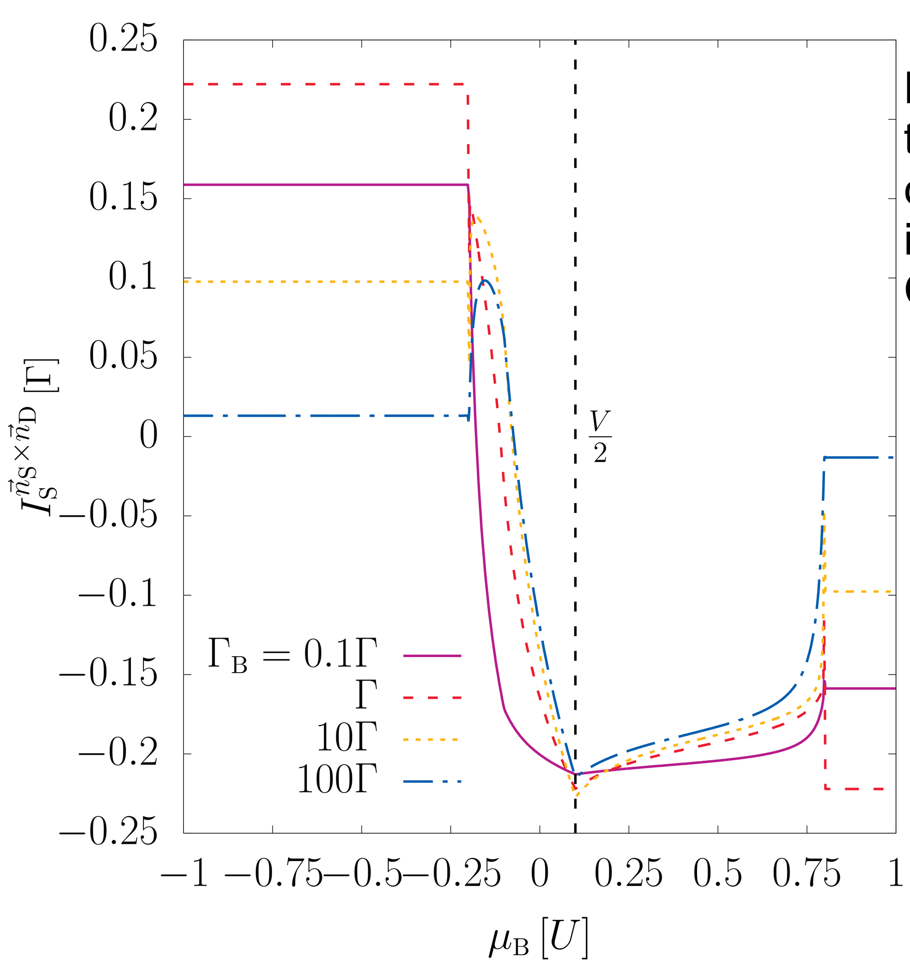


we start here and e.g. alter μ_{B}



Source/Drain-asymmetry smoothes the transition.





Reducing the coupling to the unpolarised reservoir consequently reduces its influence, especially in the Coulomb blockade region.

Summary

The unpolarised reservoir can massively alter the spin flow between the two polarised leads without taking part in it.

It offers a spin relaxation channel, i.e. altering the spin waiting times on the dot and its non-stationary spin occupations.

References

[1] Braun, König and Martinek, Phys. Rev. B 70, 195345 (2004)
[2] Hell et al., Phys. Rev. B 90, 195404 (2015)
[3] Schoeller and Reininghaus, Phys. Rev. B 80, 045117 (2009)
[4] Schoeller, Eur. Phys. J. Special Topics 168, 179266 (2009)
[5] Saptsov and Wegewijs, Phys. Rev. B 86, 235432 (2012)