Kondo excitons and spin-dependent optical phenomena in charged quantum dots

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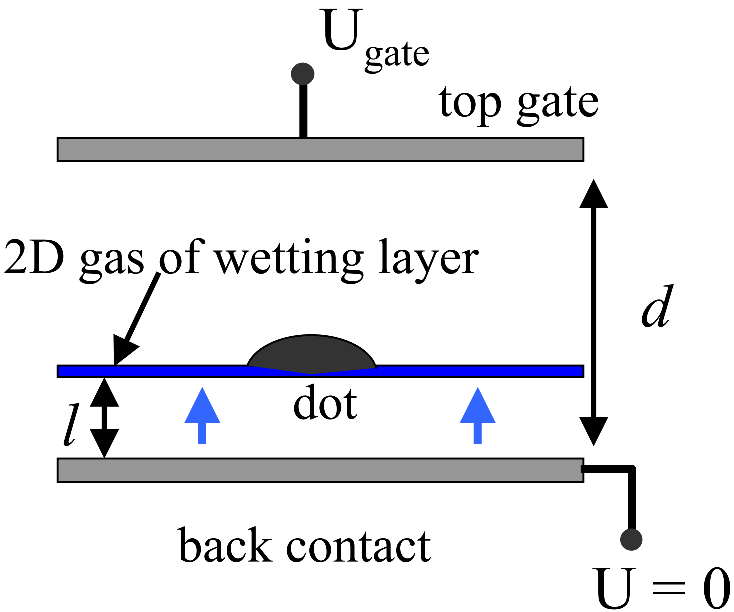
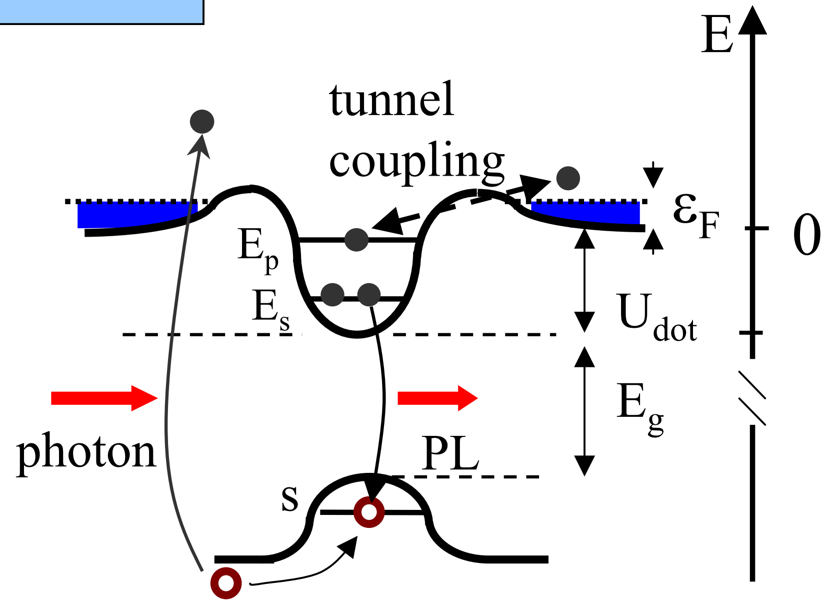
Model



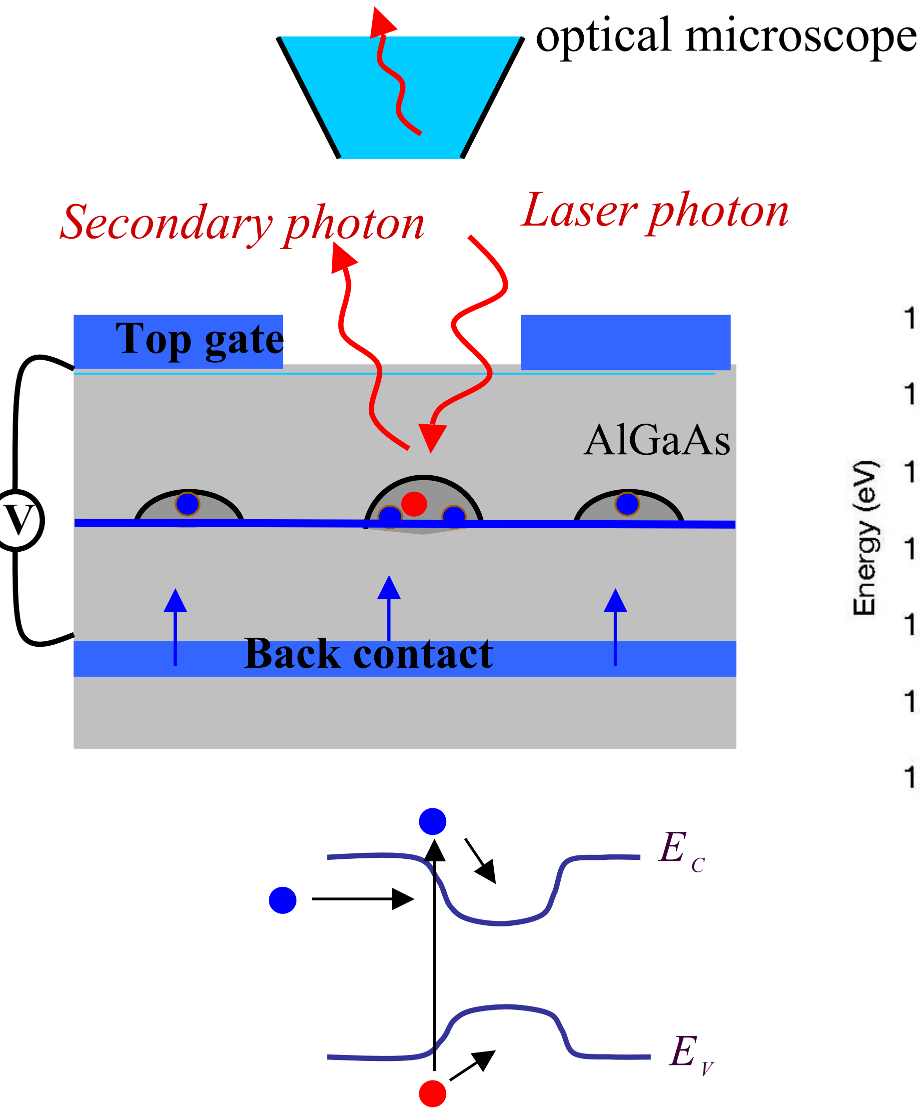


Anderson Hamiltonian:

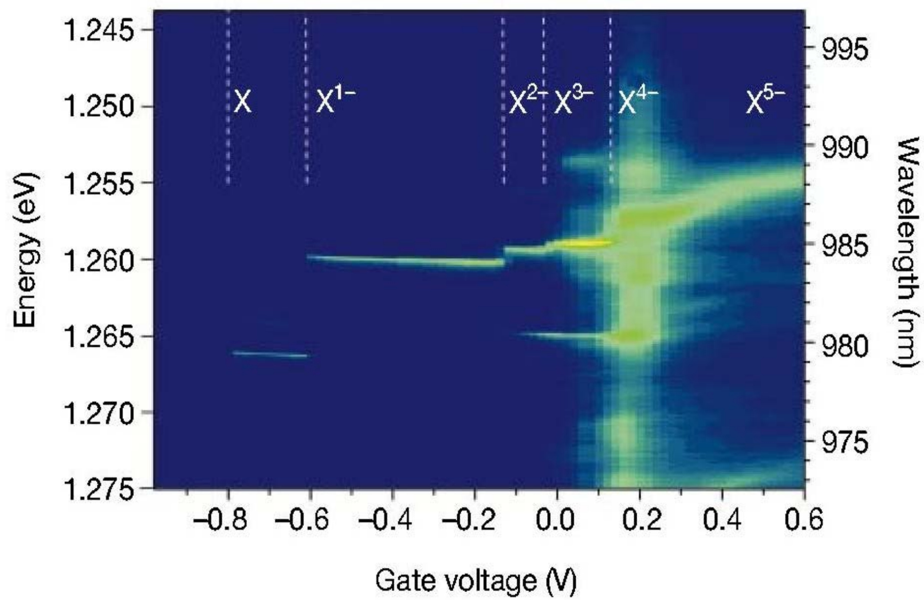
$$\hat{H} = \hat{H}_{\text{single-particle}} + \hat{H}^{\text{intra-dot}}_{\text{Coulomb}} + \hat{H}_{\text{hybridization}}$$

$$\hat{H}_{\text{hybridization}} = \sum_{k,\sigma} V_k [a^{+}_{p,\sigma}\hat{c}_{k,\sigma} + \hat{c}^{+}_{k,\sigma} a_{p,\sigma}]$$

Neutral and Charged excitons in quantum dots



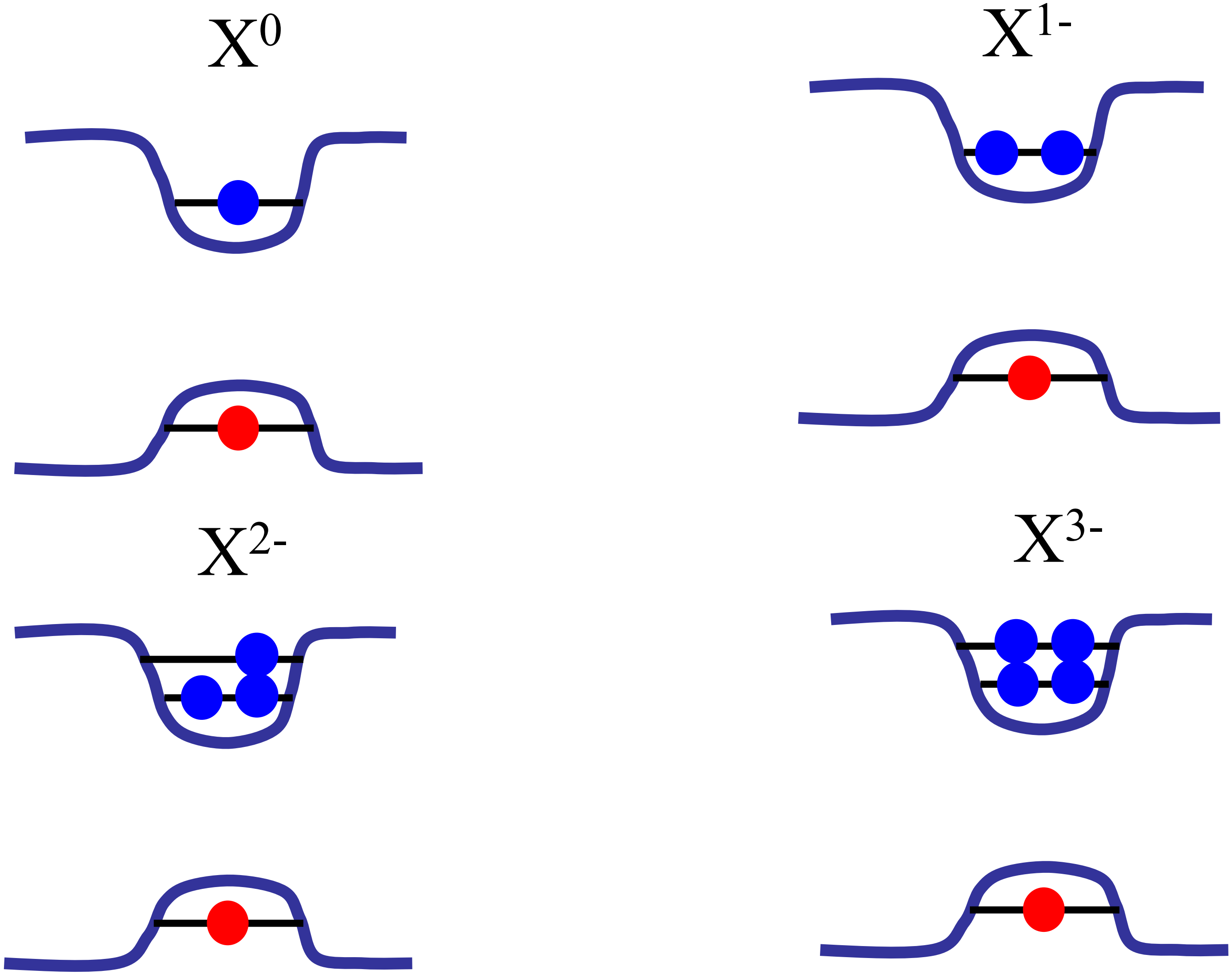
Single-dot spectroscopy



R. Warburton, K.Karrai et al., Nature - 2000

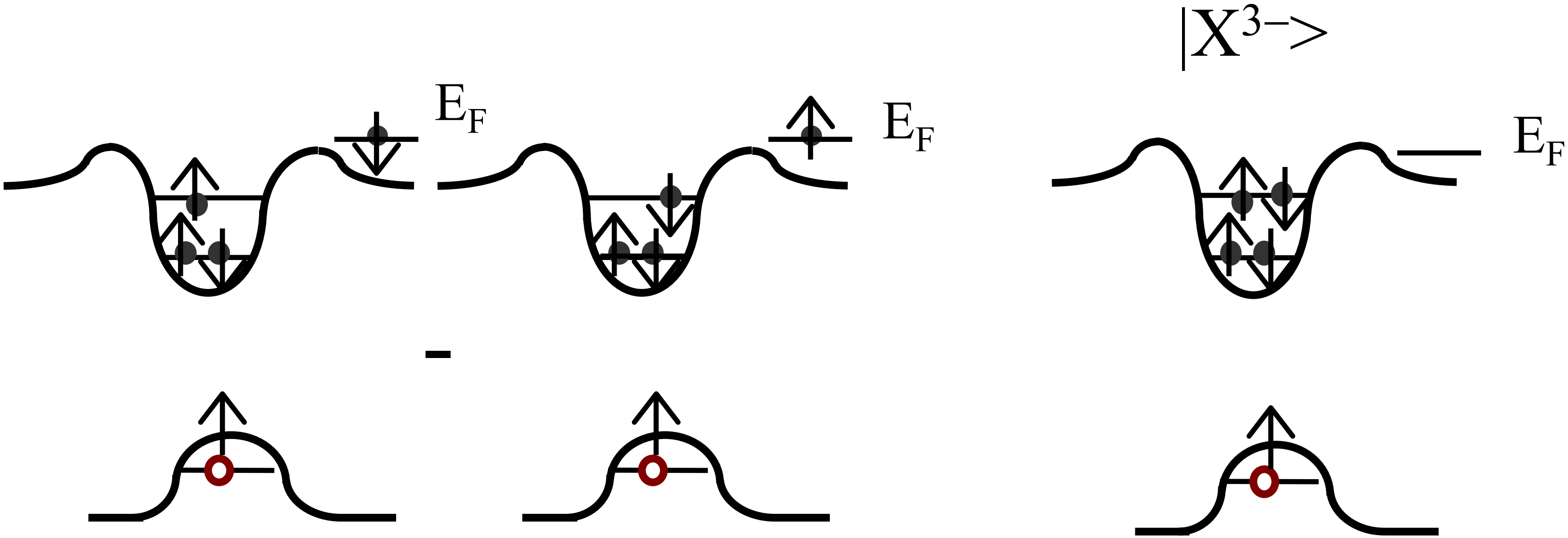
Neutral and charged excitons in quantum dots

X^{n-} ($n+1$ electrons and one hole)



Zero bandwidth model

$|X^{2-}>$, Kondo exciton

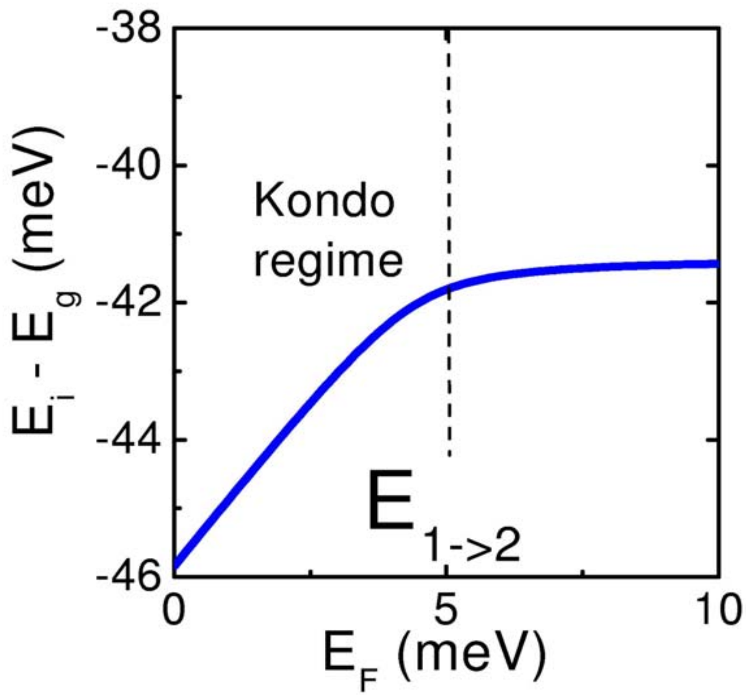


Ground state: $S_{electrons} = 0$

$$|\Psi_{initial}> = a_1|X^{2-}> + a_2|X^{3-}>$$

Initial state energy

$|X^{2-}\rangle$ $|X^{3-}\rangle$



Harmonic-oscillator functions with

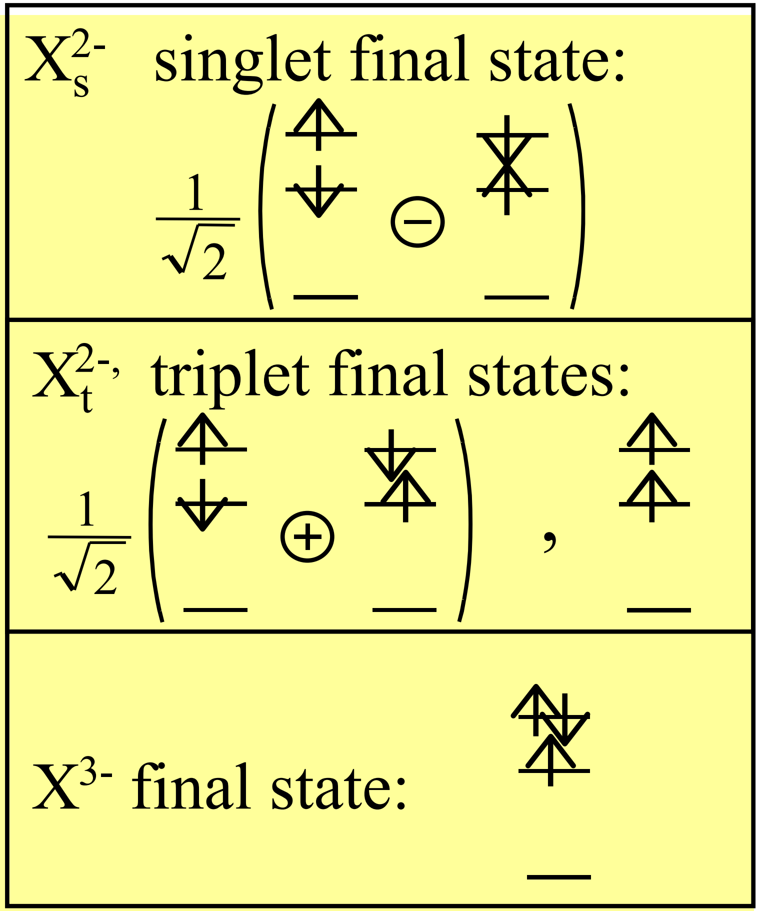
$\hbar\omega_x = 20 \ \ meV$

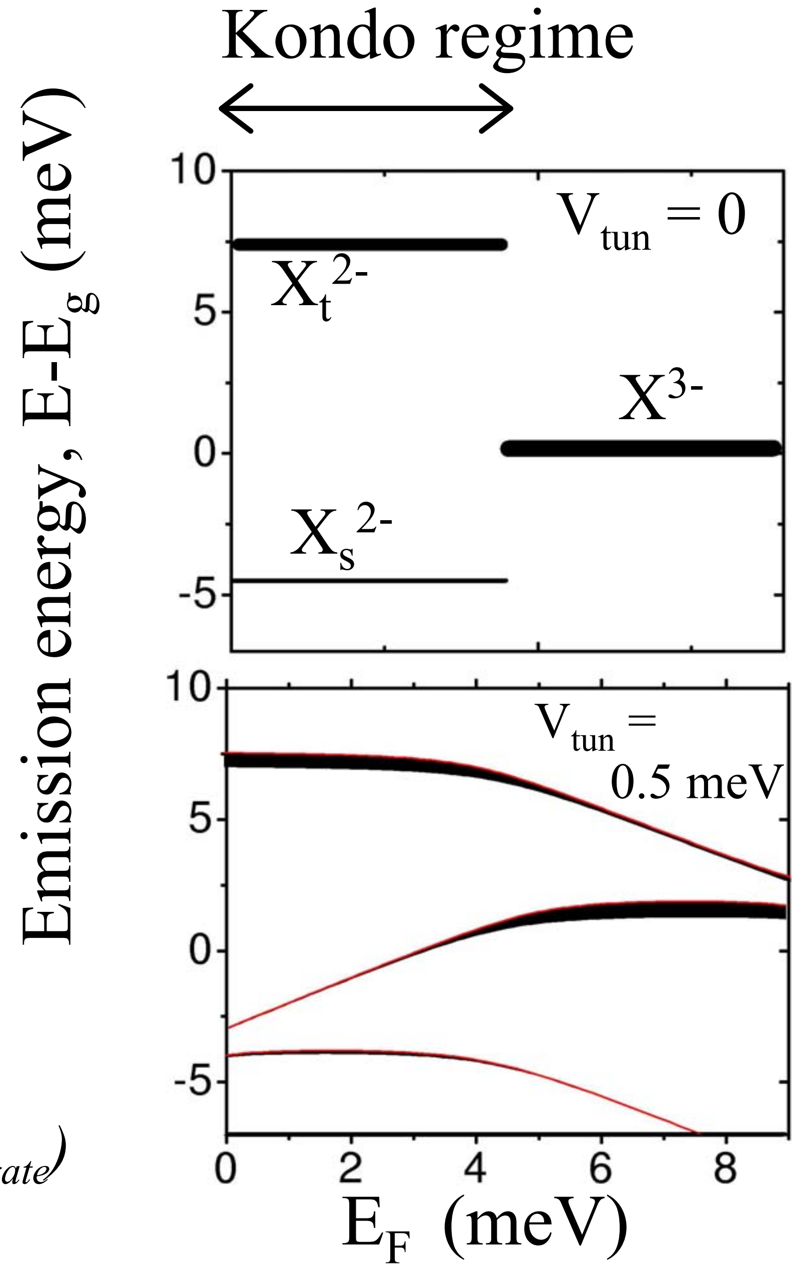
$\hbar\omega_y = 25 \ \ meV$

$U_{dot} = 64 \ \ meV$

$$I_{PL}(\omega) = \mathrm{Re}\int_0^\infty e^{-i\omega t} \left\langle i \,|\, \hat{V}_{opt}^{+}(t) \hat{V}_{opt}^{+}(0) \,|\, i \right\rangle dt$$

R.J. Warburton et al., Nature – 2000
F. Findeis et al., Phys. Rev. B - 2001

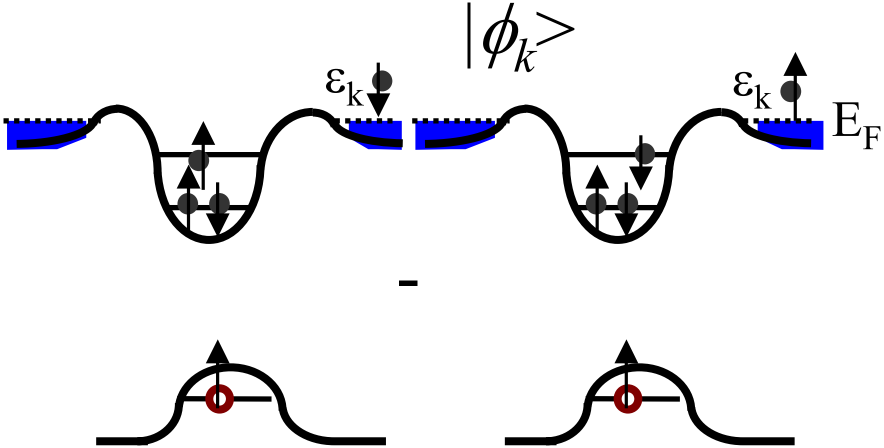


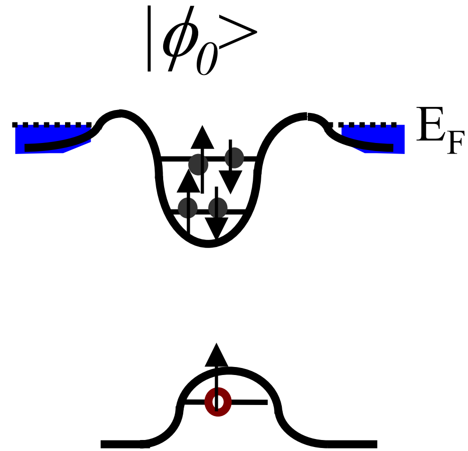


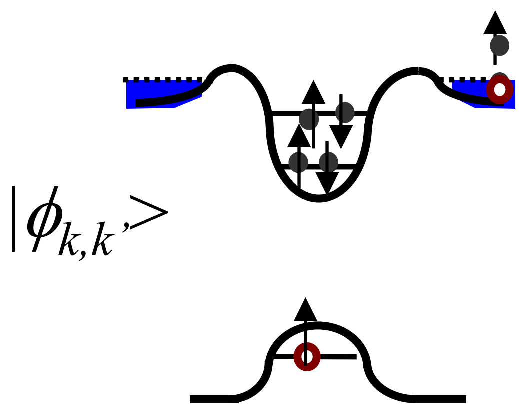
The emission energy depends on $E_F(U_{gate})$

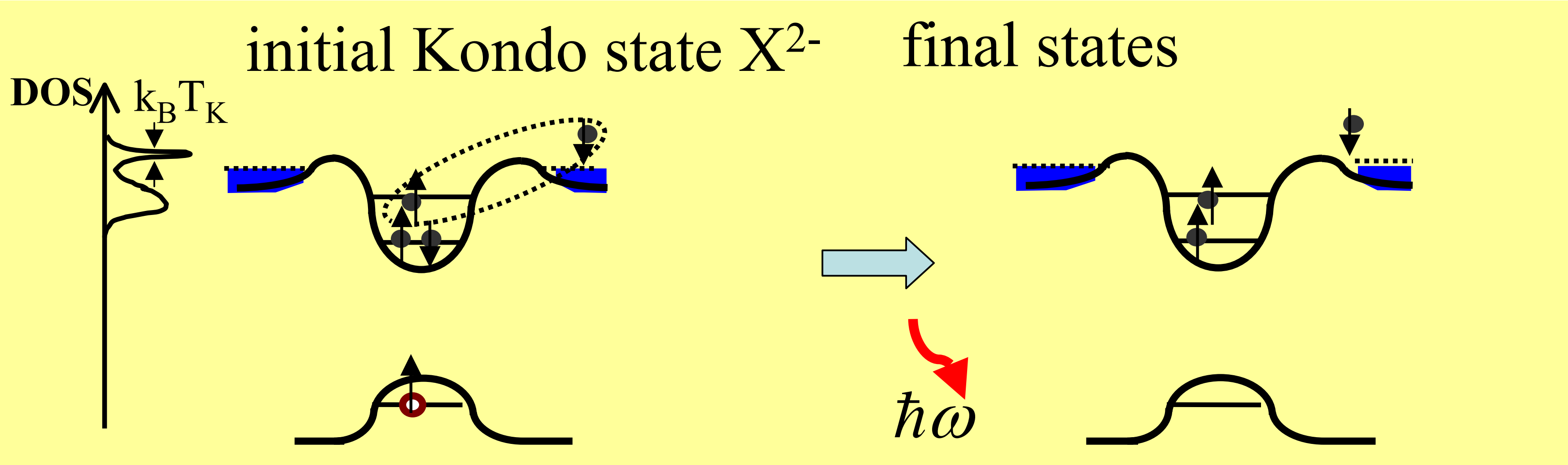
Finite bandwidth model

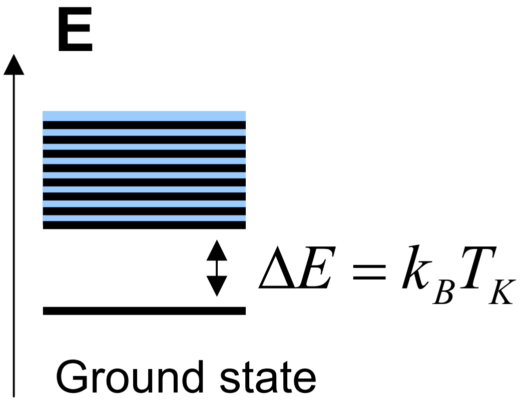
$$\left|\Psi_{initial}\right\rangle = A_0\left|\phi_0\right\rangle + \sum_{k>k_F} A_k\left|\phi_k\right\rangle + \sum_{\substack{k>k_F \\ k'<k_F}} A_{k,k'}\left|\phi_{k,k'}\right\rangle$$



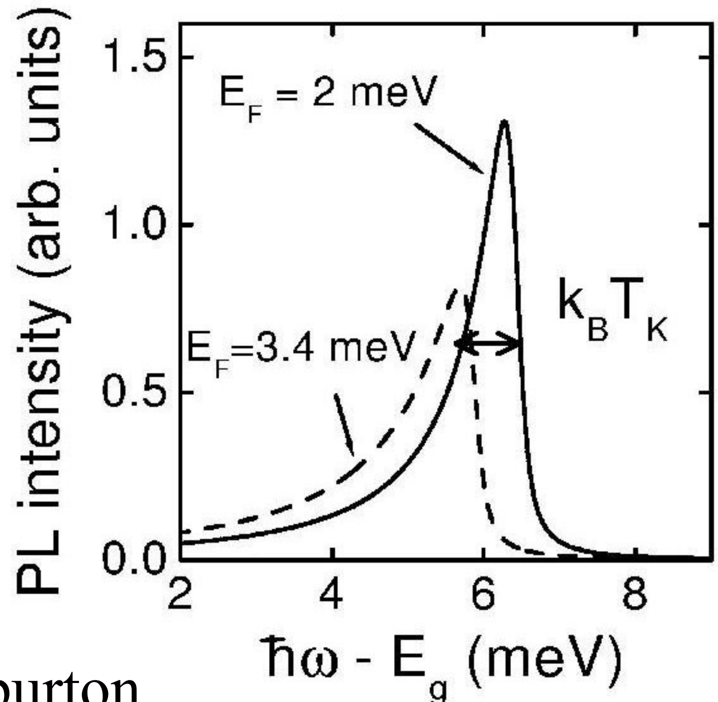






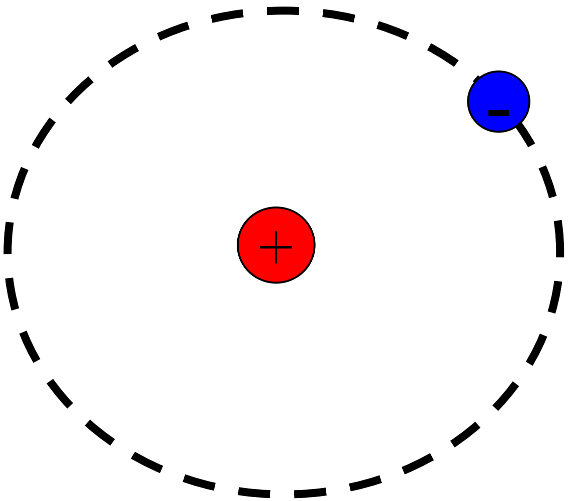


$T_K \approx 5\ K$



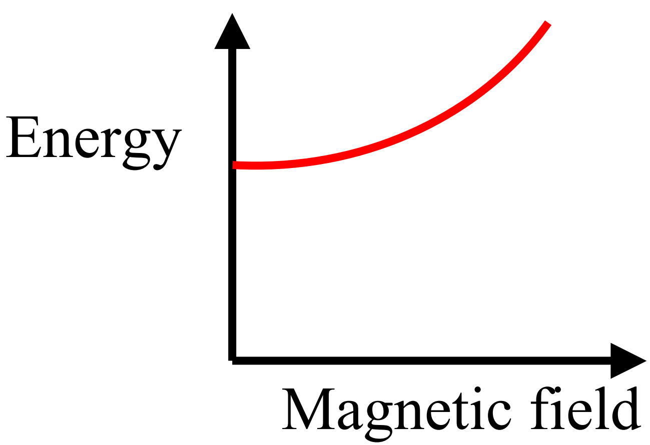
A.O. Govorov, K. Karrai, and R. Warburton, PRB RC- 2003

Magnetic field effects



Excitons in 3D

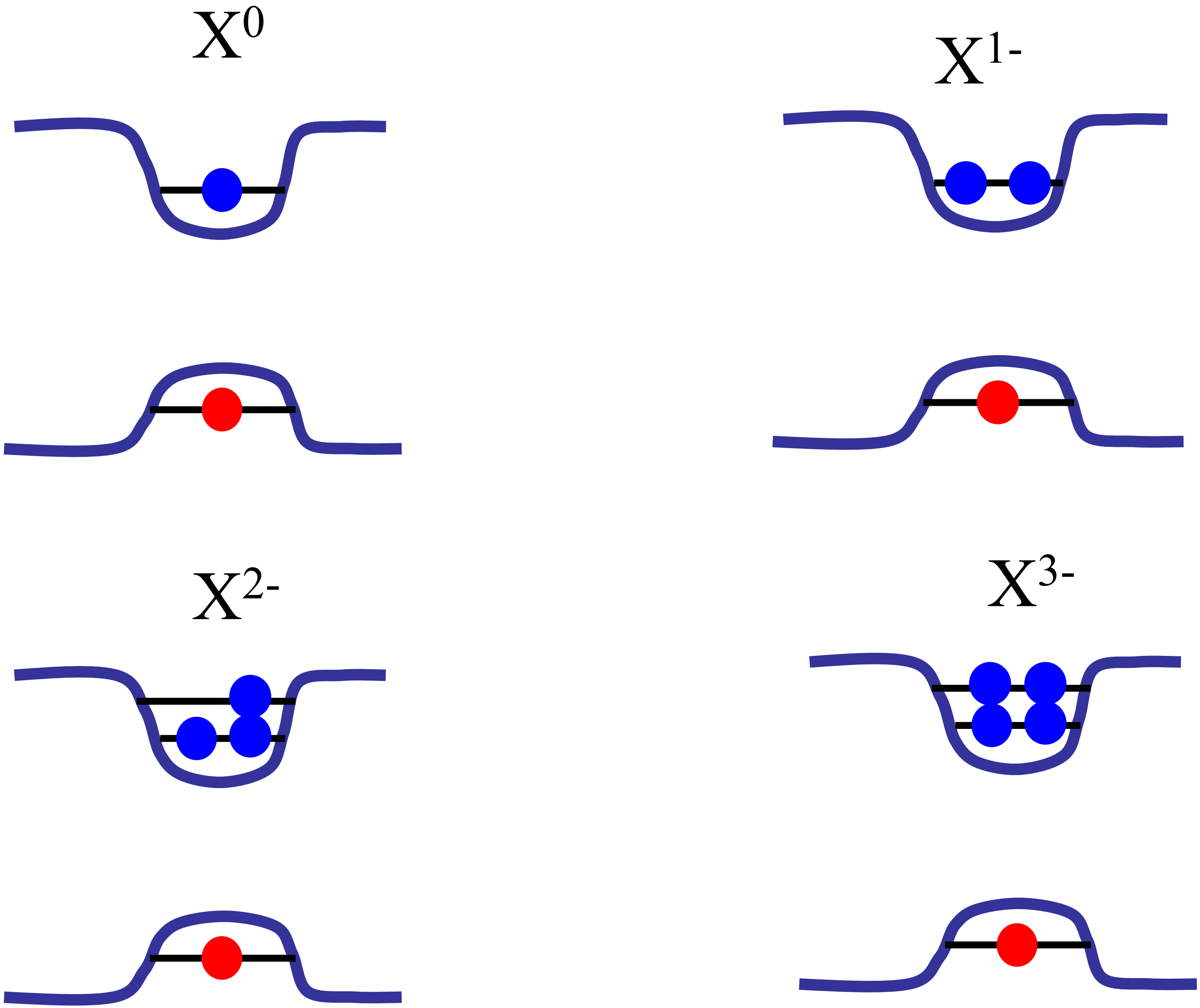
$$a_0^* \approx 100\ \mathring{A} >> a_0$$



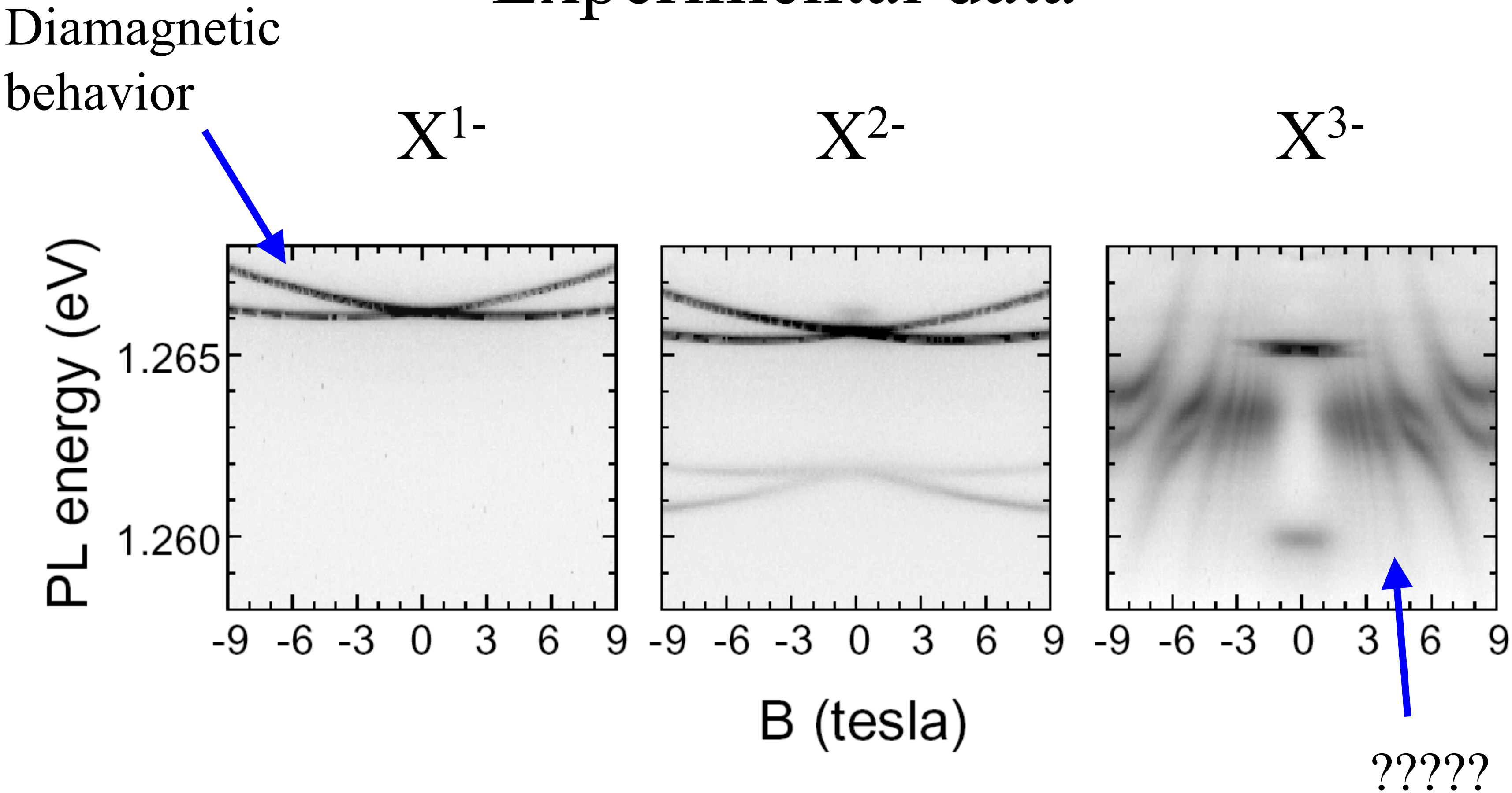
$$E_{exc} = E_{exc}(0) + \alpha B^2$$

$$\alpha \propto (a_0^*)^2$$

Neutral and charged excitons in quantum dots

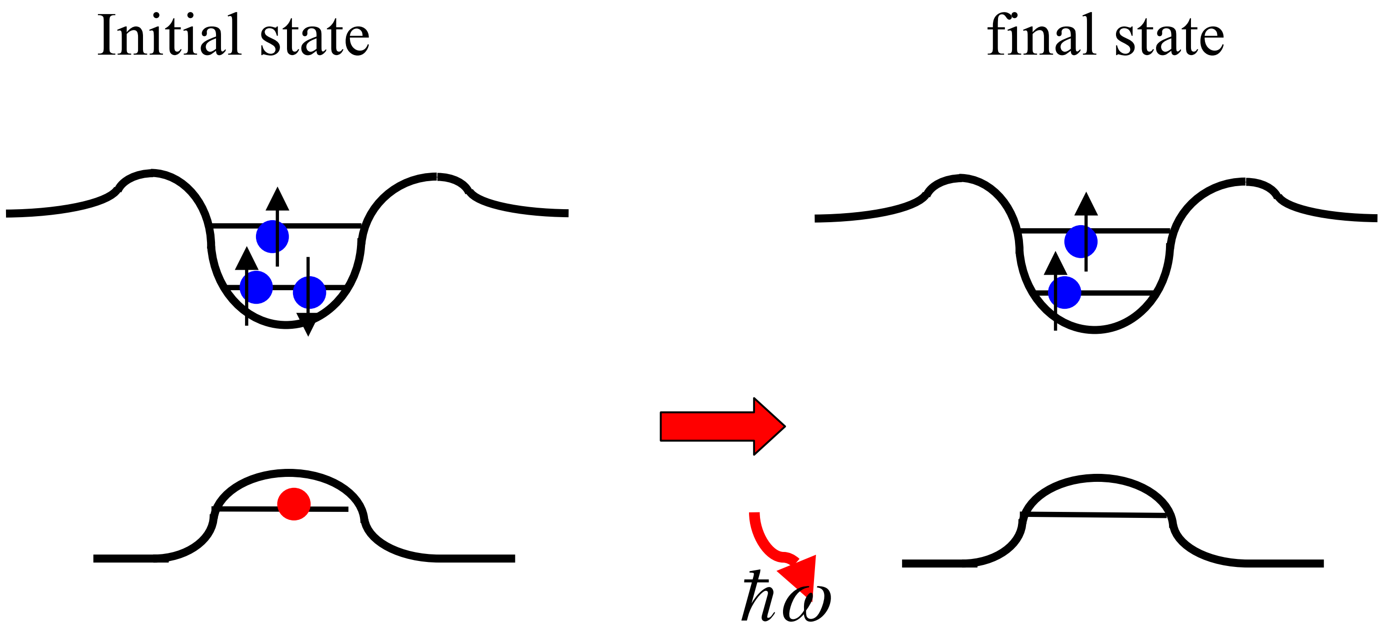


Experimental data



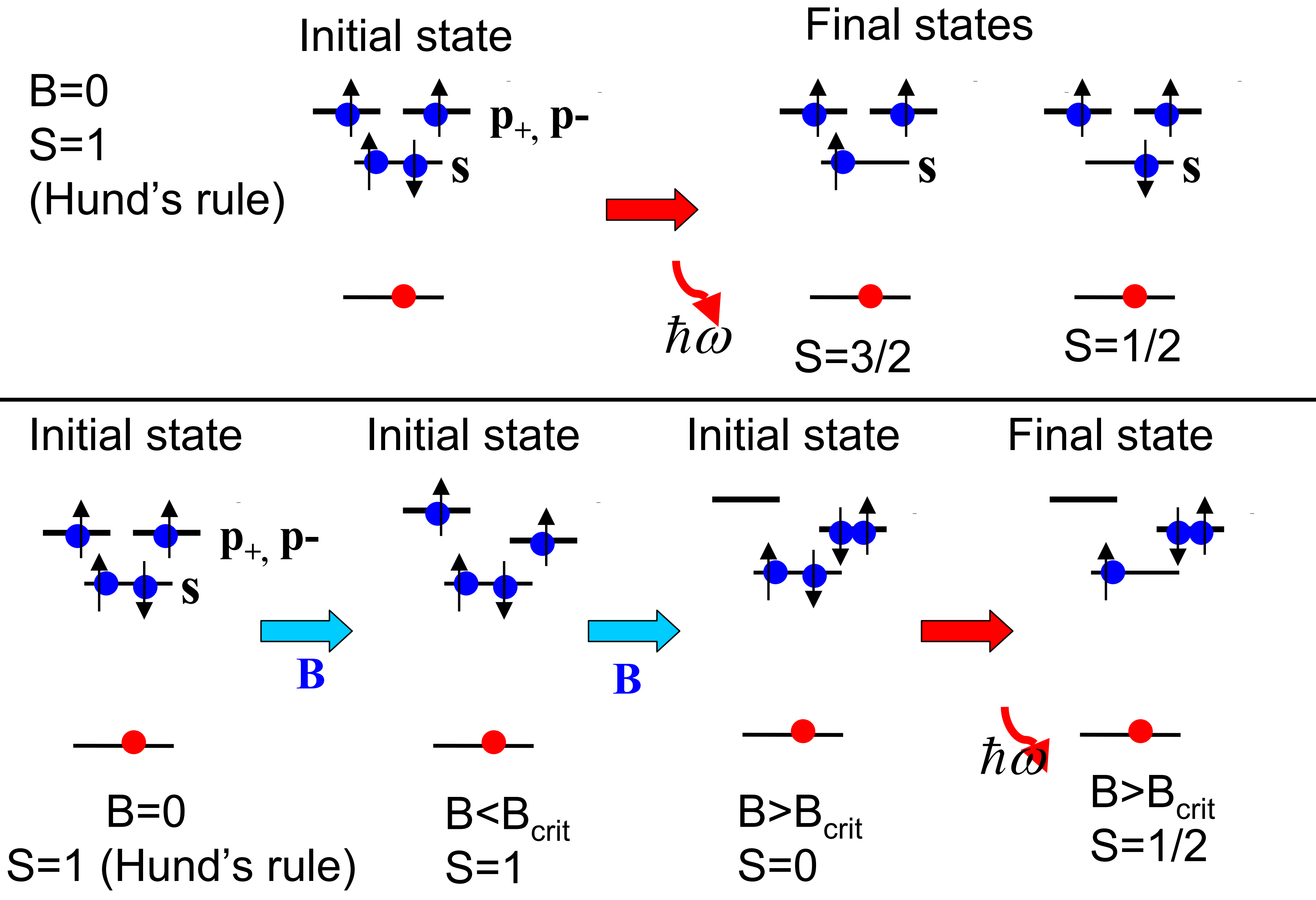
R.J. Warburton, B. Urbaszek, E.J. McGhee, C. Schulhauser, A. Högele, K. Karrai, A.O.Govorov, J.M. Garcia, B.D.Gerardot, and P.M. Petroff, *Nature*, 2004.

X^{2-} - exciton

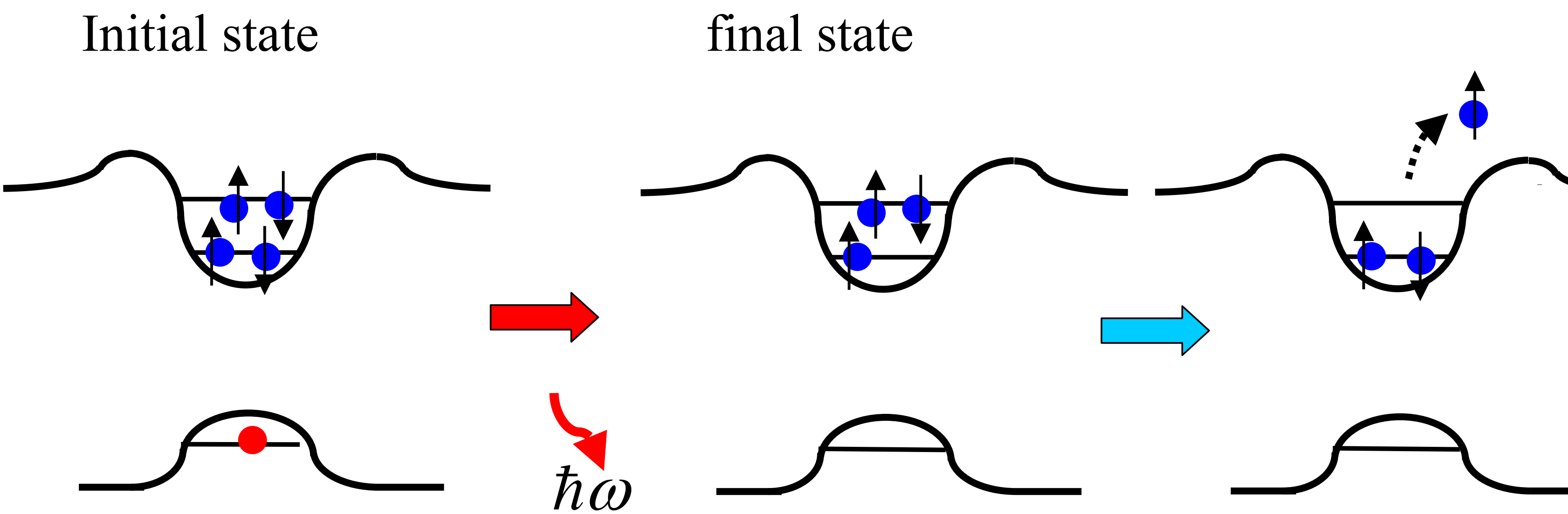


The final state is stable:
Spin blockade

X^{3-} - exciton in a symmetric dot



Exciton X^{3-}

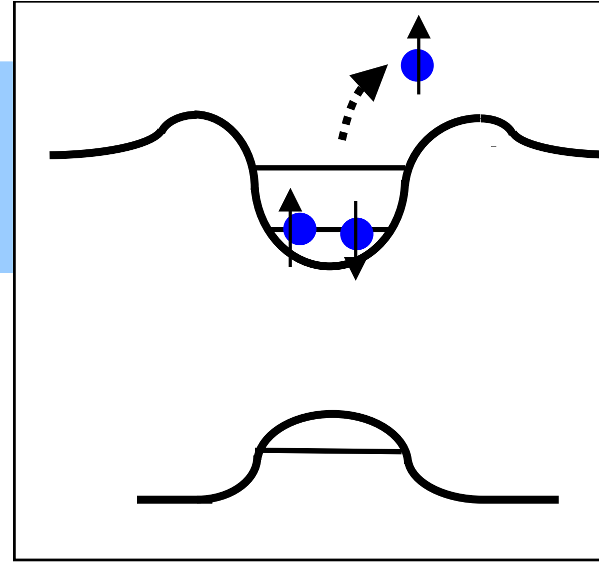


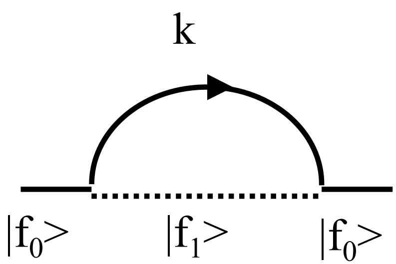
The final state is not stable
Intra-band Auger-like process

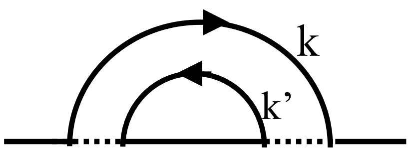
Coulomb coupling with the d-shell:

A. Wojs and P. Hawrylak, Phys. Rev. B – 1997.

$$\hat{H} = \hat{H}^{\text{intra-dot}} + \hat{H}_{\text{hybridization}}$$



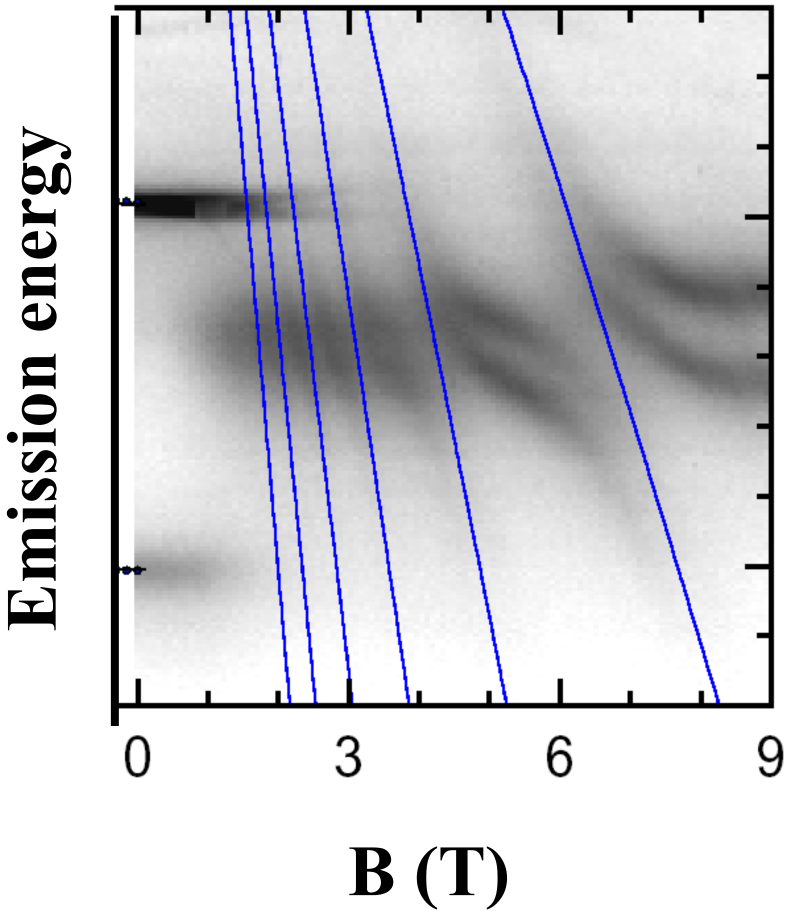


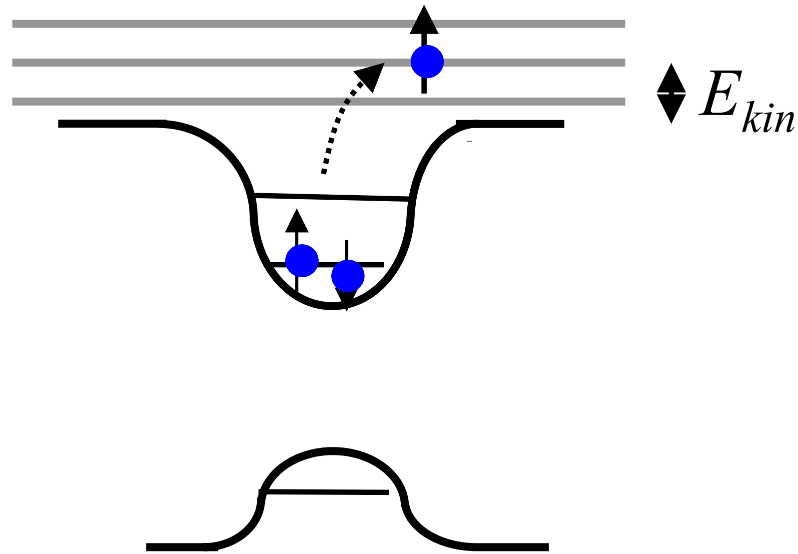


$$I_{PL}(\omega) \propto \mathrm{Re}\left[\frac{-i}{\tilde{\omega} - \Sigma_a - i0}\right]$$

$$\Sigma_a = \int_0^\infty \frac{W_\varepsilon^2 (1 - f_\varepsilon)\rho(\varepsilon) d\varepsilon}{\tilde{\omega} - \delta E_a + \varepsilon - \int_0^\infty \frac{W_\varepsilon^2 f_{\varepsilon'} \rho(\varepsilon') d\varepsilon'}{\tilde{\omega} - \delta E_a + \varepsilon - \varepsilon'}}$$

A. Govorov, R.J. Warburton, and K. Karrai, Physica E, 2004

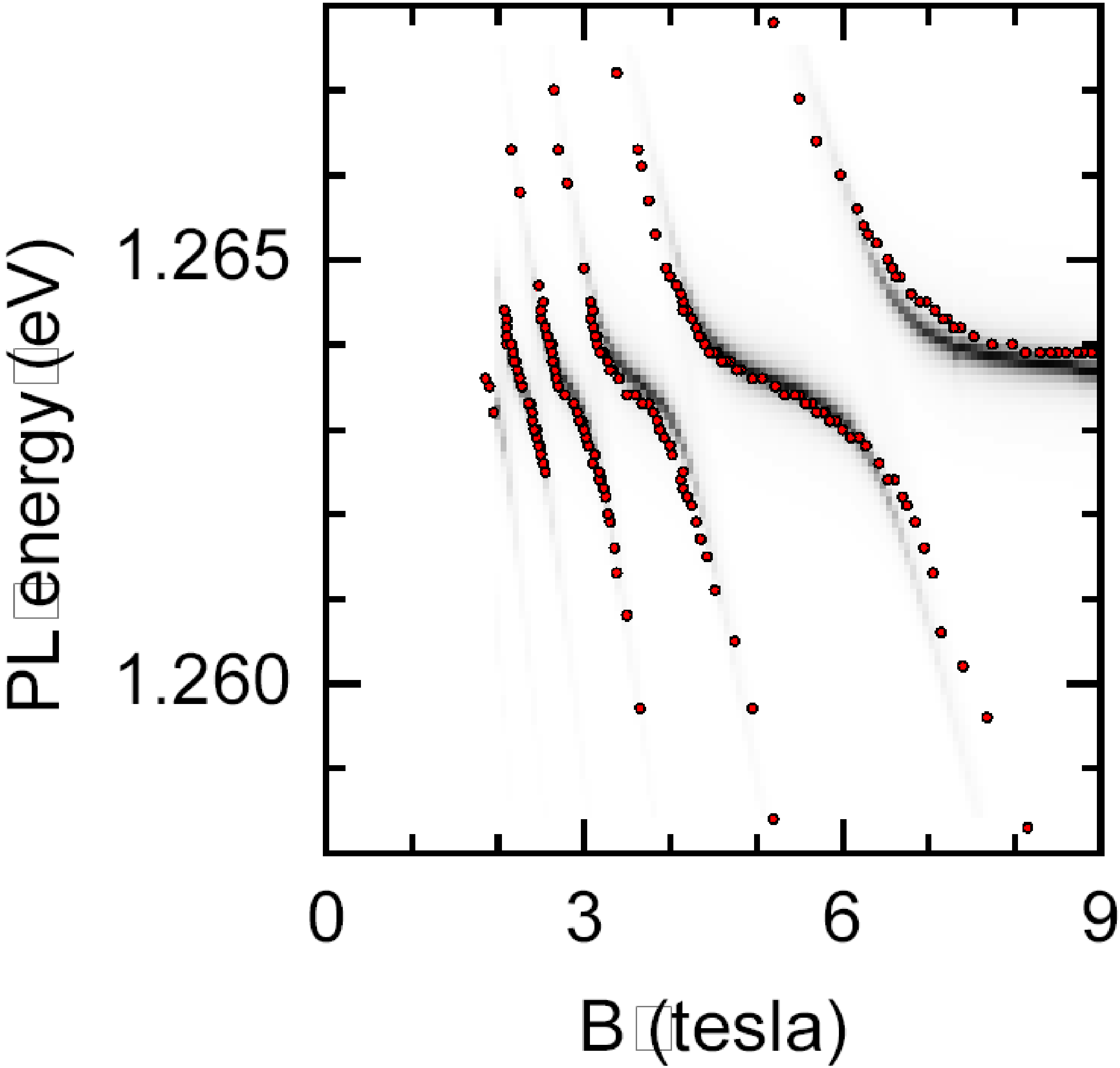




Anticrossing condition:

Excess kinetic energy

$$E_{kin} = E_0 - E_1 = \hbar\omega_c\left(n + \frac{1}{2}\right)$$



Dots - experiment

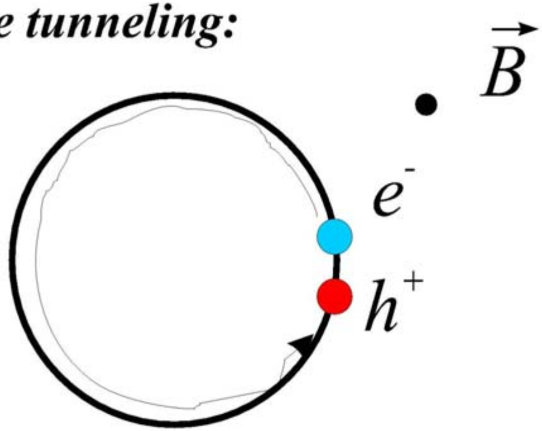
Grey scale - theory

Exciton in ring-like dots

1D ring

Electron-to-hole tunneling:

$$\sum_i q_i = 0$$



$$\Phi = \pi R^2 B > \Phi_0/2$$

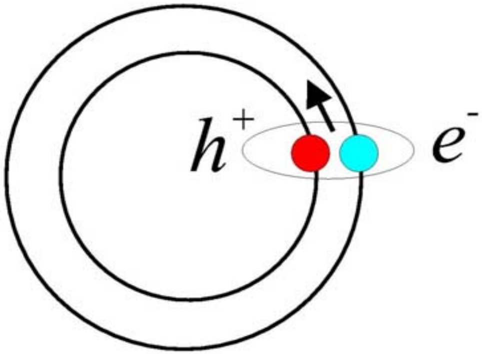
$$\Delta E_{exc}(B) = \delta E_{exc}(0) exp[-2\pi^2 V_0/\varepsilon_0] cos[2\pi\Phi/\Phi]$$

A.V. Chaplik, JETP Lett. - 1995

R.A. Römer and M. E. Raikh,
Phys. Rev. B-2000

quasi-1D ring

Polarized exciton: rotating dipole

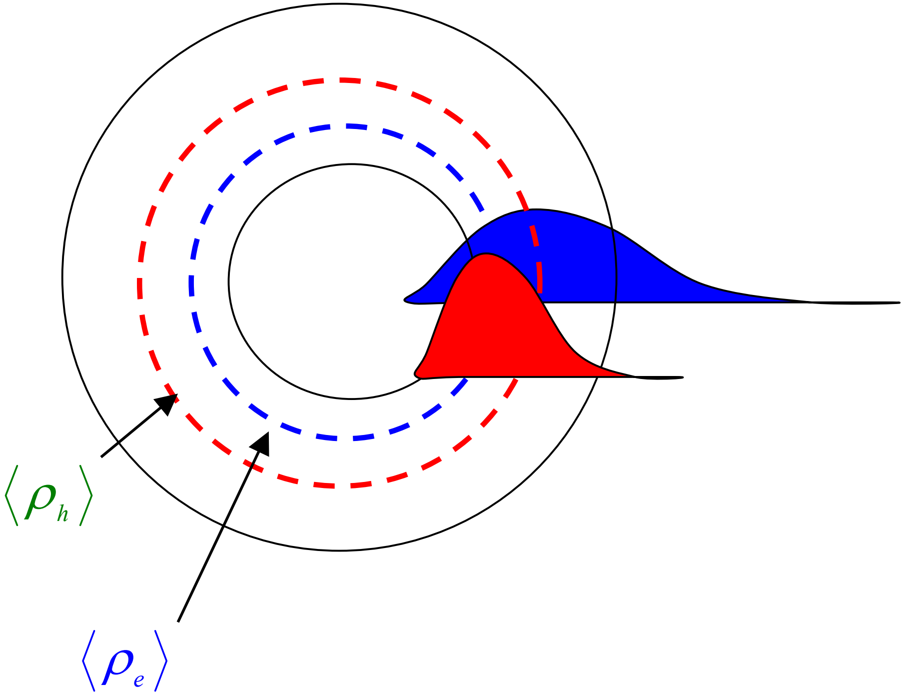


$$\Delta\Phi = 2\pi(R_1^2 - R_2^2)B > \Phi_0/2$$

$$\Delta E_{exc}(B) = f(\Delta\Phi)$$

A.V.Kalameitsev, and V.Kovalev,
and A.O.Govorov,
JETP Lett. - 1998

Models of semiconductor nano-ring

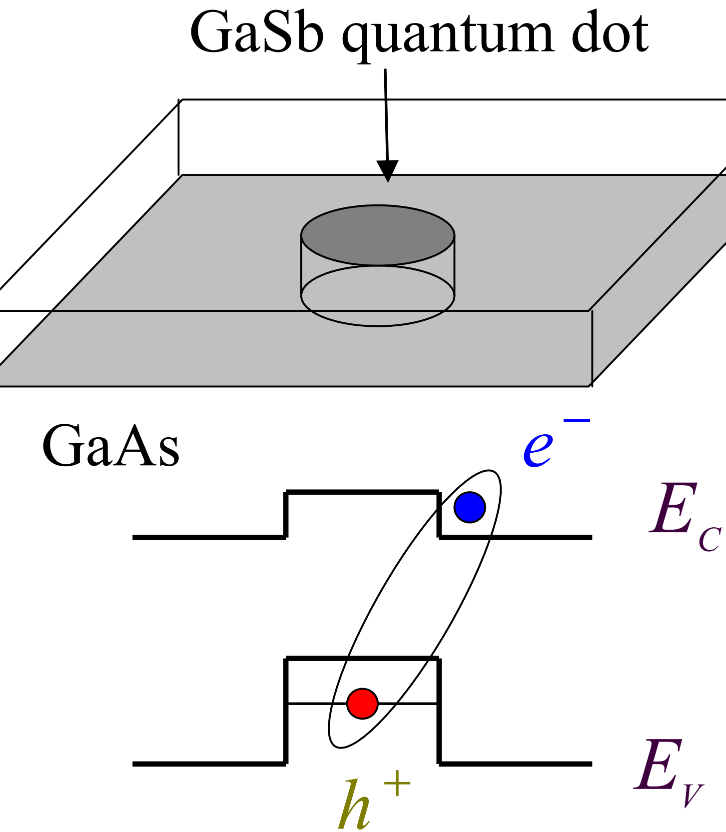


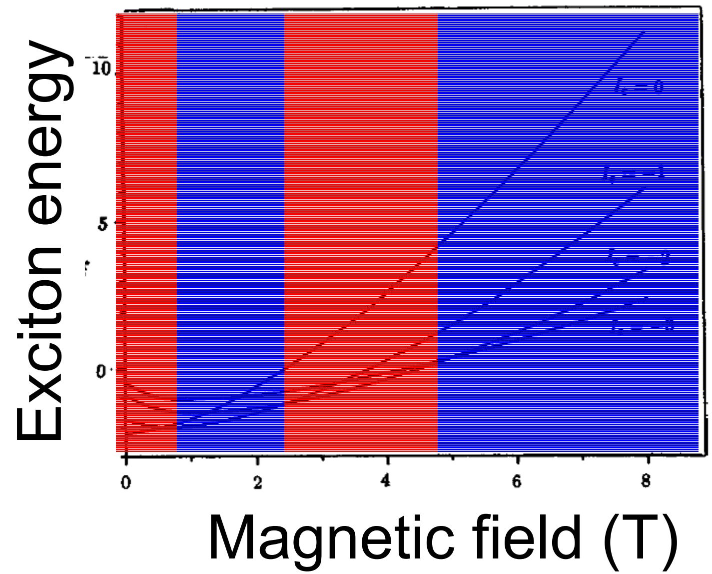
$$U_{e(h)} = \frac{m_{e(h)}\Omega_{e(h)}^{2}}{2}(\rho - R_0)^2$$

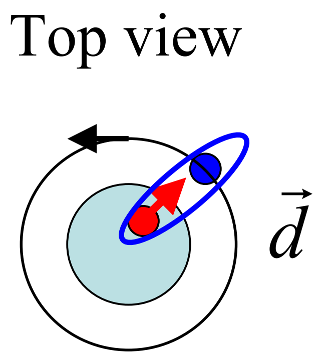
$$m_e\Omega_e \neq m_h\Omega_h$$

A.O. Govorov, S. E. Ulloa, K. Karrai, and R. J. Warburton, PRB RC - 2002.

Type-II quantum dots



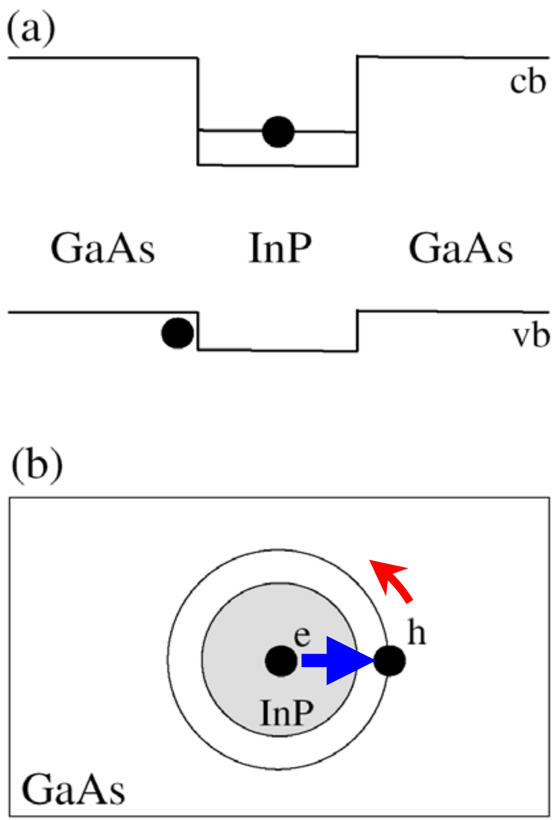


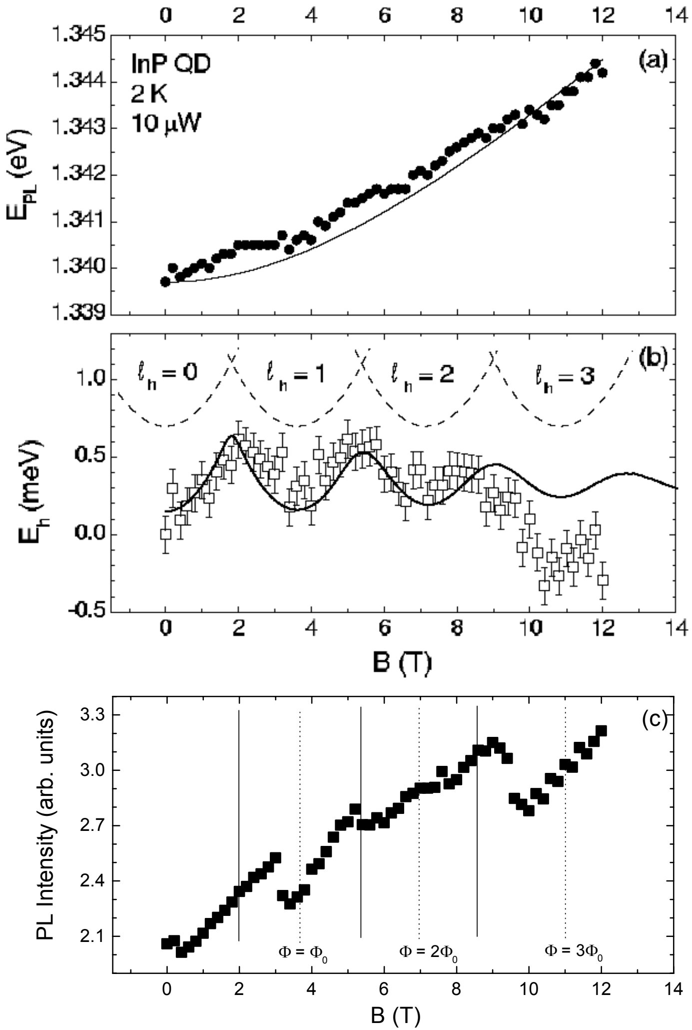


$$\phi = \pi(R_e^2 - R_h^2)B \approx \phi_0$$

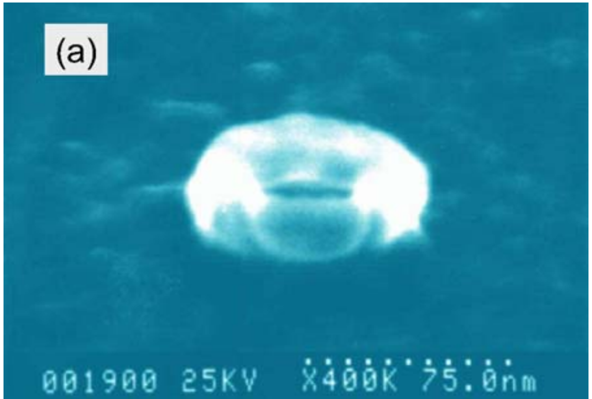
A.V.Kalameitsev, and V.Kovalev, and A.O.Govorov, JETP Lett. - 1998

Experiment with type-II quantum dots

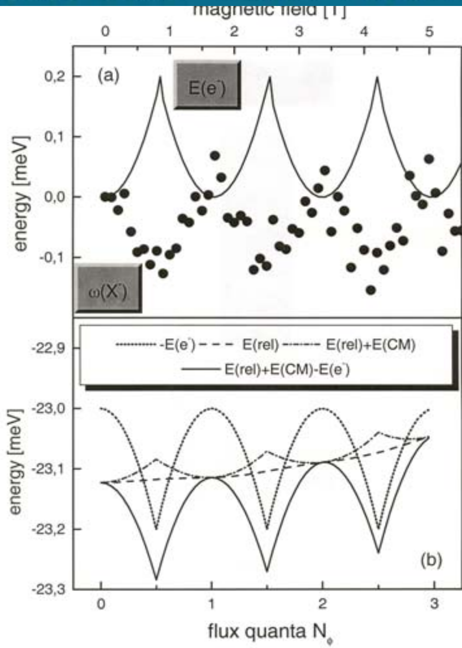


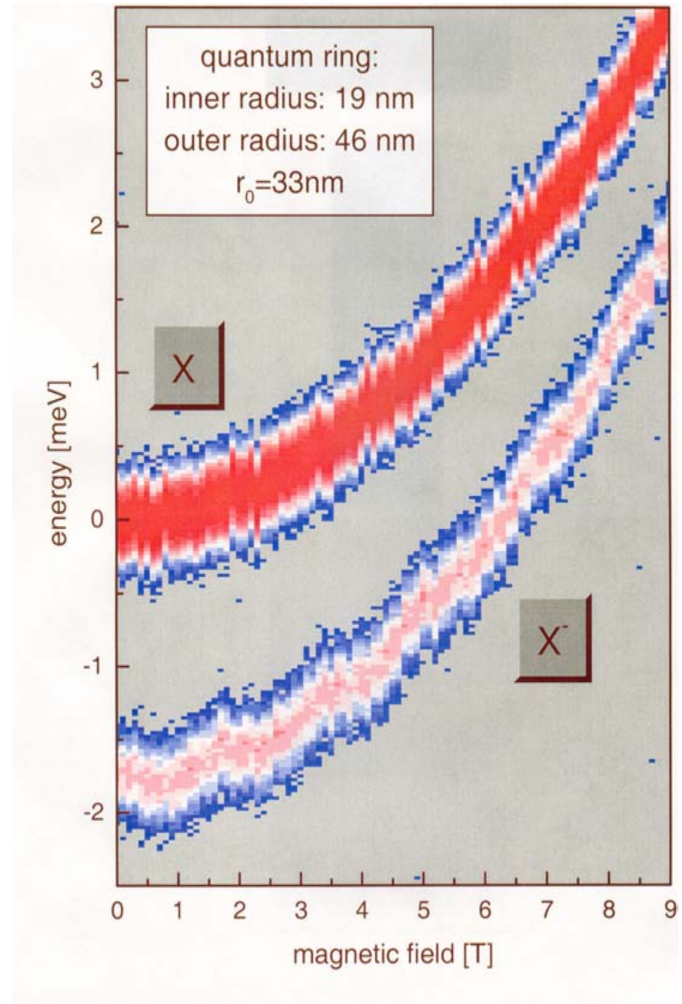


E. Ribeiro, A.O. Govorov, G. Medeiros-Ribeiro, and W. Carvalho Jr
Phys. Rev. Lett. (2004) .



X^{1-}



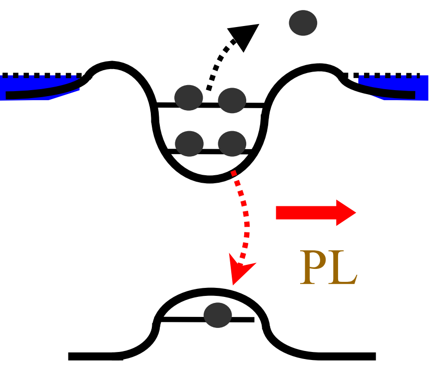


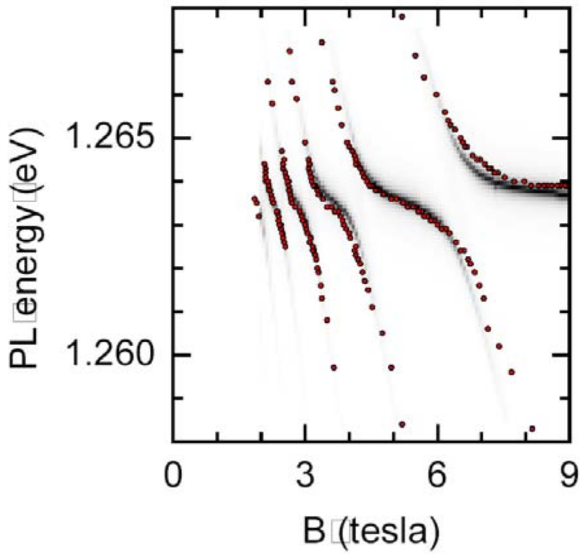
M. Bayer, M. Korkusinski, P. Hawrylak, T. Gutbrod, M. Michel, and A. Forchel , Phys. Rev. Lett. - 2003

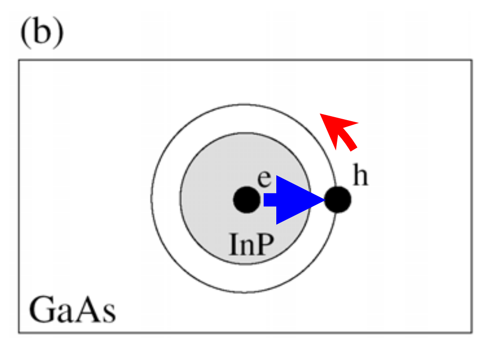
Conclusions

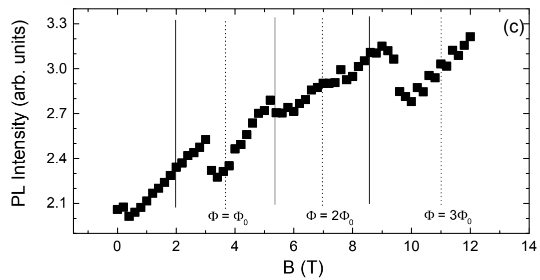
Quantum dots as an open system
Hybridization with extended states

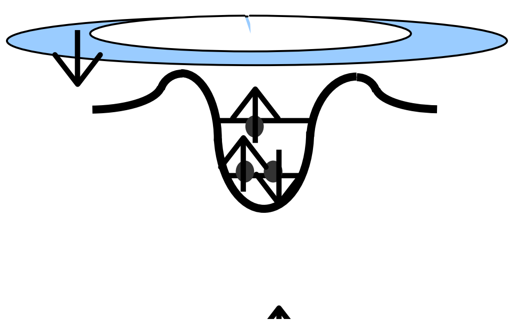
a neutral exciton “traps” magnetic flux quanta











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E. Ribeiro

Alexander Kalameitsev