

1. Open Dot Experiments

2. Kondo effect

3. Few Electron Dots

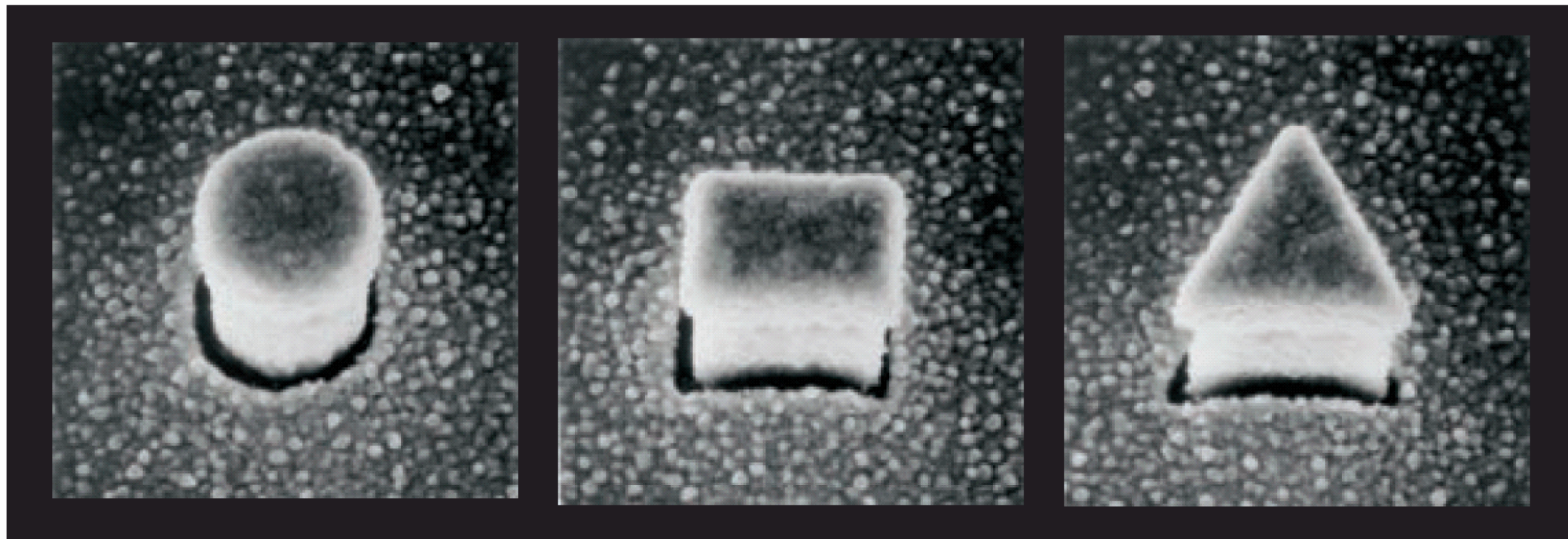
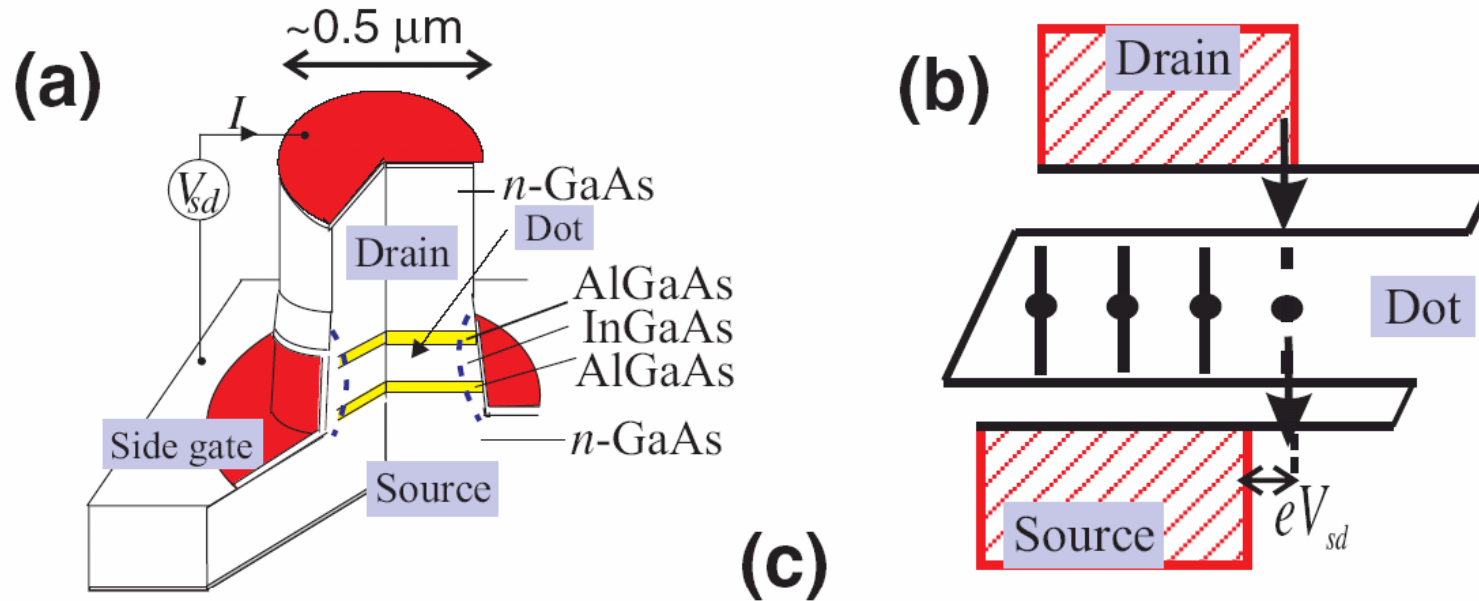
4. Double Quantum Dots

Kouwenhoven, Austing and Tarucha, RPP 64, 701 (2002)

Tarucha et al., PRL77, 3613 (1996)

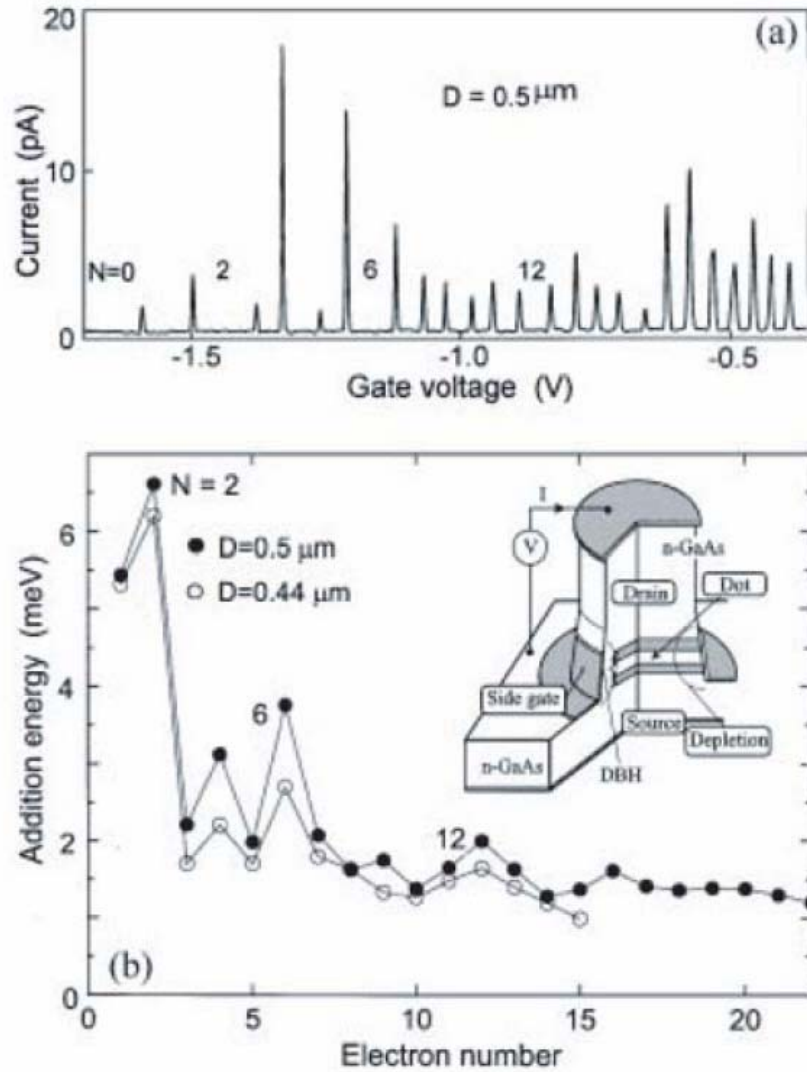
Kouwenhoven et al., Science 278, 1788 (1997)

Few Electron Quantum Dots: Vertical



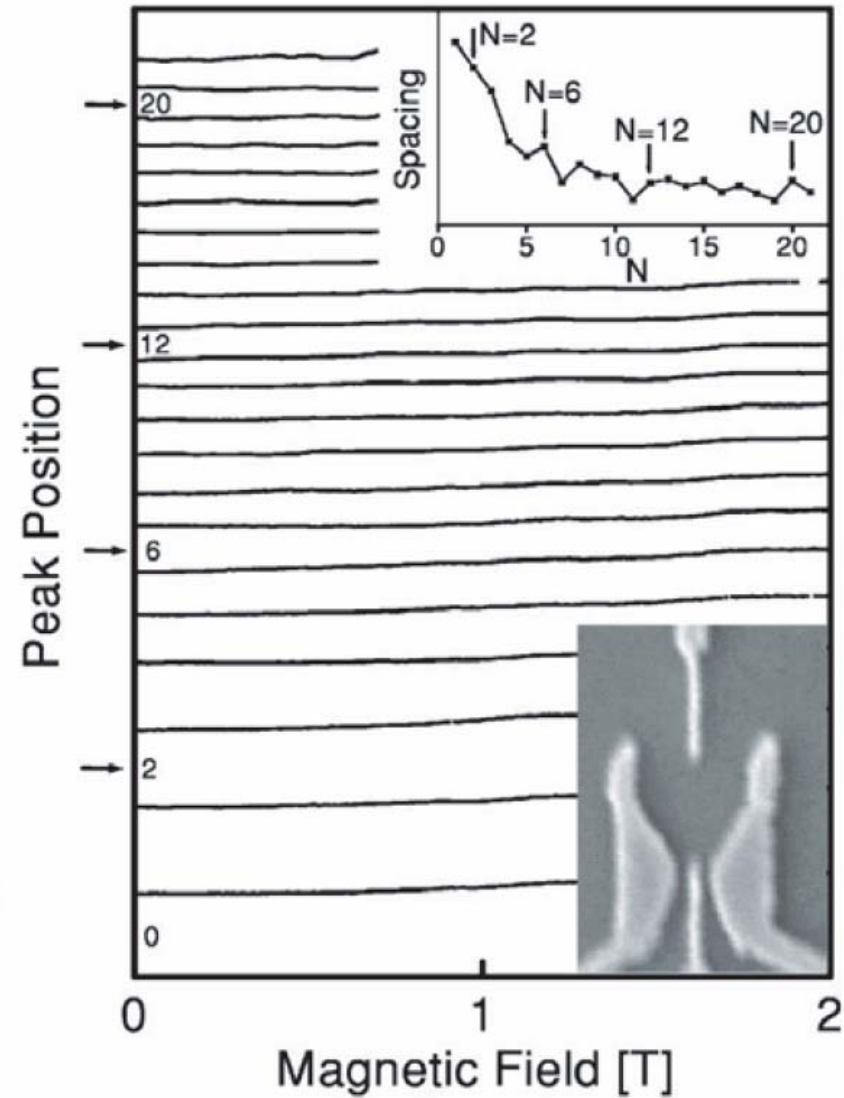
Rotation Symmetry and Angular Momentum

circular symmetry: 2D shell filling



Tarucha et al., PRL77, 3613 (1996)

circular symmetry broken



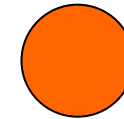
Ciorga et al., PRB61, R16315 (2000)

Quantum Harmonic Oscillator

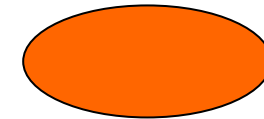
harmonic oscillator Hamiltonian

$$H = \frac{p_x^2}{2m^*} + \frac{1}{2}m^*\omega^2 x^2 + \frac{p_y^2}{2m^*} + \frac{1}{2}m^*\omega^2 y^2$$

isotropic, circular symmetry: $\omega_x = \omega_y$



anisotropic, no rotation symmetry: $\omega_x \neq \omega_y$



energy levels:

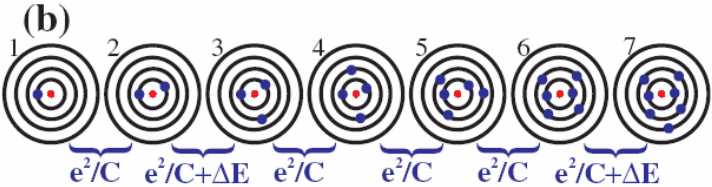
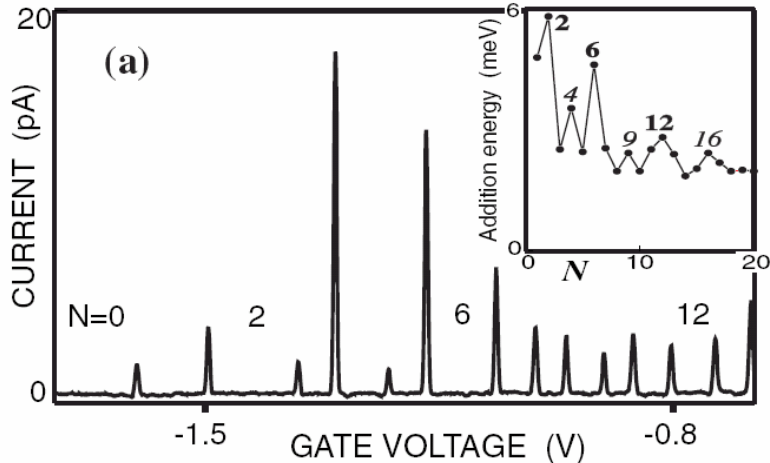
$$E_{p,q} = \left(p + \frac{1}{2}\right) \hbar\omega_x + \left(q + \frac{1}{2}\right) \hbar\omega_y$$

in magnetic field

$$\epsilon_{jk} = j \frac{\hbar}{2} \sqrt{\omega_c^2 + (\omega_a + \omega_b)^2} + k \frac{\hbar}{2} \sqrt{\omega_c^2 + (\omega_a - \omega_b)^2}$$

$$j \in \{1, 2, \dots\} \text{ and } k \in \{j - 1, j - 3, \dots, -j + 1\}$$

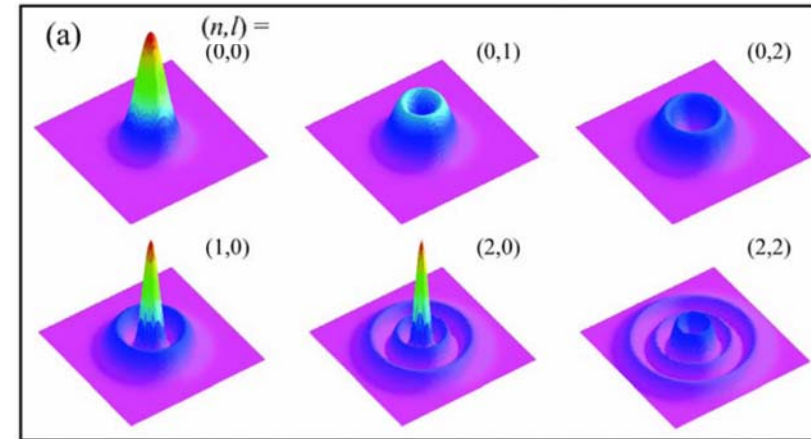
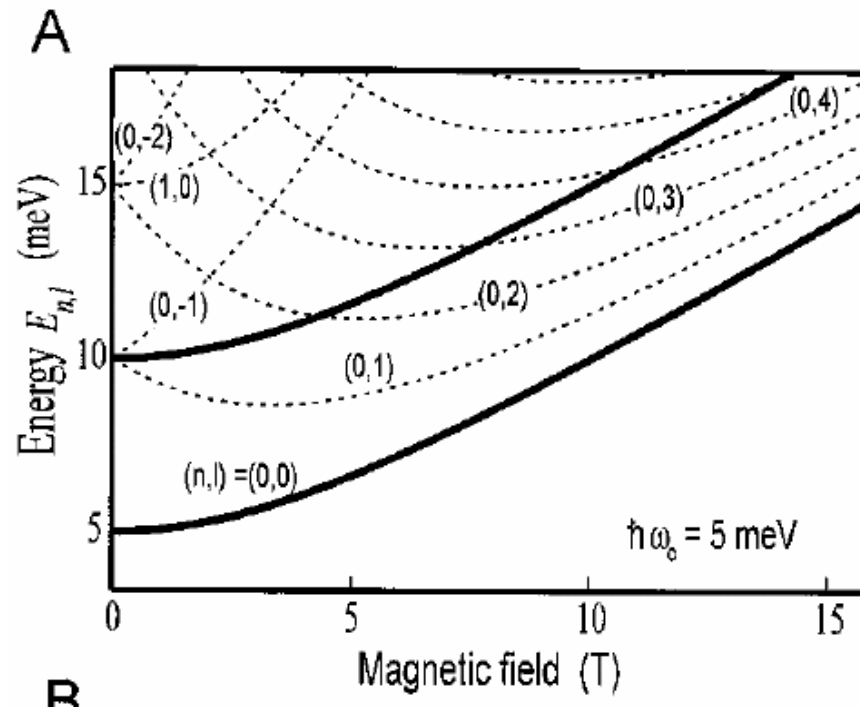
2D Periodic Table of Elements



(c) **Periodic Table of 2D Artificial Atoms**

1 Ta						2 Ha
3 Et	4 Au				5 Ko	6 Oo
7 Sa	8 To	9 Ho			10 Mi	11 Cr
13	14	15	16 Wi	17 Fr	18 El	19
						20 Da

Fock-Darwin States: Single Particle Levels



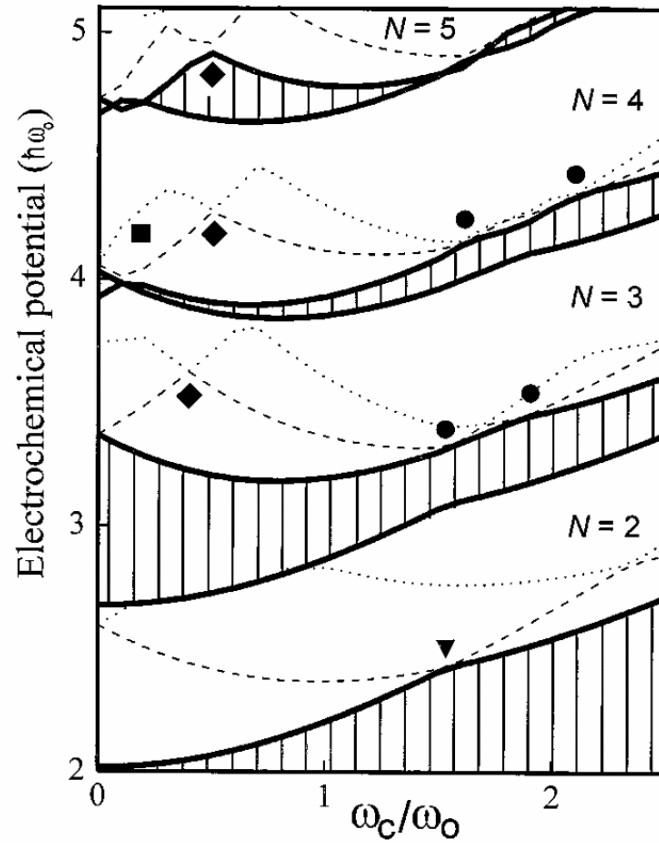
Fock-Darwin Energies

$$E_{n,\ell} = (2n + |\ell| + 1)\hbar \sqrt{\left(\frac{1}{4}\omega_c^2 + \omega_0^2\right)} - \frac{1}{2}\ell\hbar\omega_c$$

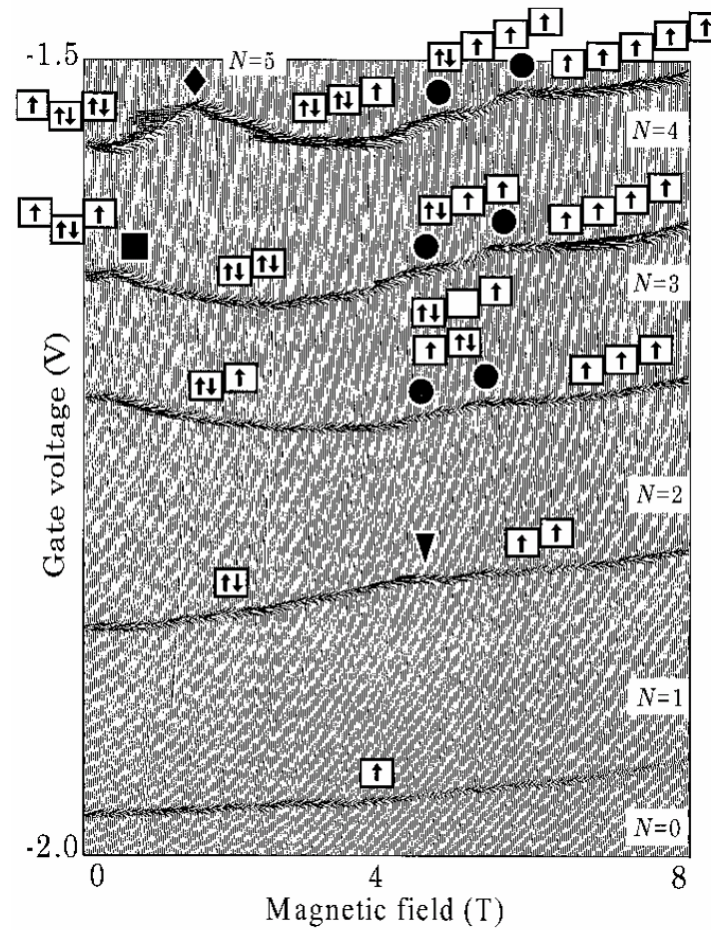
$n = 0, 1, 2, \dots$ radial

$l = 0, \pm 1, \pm 2, \dots$ angular momentum

Magnetic Field Transitions



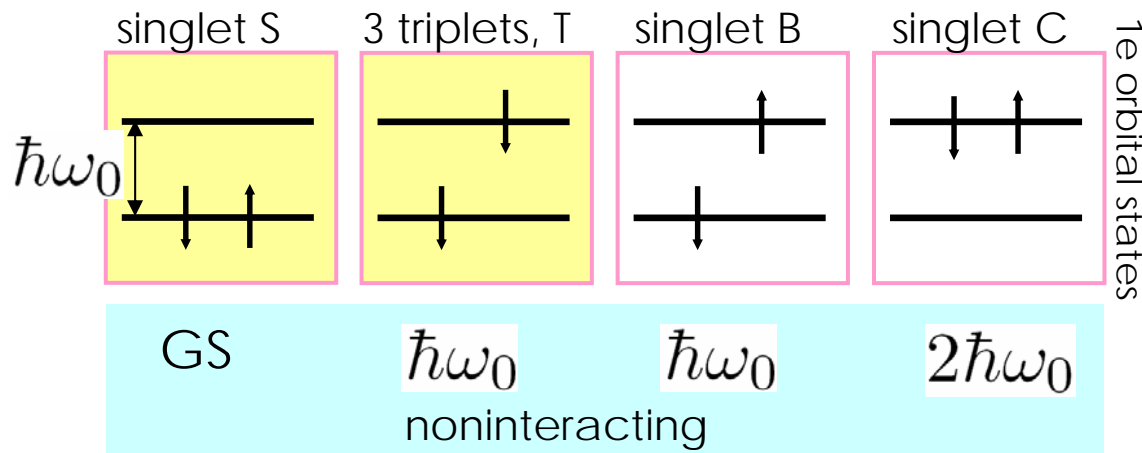
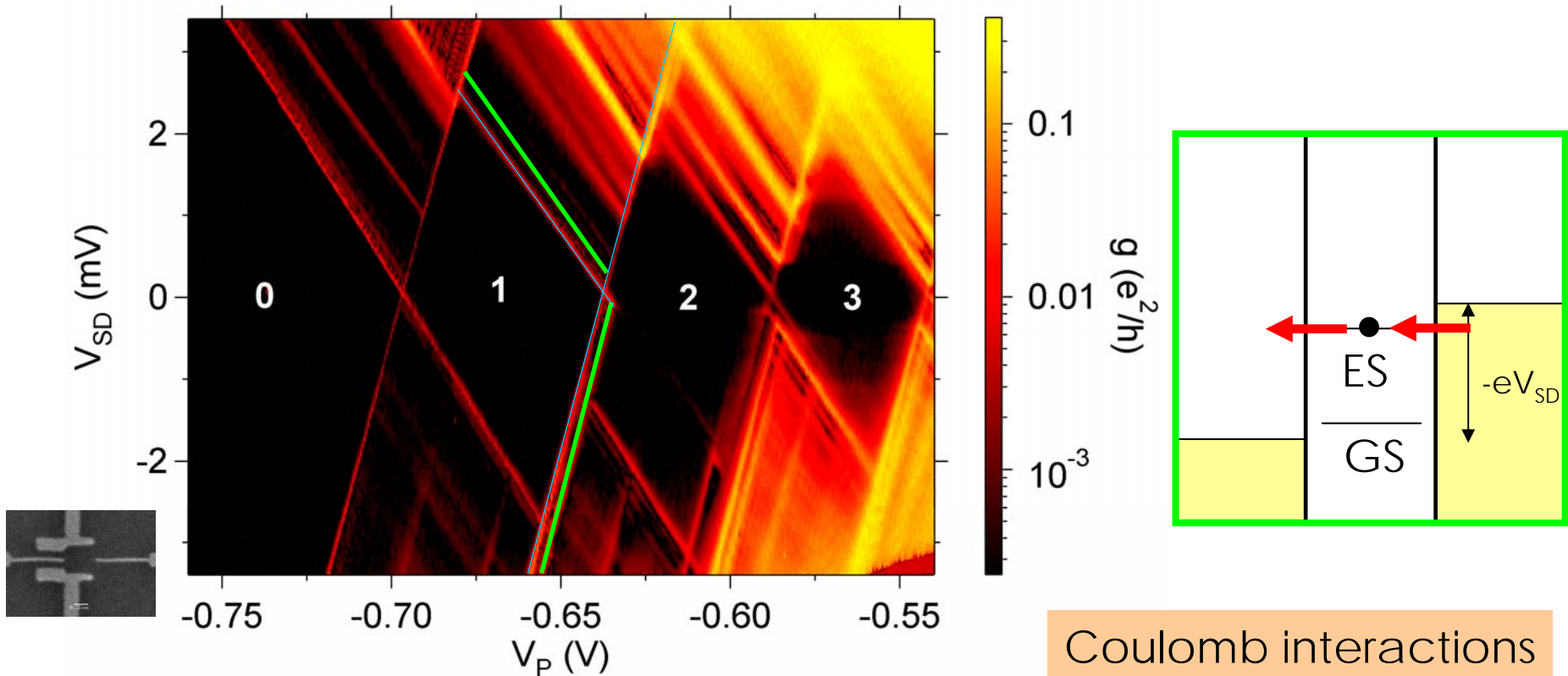
exact calculation



experiment

“atomic physics” like experiments not accessible in real atoms!!

Two Electron States



Coulomb interactions

$$E_{\text{singlet B, C}} \gg E_{\text{S, T}}$$

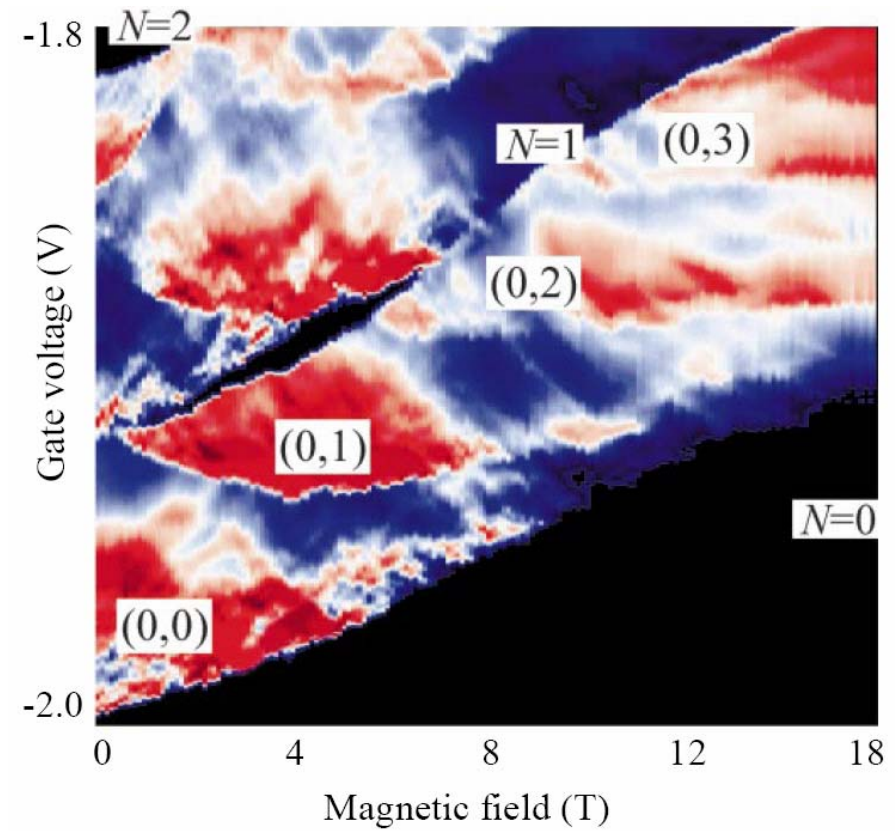
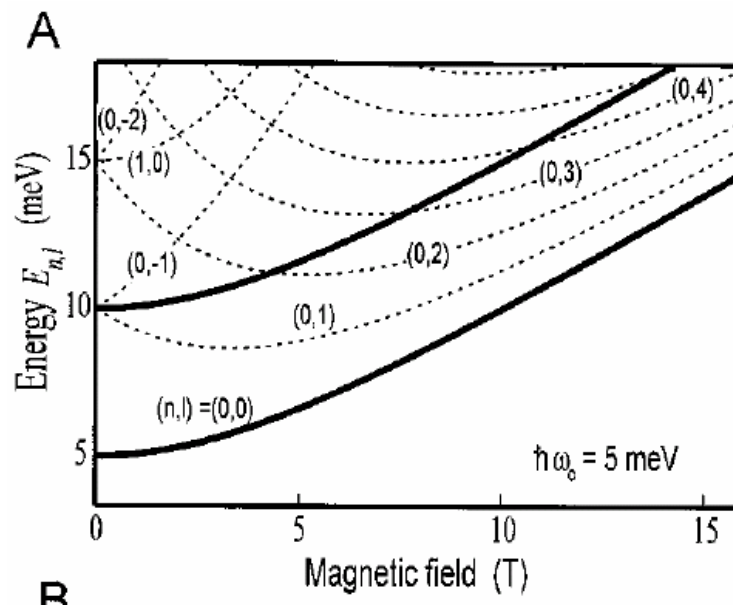
$$J = E_{\text{T}} - E_{\text{S}} \sim 0.15 \text{ meV}$$

note:

$$J \ll \hbar\omega_0 = 1 \text{ meV}$$

$$E_{\text{T}} > E_{\text{S}} \text{ for } N=2, B=0$$

Zero to One Electron Transition



Higher Transitions

