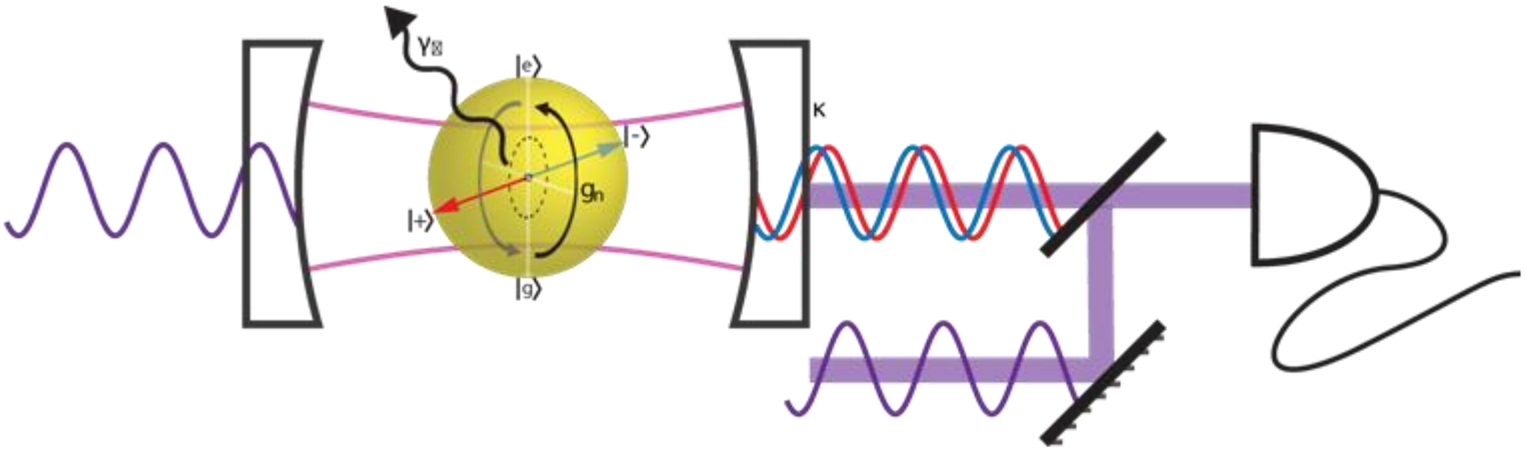
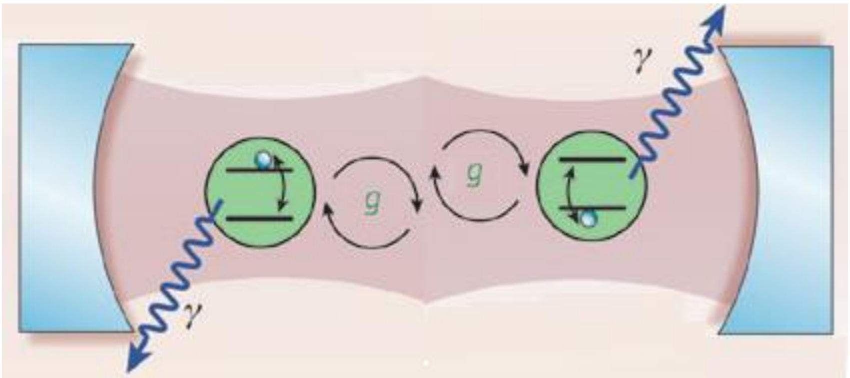
Other Results

QUANTUM DOTS AND OPTICAL CAVITIES

PHOTONS, COUPLED QUANTUM DOTS AND QUBITS

TWO EXCITONS IN QD WITH COHERENT FIELD





From the following article:
Wiring up quantum systems
R. J. Schoelkopf & S. M. Girvin
Nature 451, 664-669(7 February 2008)
doi:10.1038/451664a

EXITONIC MODEL

$$\hat{H} = \frac{1}{2}\hbar\omega[\hat{\sigma}_+, \hat{\sigma}\_] + \hbar\omega\hat{a}^+\hat{a} + i\hbar\lambda(\hat{\sigma}\_\hat{a}^+ - \hat{\sigma}_+\hat{a})$$

$$\hat{\sigma}_+ = |e\rangle\langle g| \qquad \hat{\sigma}\_ = |g\rangle\langle e|$$

MASTER EQUATION

$$\frac{d\rho}{dt} = -i[H,\rho] + L_{qd}^{A} + L_{qd}^{B} + L_{c}$$

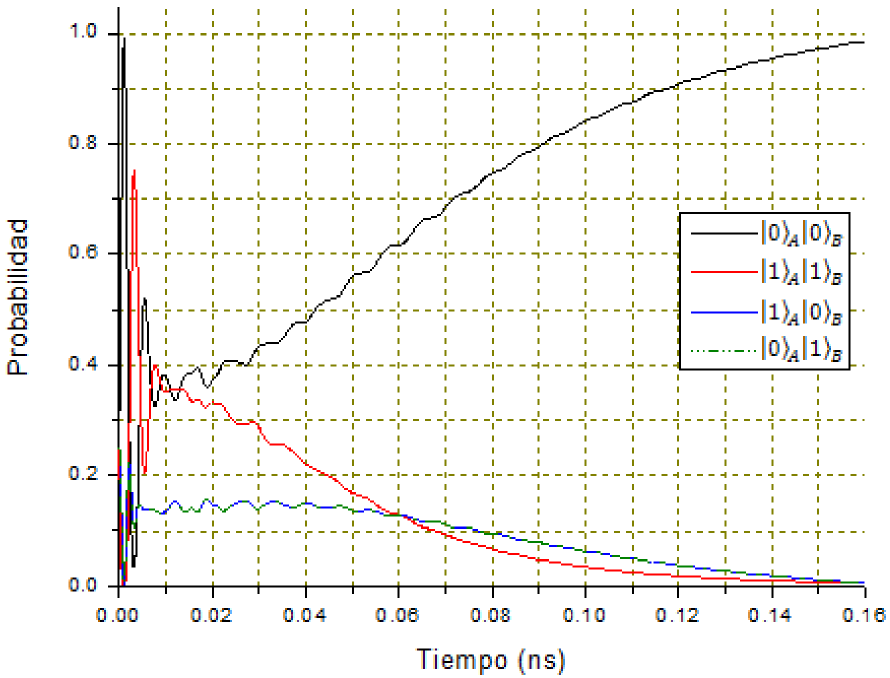
$$L_{qd}^{A} = \frac{g_{A}}{2}\left(2\sigma_{0}^{A}\rho\sigma_{1}^{A} - \sigma_{1}^{A}\sigma_{0}^{A}\rho - \rho\sigma_{1}^{A}\sigma_{0}^{A}\right)$$

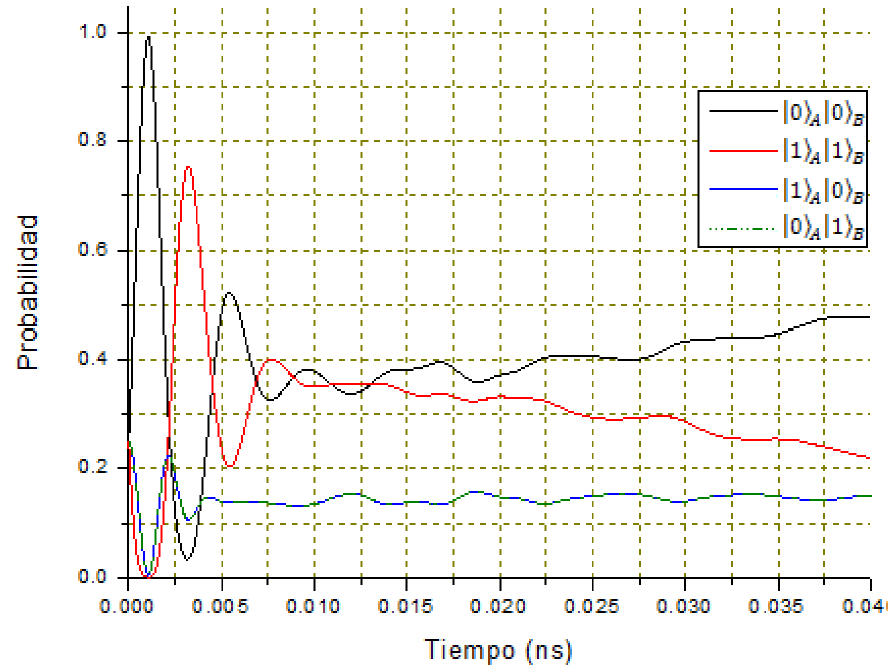
$$L_{qd}^{B} = \frac{g_{B}}{2}\left(2\sigma_{0}^{B}\rho\sigma_{1}^{B} - \sigma_{1}^{B}\sigma_{0}^{B}\rho - \rho\sigma_{1}^{B}\sigma_{0}^{B}\right)$$

$$L_{c} = g_{c}\left(2a\rho a^{+} - a^{+}a\rho - \rho a^{+}a\right)$$

$$H = \frac{\omega_{qd}^{A}}{2}\left[\sigma_{+}^{A},\sigma_{-}^{A}\right] + \frac{\omega_{qd}^{B}}{2}\left[\sigma_{+}^{B},\sigma_{-}^{B}\right]$$
$$+\omega_{c}a^{+}a + i\lambda^{A}\left(a^{+}\sigma_{-}^{A} - a\sigma_{+}^{A}\right) + i\lambda^{B}\left(a^{+}\sigma_{-}^{B} - a\sigma_{+}^{B}\right)$$

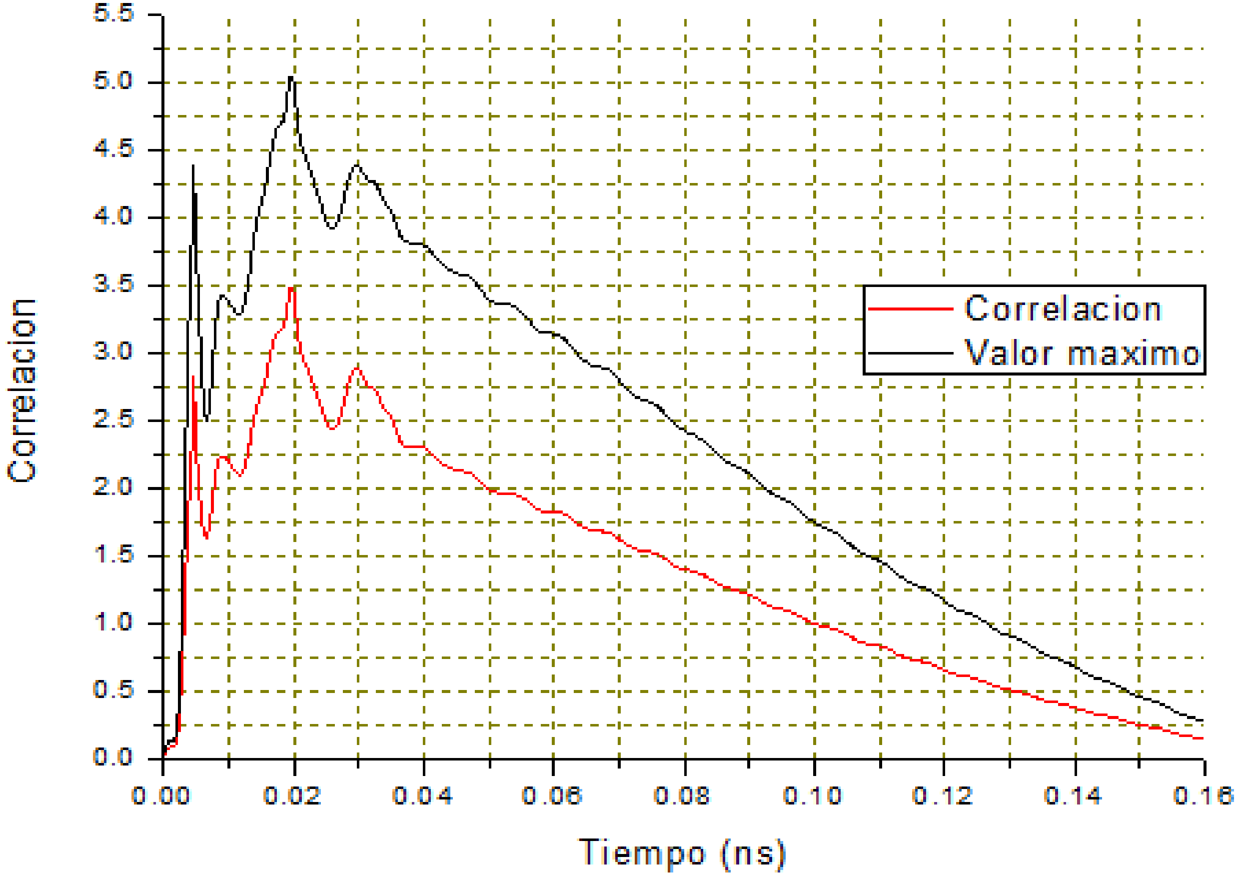
RABI OSCLLIATIONS



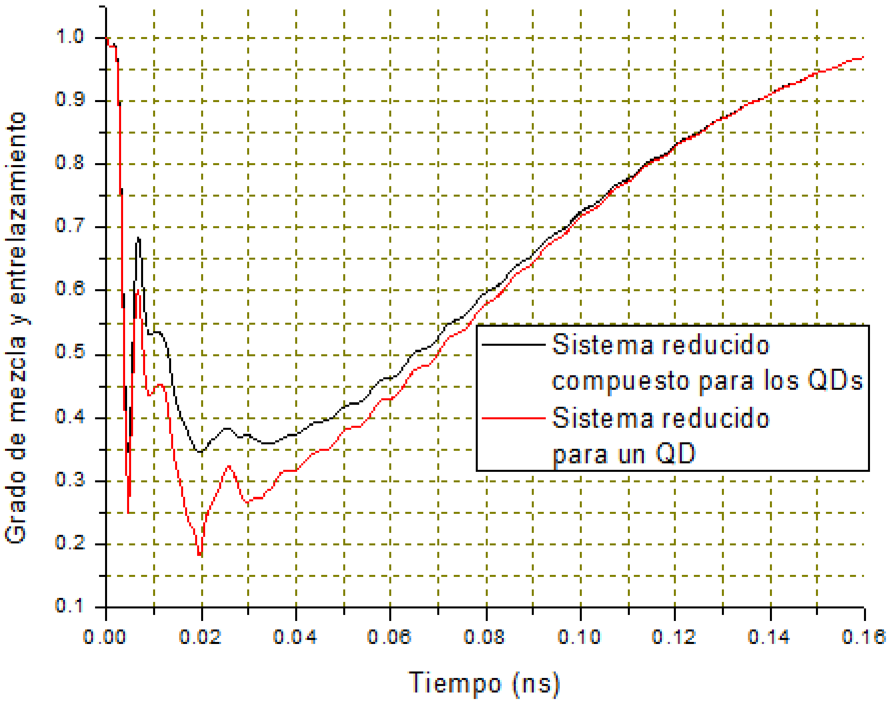


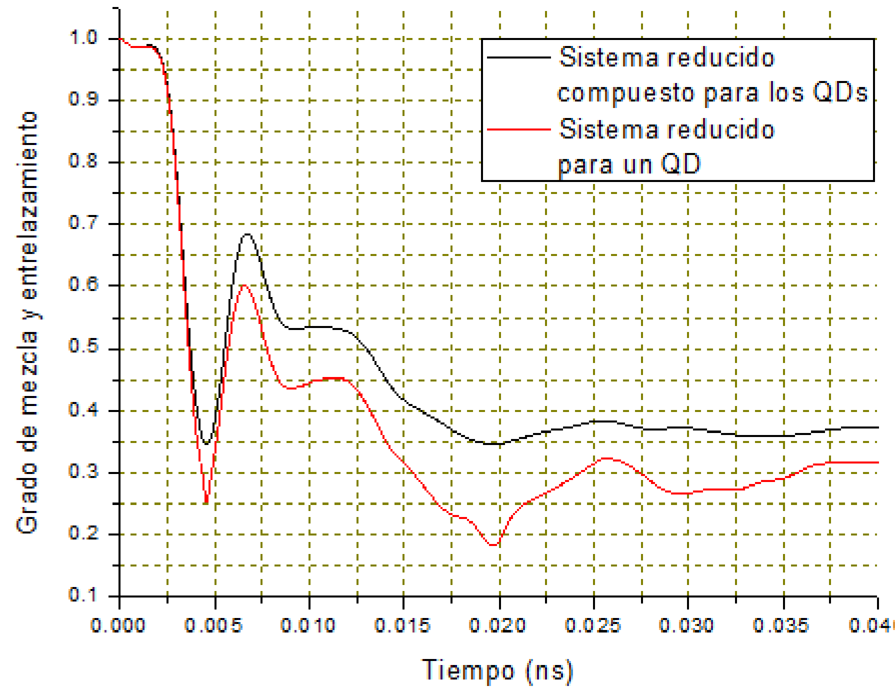
- Time (T.I): 0.013ns

CORRELATION



SQUARE OF THE DENSITY TRACE OPERATOR

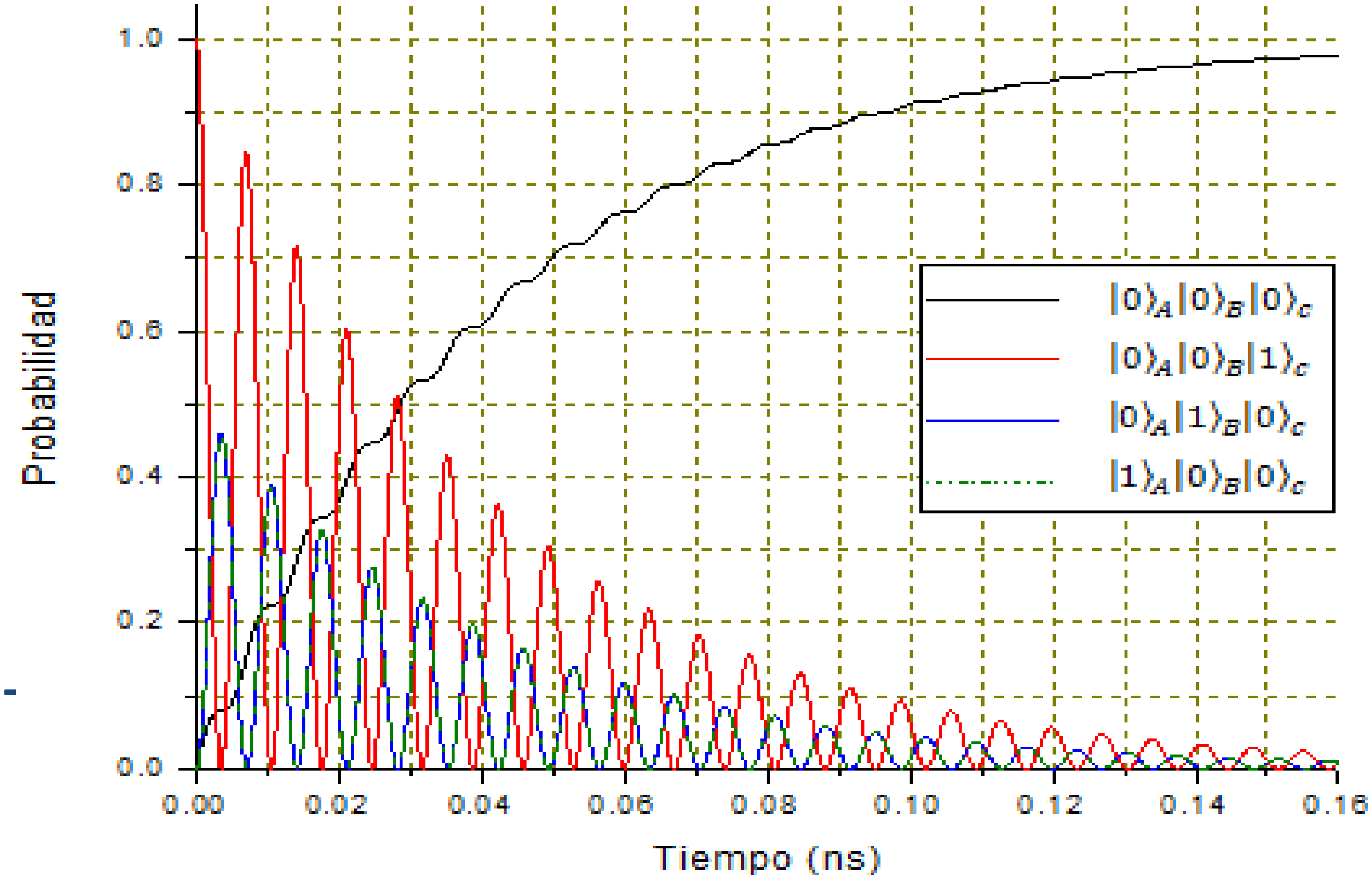




- T.I: (0.001415ns -0. 12ns), peaks: 0.0046, 0.0066 y 0.0197ns

TWO EXCITONS AND SPIN OF QDs IN EMPTY FIELD

➢ RABI OSCILLATIONS BY EXCITONS



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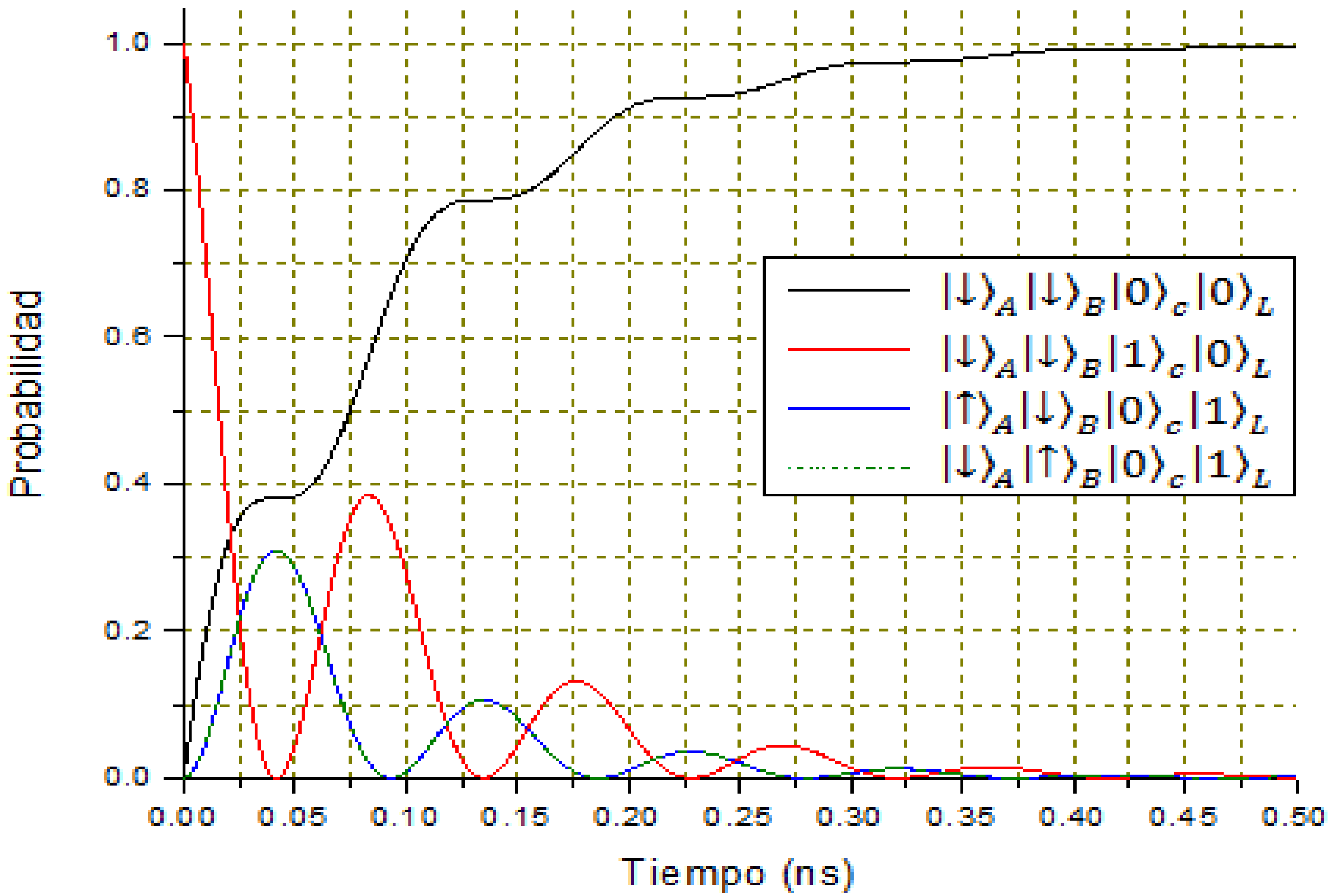


Probabilidad
Tiempo (ns)
0.0
0.2
0.4
0.6
0.8
1.0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
$|\downarrow\rangle_A|\downarrow\rangle_B|0\rangle_c|0\rangle_L$
$|\downarrow\rangle_A|\downarrow\rangle_B|1\rangle_c|0\rangle_L$
$|\uparrow\rangle_A|\downarrow\rangle_B|0\rangle_c|1\rangle_L$
$|\downarrow\rangle_A|\uparrow\rangle_B|0\rangle_c|1\rangle_L$

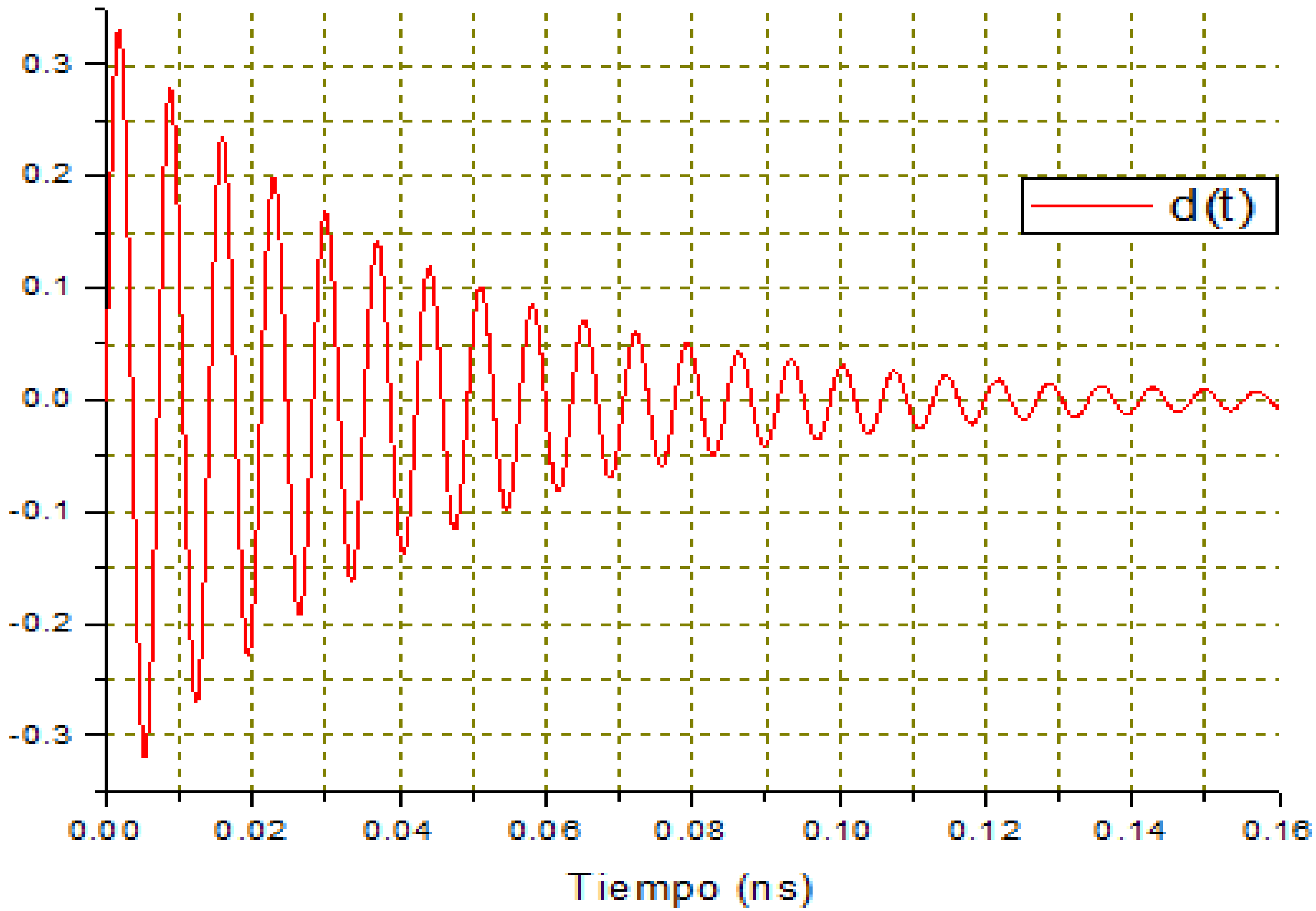
DENSITY MATRIX

Table: Matrix Density of the QDs and photon in the cavity.

	$\langle 0\vert_A \langle 0\vert_B \langle 0\vert_c$	$\langle 0\vert_A \langle 0\vert_B \langle 1\vert_c$	$\langle 0\vert_A \langle 1\vert_B \langle 0\vert_c$	$\langle 1\vert_A \langle 0\vert_B \langle 0\vert_c$
$\vert 0\rangle_A \vert 0\rangle_B \vert 0\rangle_c$	$a(t)$	**0**	**0**	**0**
$\vert 0\rangle_A \vert 0\rangle_B \vert 1\rangle_c$	**0**	$b(t)$	$d(t)$	$d(t)$
$\vert 0\rangle_A \vert 1\rangle_B \vert 0\rangle_c$	**0**	$d(t)$	$c(t)$	$c(t)$
$\vert 1\rangle_A \vert 0\rangle_B \vert 0\rangle_c$	**0**	$d(t)$	$c(t)$	$c(t)$

	$\langle\downarrow\vert_A \langle\downarrow\vert_B \langle 0\vert_c \langle 0\vert_L$	$\langle\downarrow\vert_A \langle\downarrow\vert_B \langle 1\vert_c \langle 0\vert_L$	$\langle\uparrow\vert_A \langle\downarrow\vert_B \langle 0\vert_c \langle 1\vert_L$	$\langle\downarrow\vert_A \langle\uparrow\vert_B \langle 0\vert_c \langle 1\vert_L$
$\vert\downarrow\rangle_A \vert\downarrow\rangle_B \vert 0\rangle_c \vert 0\rangle_L$	$a(t)$	0	0	0
$\vert\downarrow\rangle_A \vert\downarrow\rangle_B \vert 1\rangle_c \vert 0\rangle_L$	0	$b(t)$	$d(t)$	$d(t)$
$\vert\uparrow\rangle_A \vert\downarrow\rangle_B \vert 0\rangle_c \vert 1\rangle_L$	0	$d(t)$	$c(t)$	$c(t)$
$\vert\downarrow\rangle_A \vert\uparrow\rangle_B \vert 0\rangle_c \vert 1\rangle_L$	0	$d(t)$	$c(t)$	$c(t)$

EVOLUTION OF d(t)



DENSITY MATRIX DIAGONALIZATION

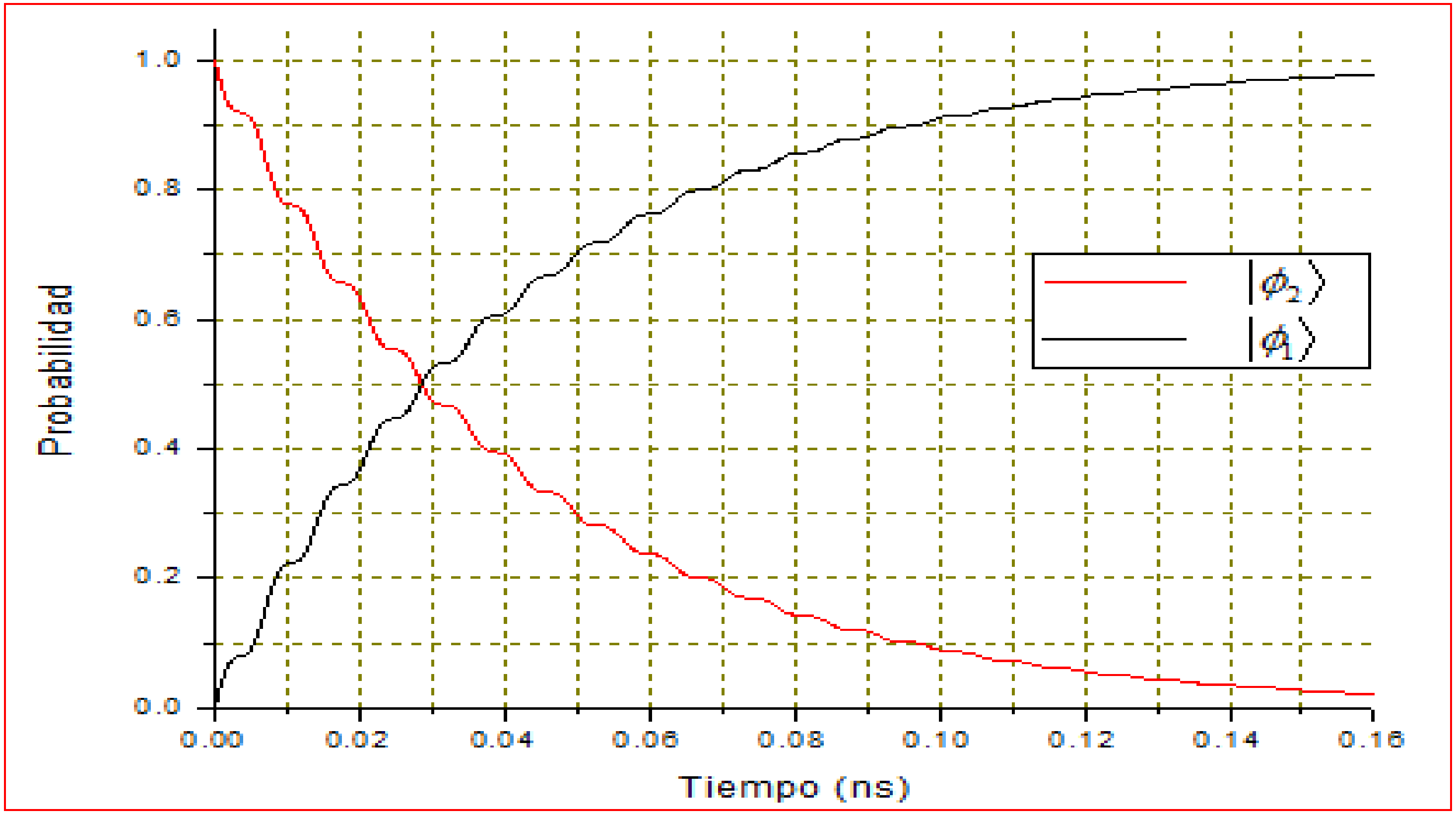
- Eigenvectors:

$$|\phi_1\rangle = |0\rangle_A |0\rangle_B |0\rangle_c$$

$$|\phi_2\rangle = \frac{\pm\sqrt{b(t)}|0\rangle_A |0\rangle_B |1\rangle_c + \sqrt{c(t)}\left(|0\rangle_A |1\rangle_B |0\rangle_c + |1\rangle_A |0\rangle_B |0\rangle_c\right)}{\sqrt{b(t)+2c(t)}}$$

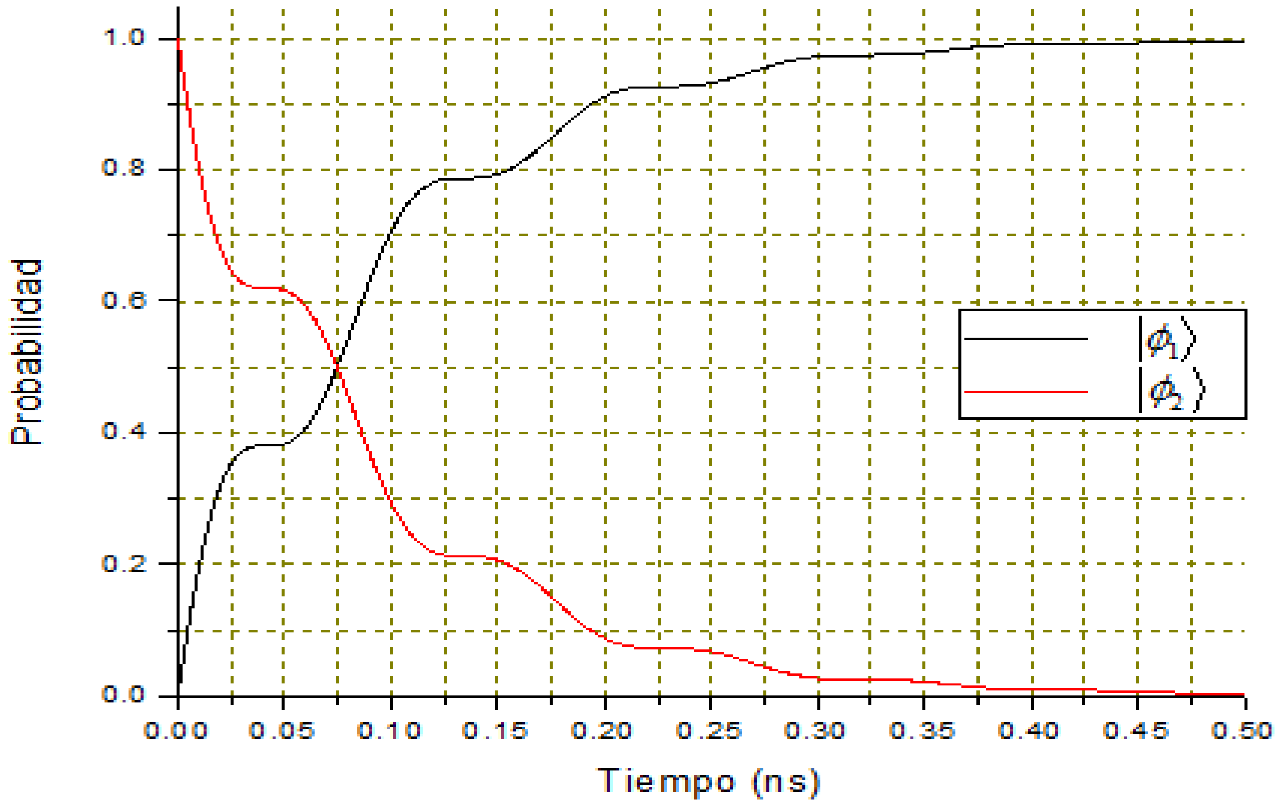
	$\langle\phi_1|$	$\langle\phi_2|$
$|\phi_1\rangle$	$a(t)$	0
$|\phi_2\rangle$	0	$b(t)+2c(t)$

EVOLUTION OF THE ENTANGLEMENT STATES FOR EXCITONS



T.I: 0.0286ns

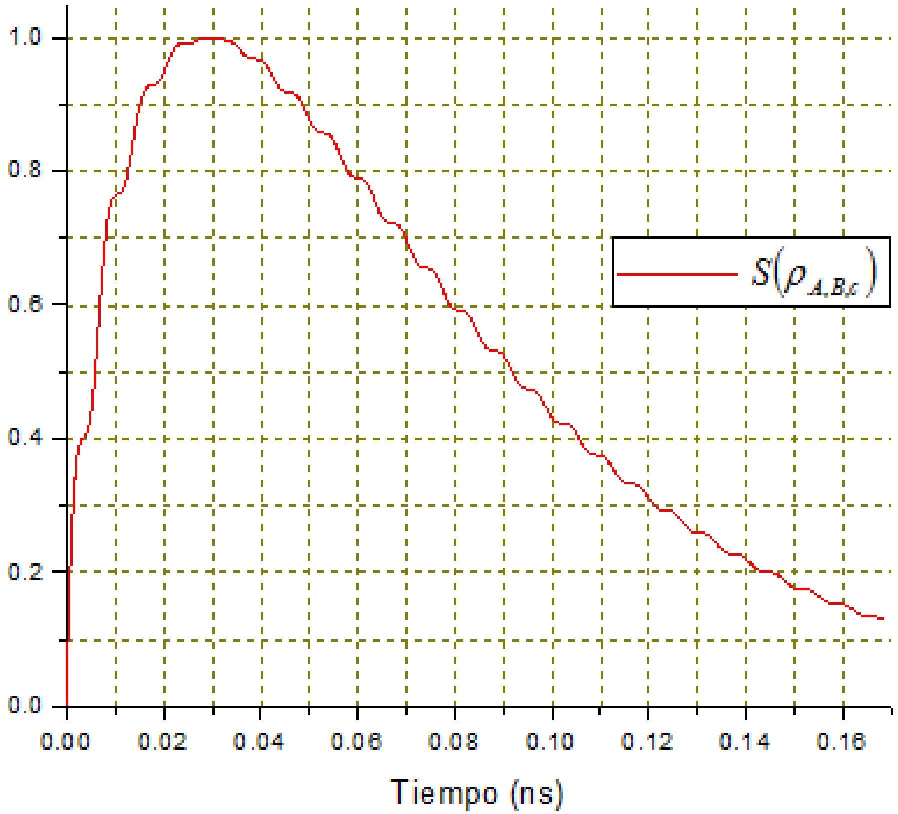
EVOLUTION OF THE ENTANGLEMENT STATES WITH SPIN

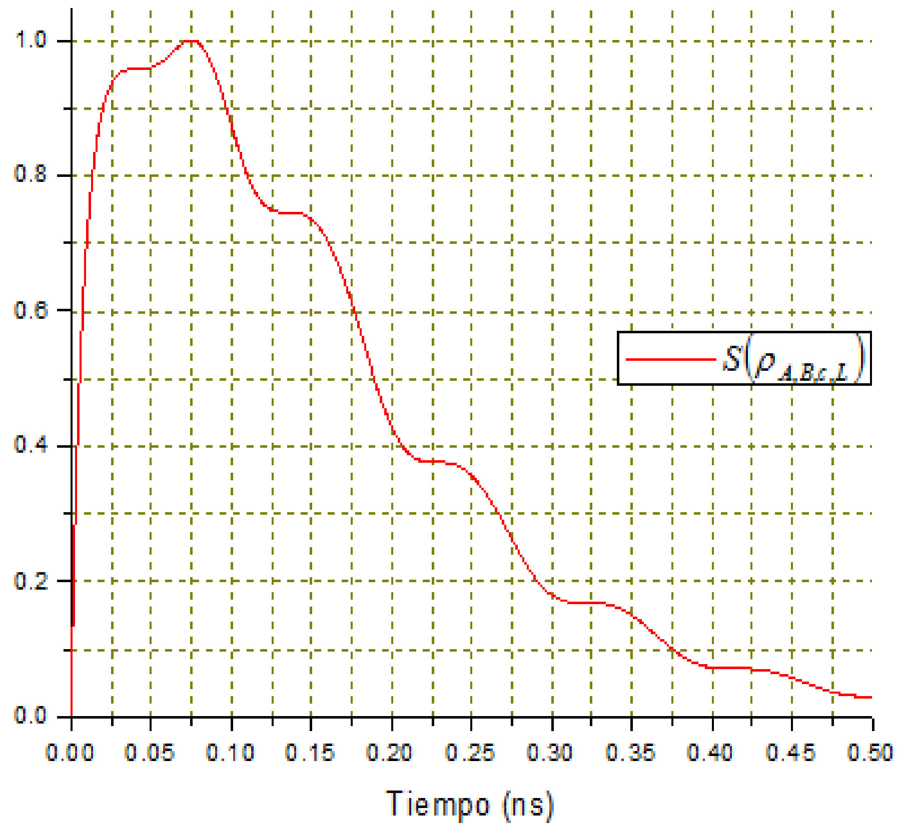


- T.I: 0.0715ns

TOTAL ENTROPY

$$S\left(\rho_{A,B,c}\right) = -\left(a(t)\ln\left[a(t)\right] + \left(b(t)+2c(t)\right)\ln\left[b(t)+2c(t)\right]\right)/\ln[2]$$





Exciton

Spin

DIAGONALIZATION OF RESTRICTED DENSITY OPERATOR IN A AND B

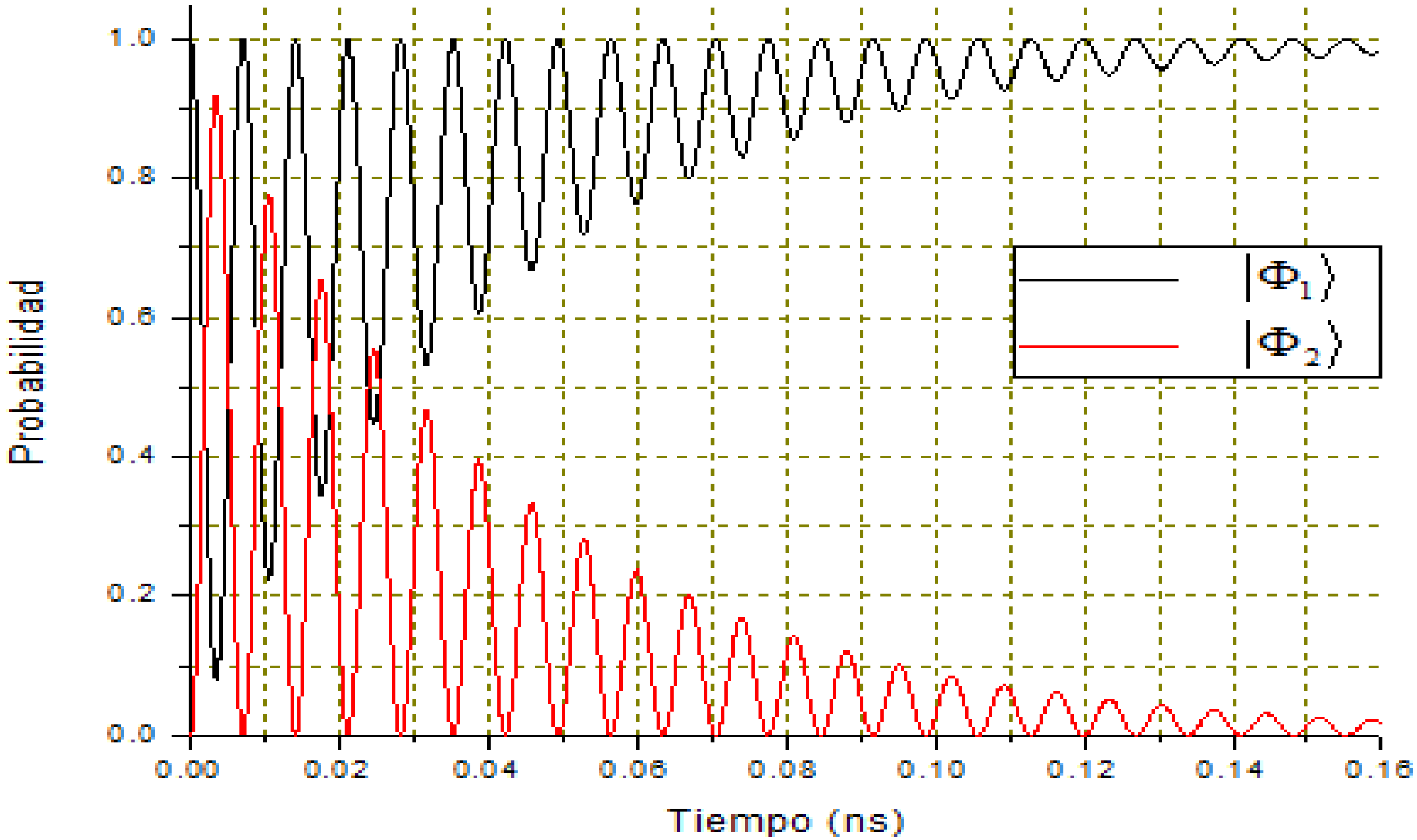
- Eigenvectors:

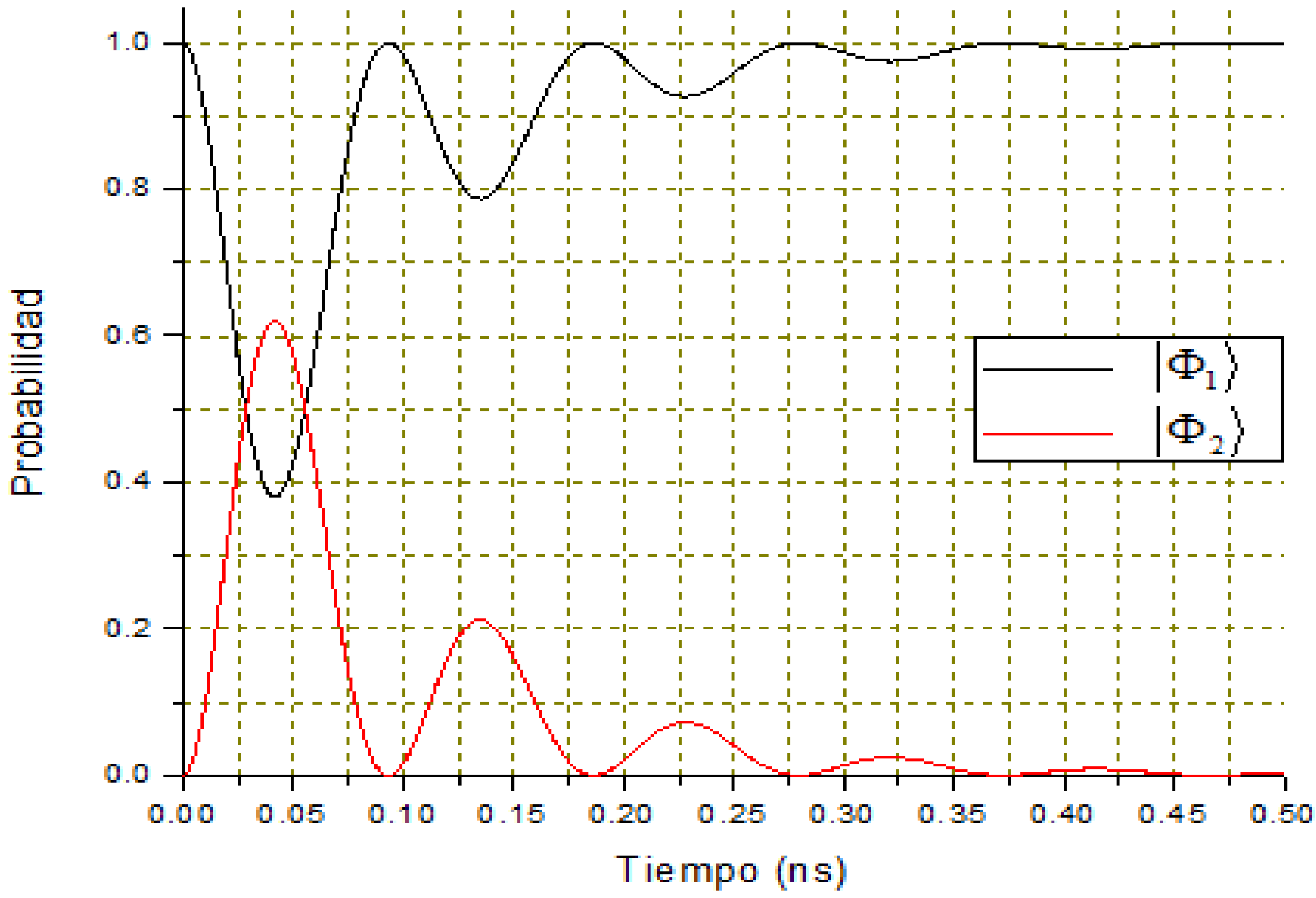
$$|\Phi_1\rangle = |0\rangle_A |0\rangle_B$$

$$|\Phi_2\rangle = \frac{1}{\sqrt{2}}\left(|0\rangle_A |1\rangle_B + |1\rangle_A |0\rangle_B\right)$$

	$\langle\Phi_1|$	$\langle\Phi_2|$
$|\Phi_1\rangle$	$a(t)+b(t)$	0
$|\Phi_2\rangle$	0	$2c(t)$

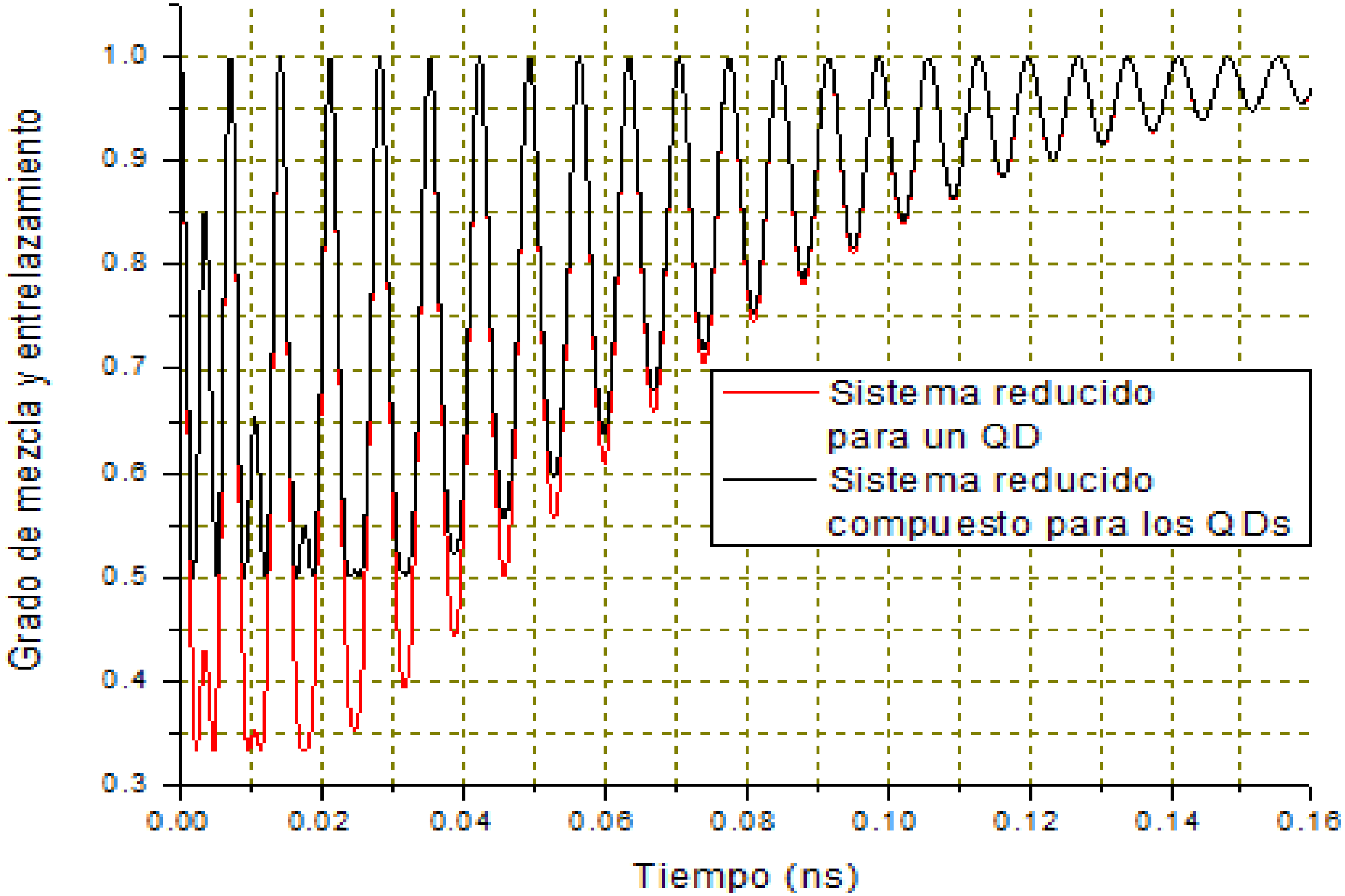
EVOLUTION OF THE ENTANGLEMENT STATES OF REDUCED EXCITONS

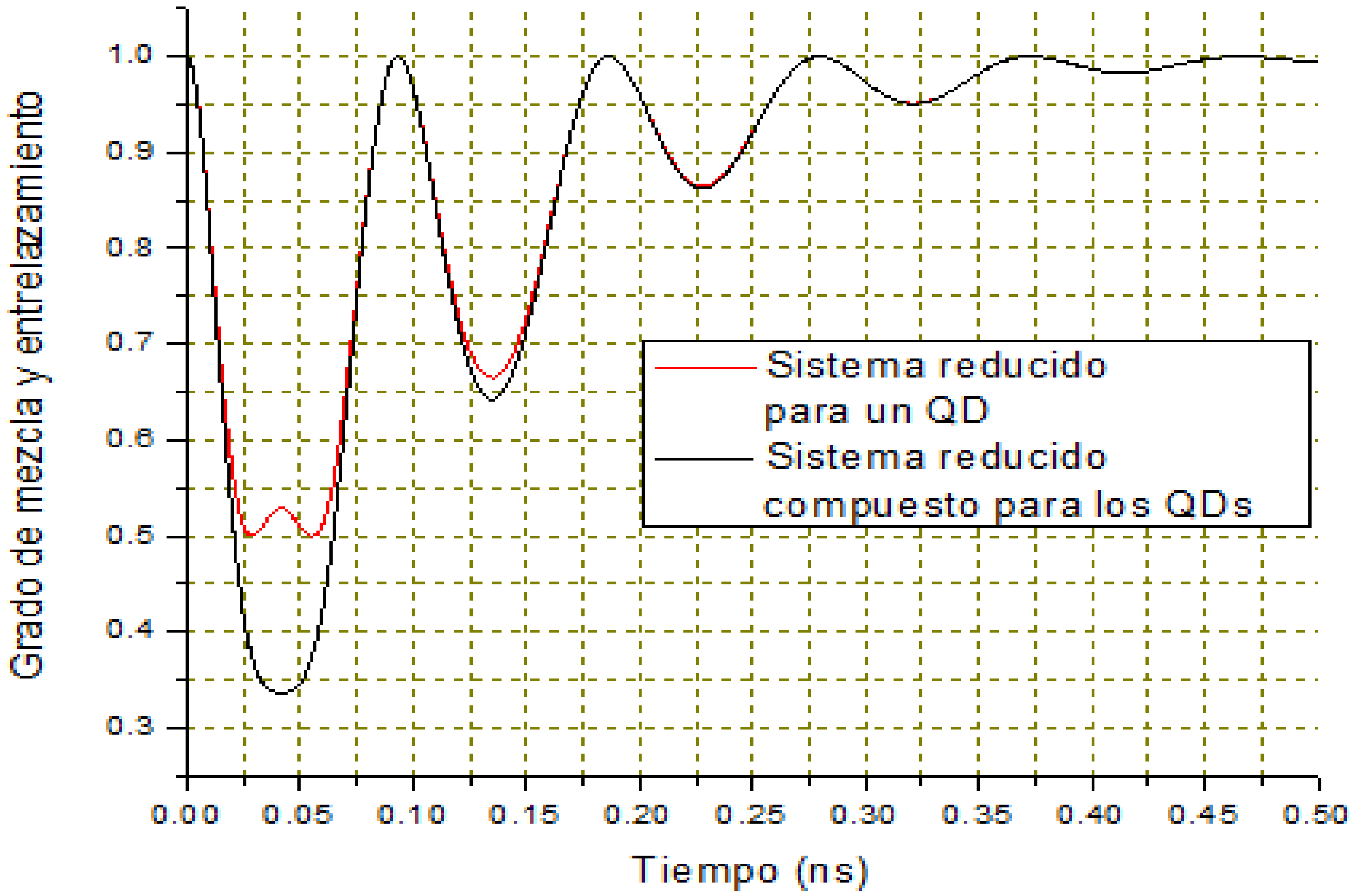




Probabilidad
1.0
0.8
0.6
0.4
0.2
0.0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
Tiempo (ns)
$|\Phi_1\rangle$
$|\Phi_2\rangle$

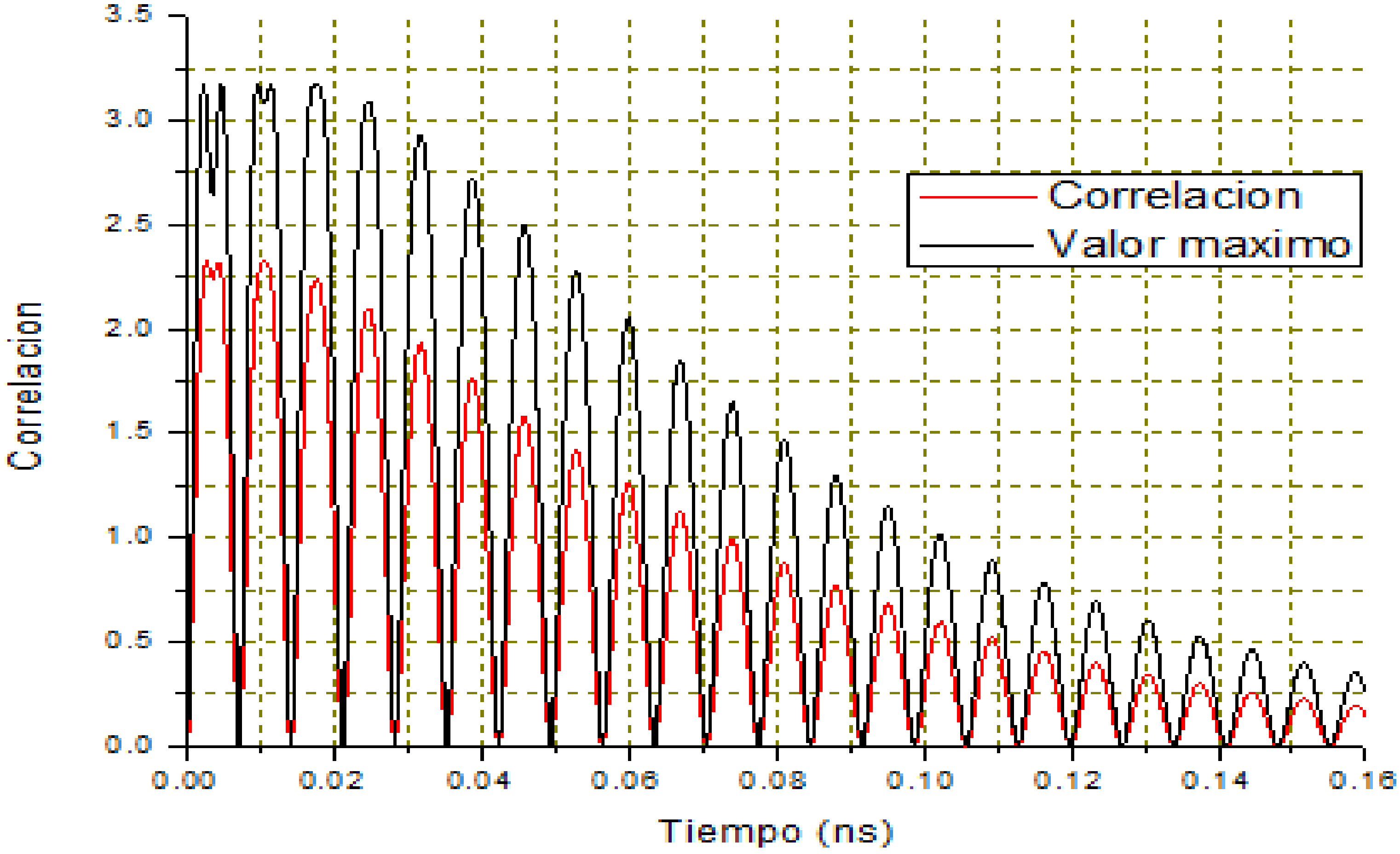
SQUARE TRACE OF DENSITY OPERATOR BY EXCITONS

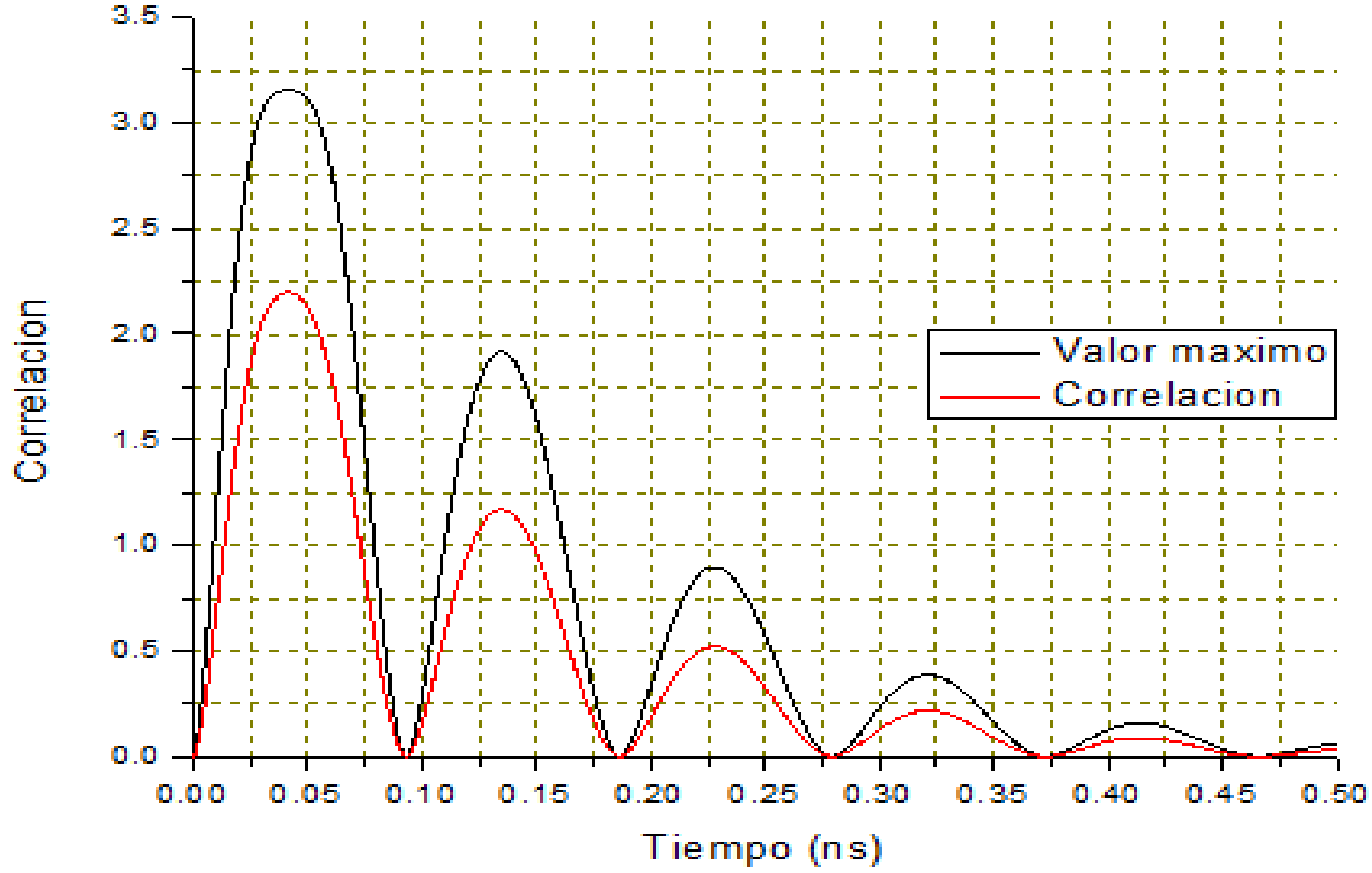




Grado de mezcla y entrelazamiento
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
Tiempo (ns)
Sistema reducido para un QD
Sistema reducido compuesto para los QDs

CORRELATION OF EXCITONS





Correlacion
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
Tiempo (ns)
Valor maximo
Correlacion

ENVIRONMENTS NO DISSIPATIVE

- Equations to solve:

$$\frac{\mathrm{d}(a(t))}{\mathrm{d}t} = 0 \quad \frac{\mathrm{d}(b(t))}{\mathrm{d}t} = -4\lambda d(t) \quad \frac{\mathrm{d}(c(t))}{\mathrm{d}t} = 2\lambda d(t) \quad \frac{\mathrm{d}(d(t))}{\mathrm{d}t} = \lambda(b(t) - 2c(t))$$

- Solutions:

$$a(t) = 0$$

$$b(t) = \cos^2\left(\sqrt{2}\lambda t\right)$$

$$c(t) = \frac{1}{2}\sin^2\left(\sqrt{2}\lambda t\right)$$

$$d(t) = \frac{1}{\sqrt{2}}\sin\left(\sqrt{2}\lambda t\right)\cos\left(\sqrt{2}\lambda t\right)$$

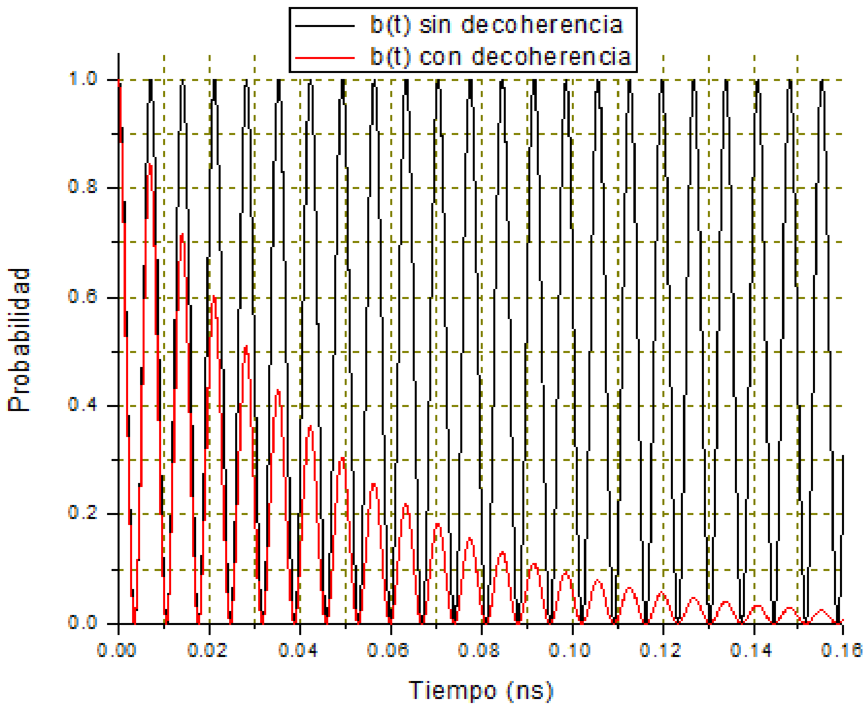
MATRIX DENSITY

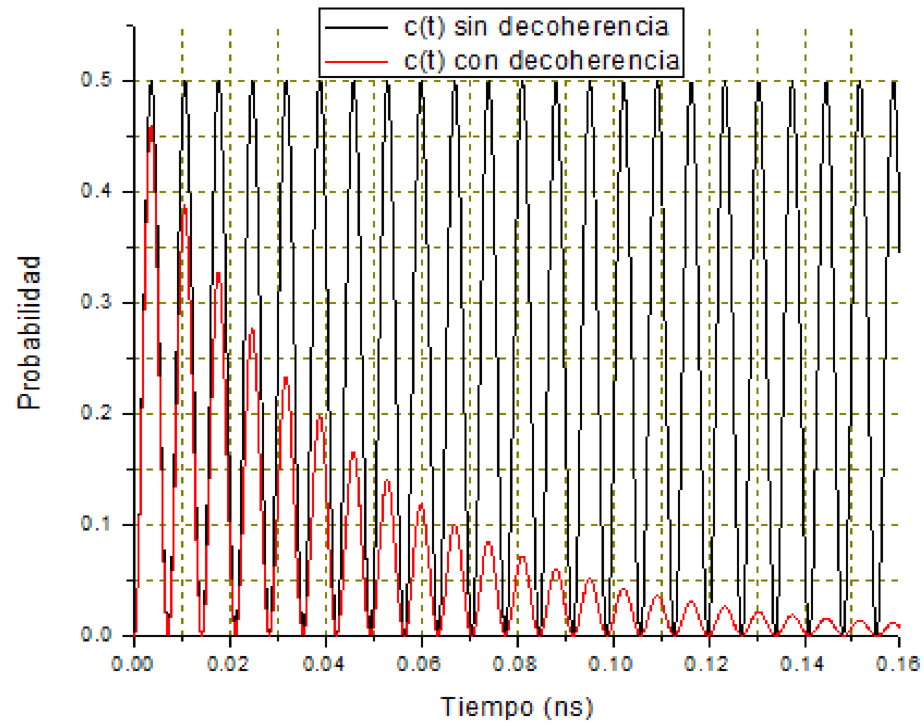
	$\langle 0\|_A \langle 0\|_B \langle 1\|_C$	$\langle 0\|_A \langle 1\|_B \langle 0\|_C$	$\langle 1\|_A \langle 0\|_B \langle 0\|_C$
$\|0\rangle_A \|0\rangle_B \|1\rangle_C$	$b(t)$	$d(t)$	$d(t)$
$\|0\rangle_A \|1\rangle_B \|0\rangle_C$	$d(t)$	$c(t)$	$c(t)$
$\|1\rangle_A \|0\rangle_B \|0\rangle_C$	$d(t)$	$c(t)$	$c(t)$

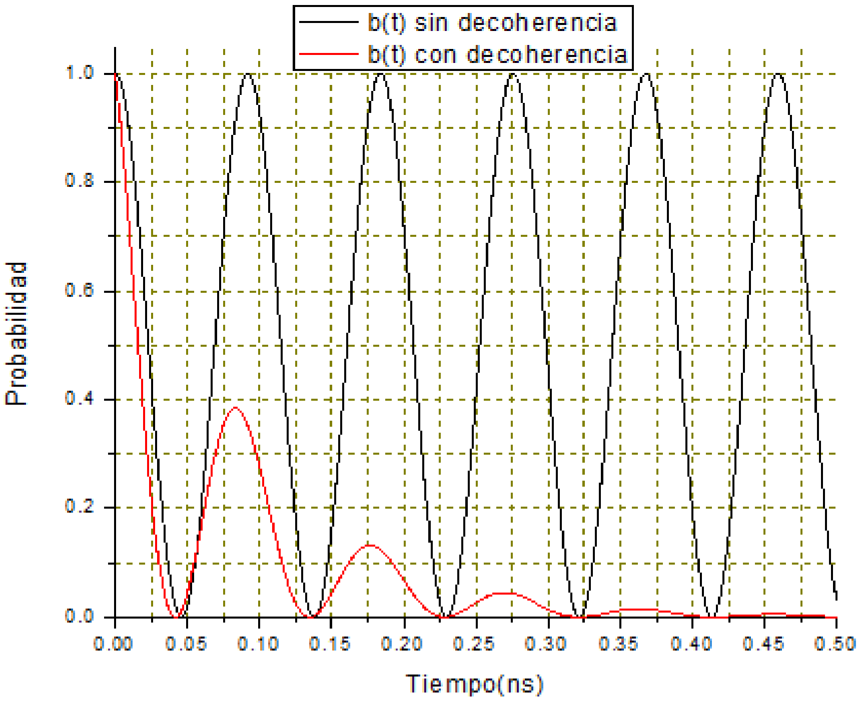
- EIGENVECTOR:

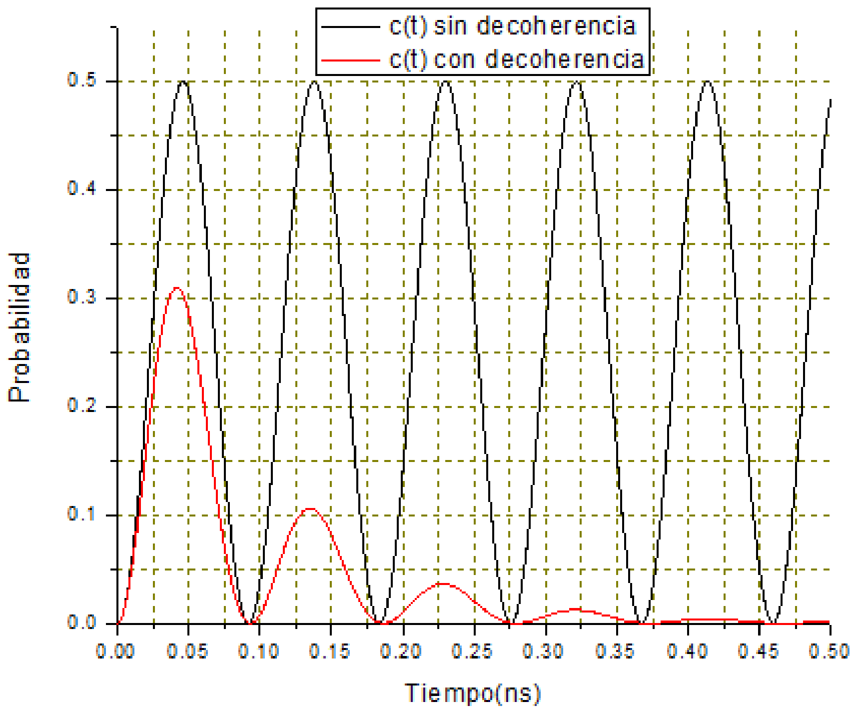
$$\left|\phi_2\right\rangle = \frac{\pm\sqrt{b(t)}\left|0\right\rangle_A\left|0\right\rangle_B\left|1\right\rangle_c + \sqrt{c(t)}\left(\left|0\right\rangle_A\left|1\right\rangle_B\left|0\right\rangle_c + \left|1\right\rangle_A\left|0\right\rangle_B\left|0\right\rangle_c\right)}{\sqrt{b(t)+2c(t)}}$$

DECOHERENCE IN EXCITONS






b(t) sin decoherencia
b(t) con decoherencia
Probabilidad
Tiempo(ns)
0.0
0.2
0.4
0.6
0.8
1.0
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50


c(t) sin decoherencia
c(t) con decoherencia
Probabilidad
Tiempo(ns)
0.0
0.1
0.2
0.3
0.4
0.5
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50

DIAGONALIZATION OF REDUCED DENSITY OPERATOR IN A AND B

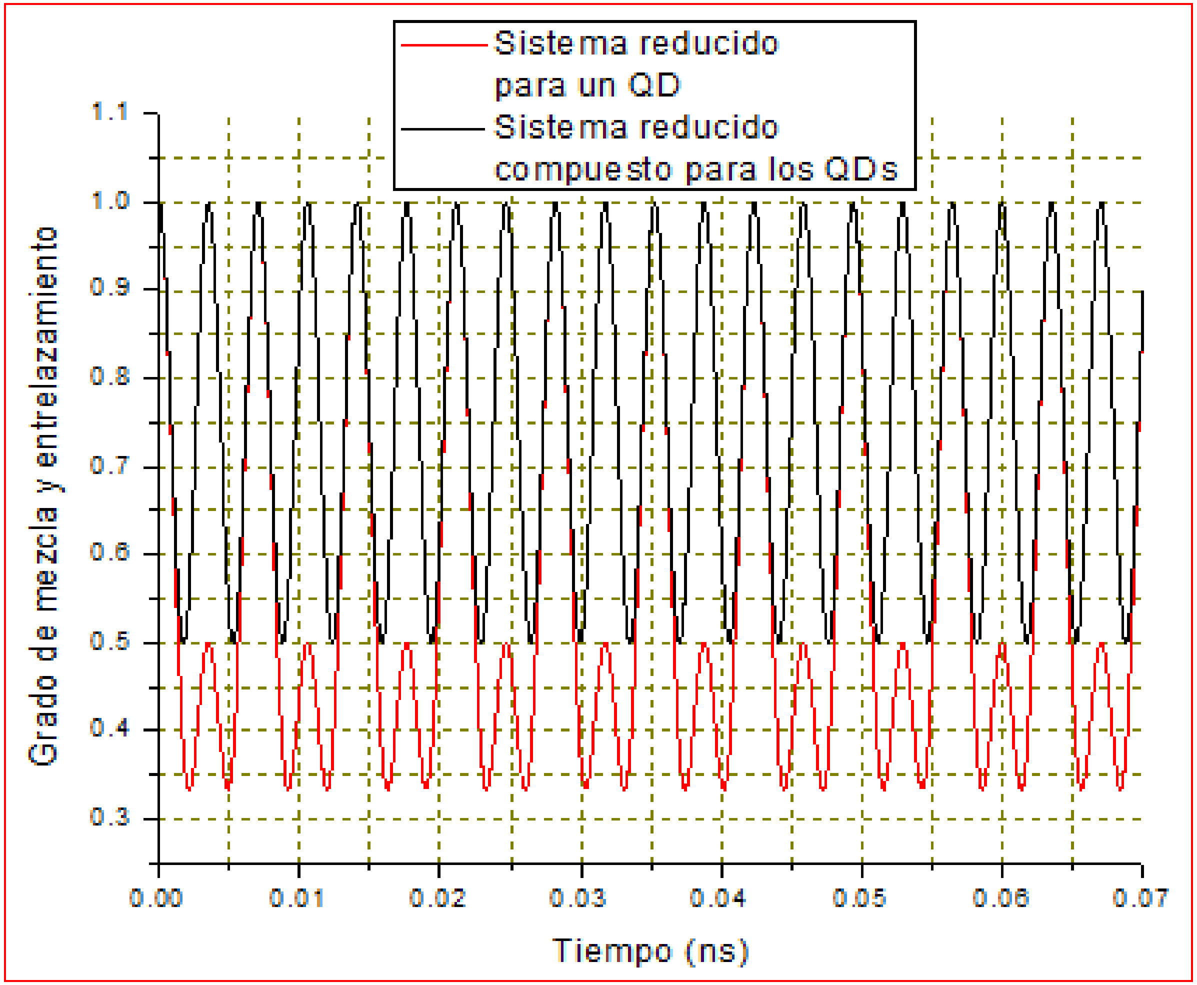
- Eigenvectors:

$$|\Phi_1\rangle = |0\rangle_A |0\rangle_B$$

$$|\Phi_2\rangle = \frac{1}{\sqrt{2}}\left(|0\rangle_A |1\rangle_B + |1\rangle_A |0\rangle_B\right)$$

	$\langle\Phi_1\|$	$\langle\Phi_2\|$
$\|\Phi_1\rangle$	$b(t)$	0
$\|\Phi_2\rangle$	0	$2c(t)$

TRACE OF SQUARE OF DENSITY OPERATOR



RABI FREQUENCES

- EXCITONES=$\sqrt{2}*\lambda= \sqrt{2}*$ 315GHz

- ESPIN= $\sqrt{2}*\lambda_{eff}= \sqrt{2}*$ 24.18GHz

ONE EXCTION OR SPIN

$$\frac{d(b(t))}{dt} = -2\lambda d(t)$$

$$\frac{d(c(t))}{dt} = 2\lambda d(t)$$

$$\frac{d(d(t))}{dt} = \lambda(b(t) - c(t))$$

	$\lvert\downarrow\rangle_{QD}\lvert 1\rangle_c$	$\lvert\uparrow\rangle_{QD}\lvert 0\rangle_c$
$\lvert\downarrow\rangle_{QD}\lvert 1\rangle_c$	$b(t)$	$d(t)$
$\lvert\uparrow\rangle_{QD}\lvert 0\rangle_c$	$d(t)$	$c(t)$

$$b(t) = \cos^2(\lambda t)$$

$$c(t) = \sin^2(\lambda t)$$

$$d(t) = \sin(\lambda t) * \cos(\lambda t)$$

CONCLUSIONS

- Excitons interaction in the quantum dot with a coherent field, the interlaced state is not defined, but the range of entanglement was predominant during the system dynamics.

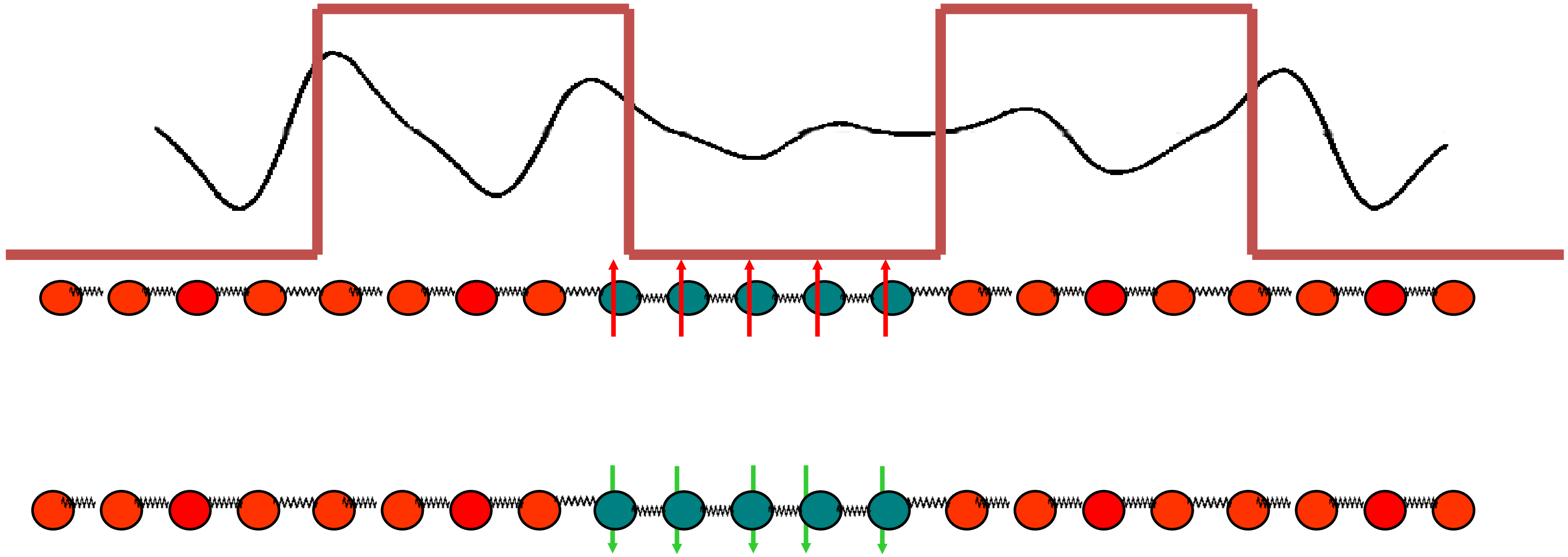
- In the interaction of quantum dot excitons with empty field in times proportional to a half-integer number of π on Rabi frequency were obtained maximally entangled states as Bell states, useful in computer science and information quantum.

- In the interaction of quantum dot spins with empty field, the dynamics were similar to that of excitons with empty field, but in this model, the frequency of Rabbi and coherence times are greater because model conditions.

- Spin model, is predominant over the exciton due to the coherence time exceeds the time for a certain computation operation (0.04ns).

They analyze the dynamics of a single quantum dot (with exciton or spin) interacting with the different fields in the cavity, we obtained results that analyze the behavior of quantum gates with two-level systems

RECTANGULAR DOUBLE BARRIER POTENTIAL



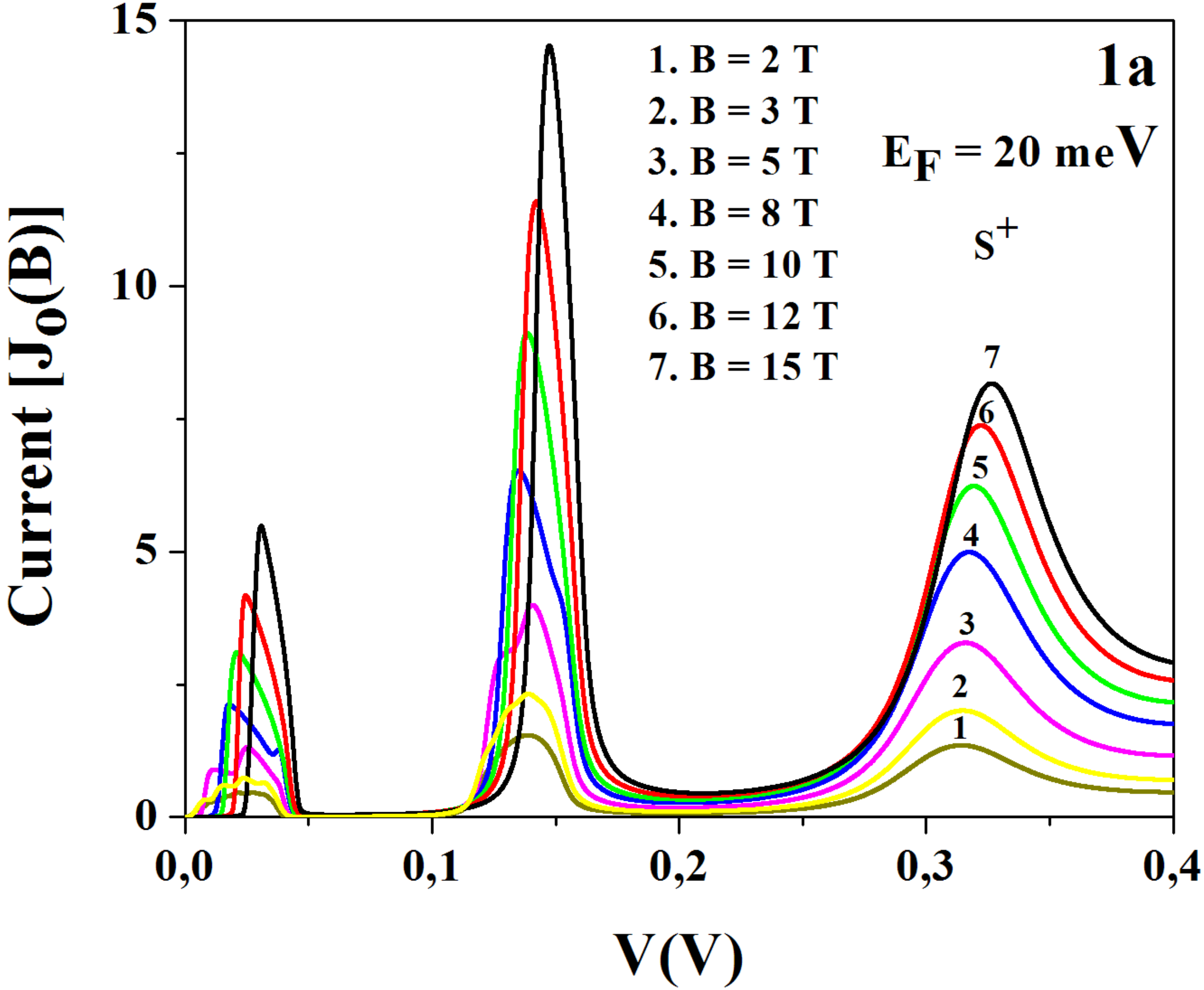
$$H = \sum_{i,\sigma} \varepsilon_i c_{i\sigma}^{\dagger} c_{i\sigma} + \sum_{i,j,\sigma} V_{ij} c_{i\sigma}^{\dagger} c_{j\sigma} + \sum_{\sigma,\sigma'} A_{\sigma,\sigma'} c_{\sigma}^{\dagger} c_{\sigma'}$$

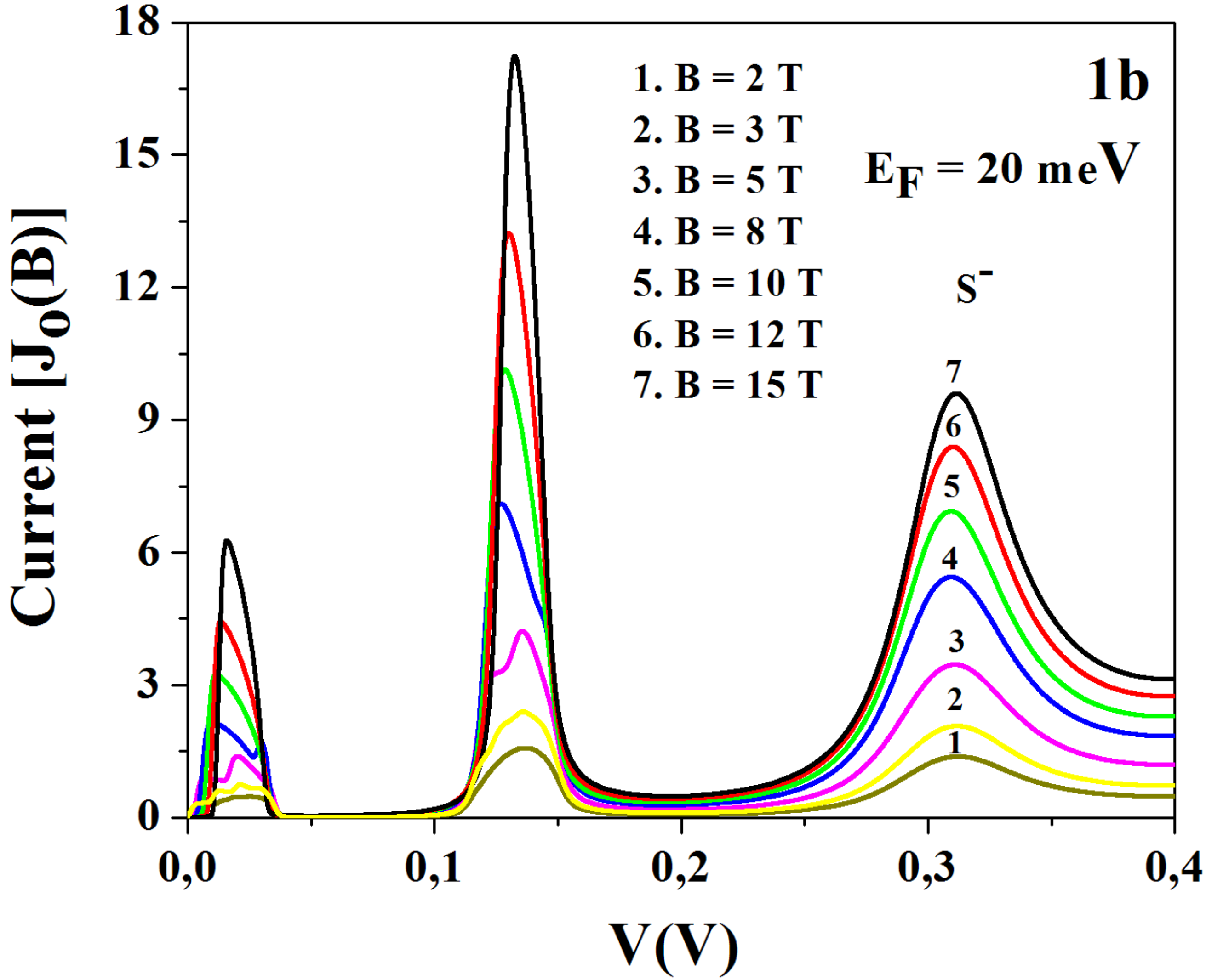
$$A_{\sigma,\sigma'} = \frac{e\hbar}{2m^*}\vec{\sigma}\cdot\vec{B}$$

$$\langle I\rangle = \frac{2eT}{\hbar}\int_{-\infty}^{+\infty} d\omega[G_{01}^{+-}(\omega) - G_{10}^{+-}(\omega)]$$

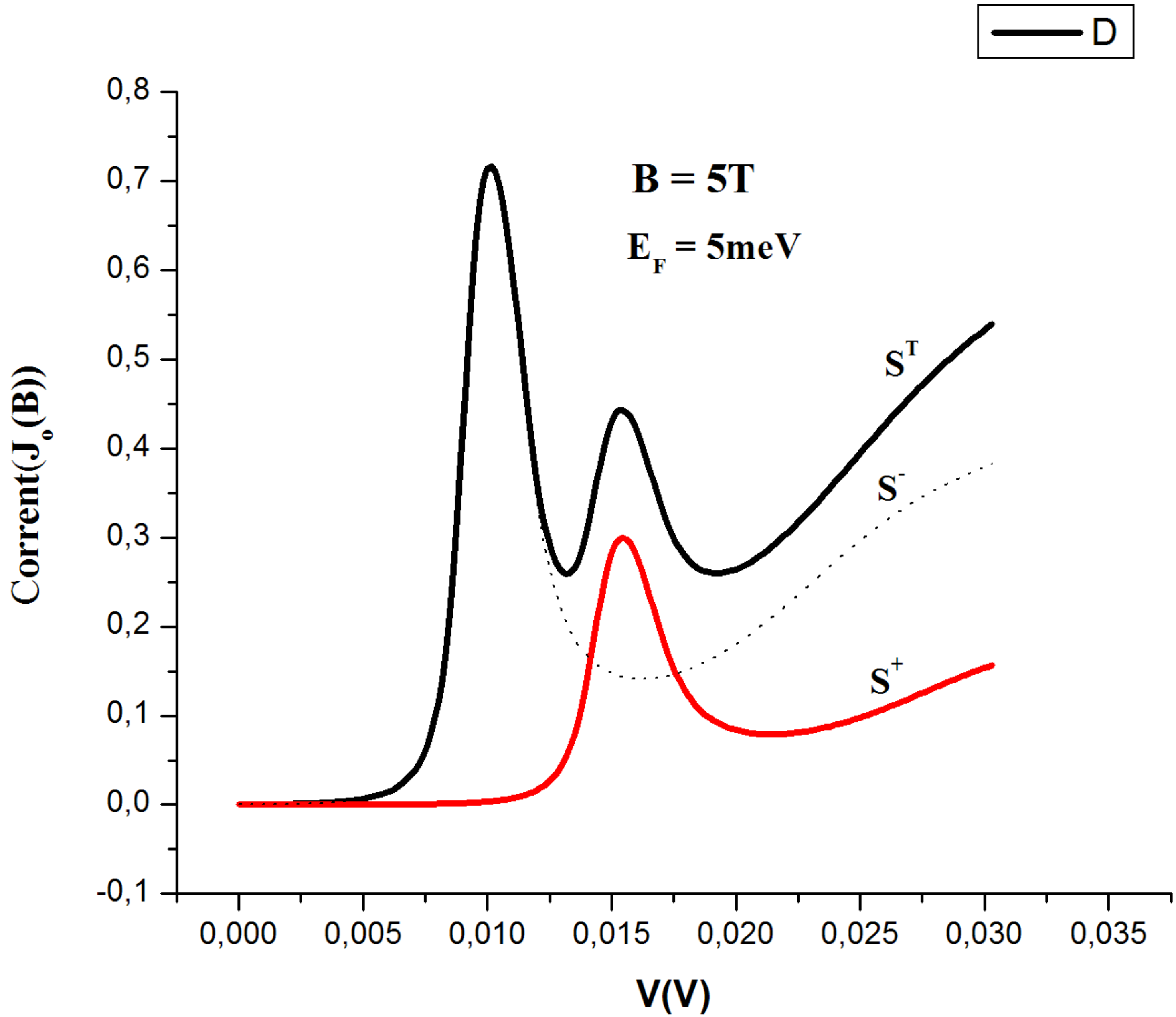
$$I = 16\pi^3 J_0(B)T^2\sum_n^N\int_{(n+\frac{1}{2})\hbar\omega}^{E_F}\frac{\rho_L(\hbar\omega)\rho_R(\hbar\omega)d(\hbar\omega)}{|\Lambda(\hbar\omega)|^2}$$

$$|\Lambda(\hbar\omega)|^2 = (1 - g_{LL}^a g_{RR}^a V^2)(1 - g_{LL}^\gamma g_{RR}^\gamma V^2)$$

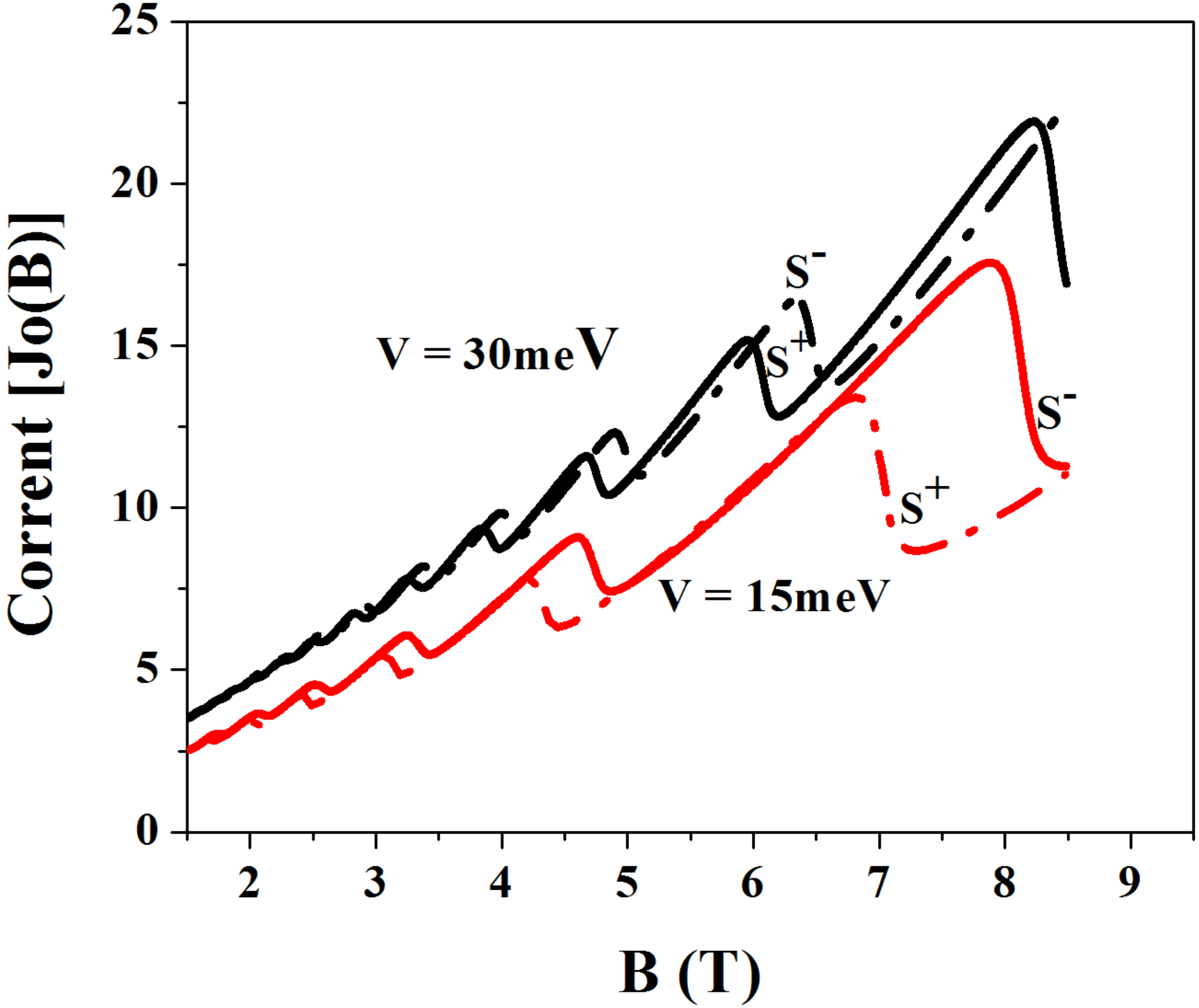

1. B = 2 T
2. B = 3 T
3. B = 5 T
4. B = 8 T
5. B = 10 T
6. B = 12 T
7. B = 15 T
1a
E_F = 20 meV
S^+
Current [J_0(B)]
V(V)
0
5
10
15
0,0
0,1
0,2
0,3
0,4
1
2
3
4
5
6
7



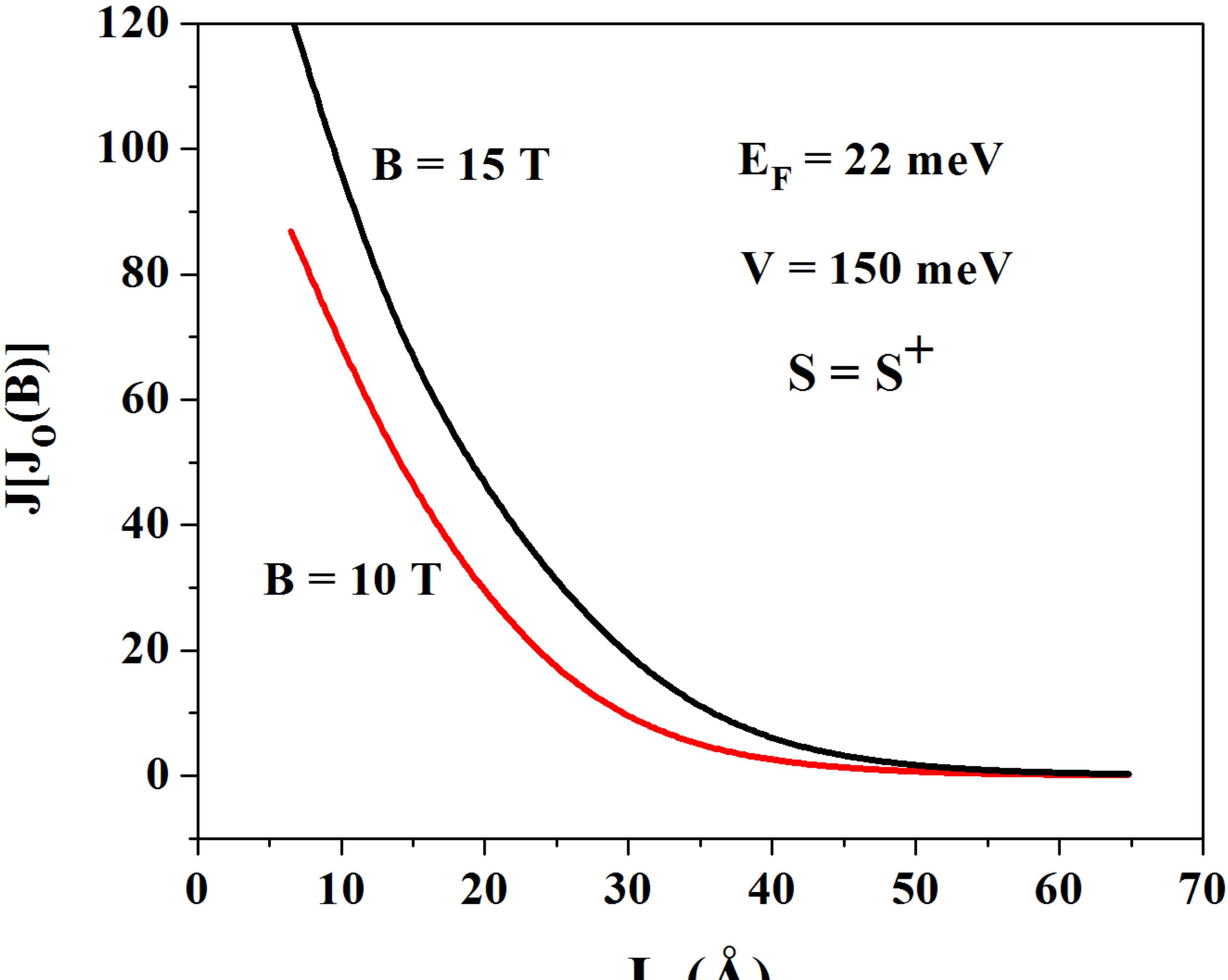
1b
E_F = 20 meV
1. B = 2 T
2. B = 3 T
3. B = 5 T
4. B = 8 T
5. B = 10 T
6. B = 12 T
7. B = 15 T
S^-
7
6
5
4
3
2
1
Current [J_0(B)]
V(V)
0
3
6
9
12
15
18
0,0
0,1
0,2
0,3
0,4



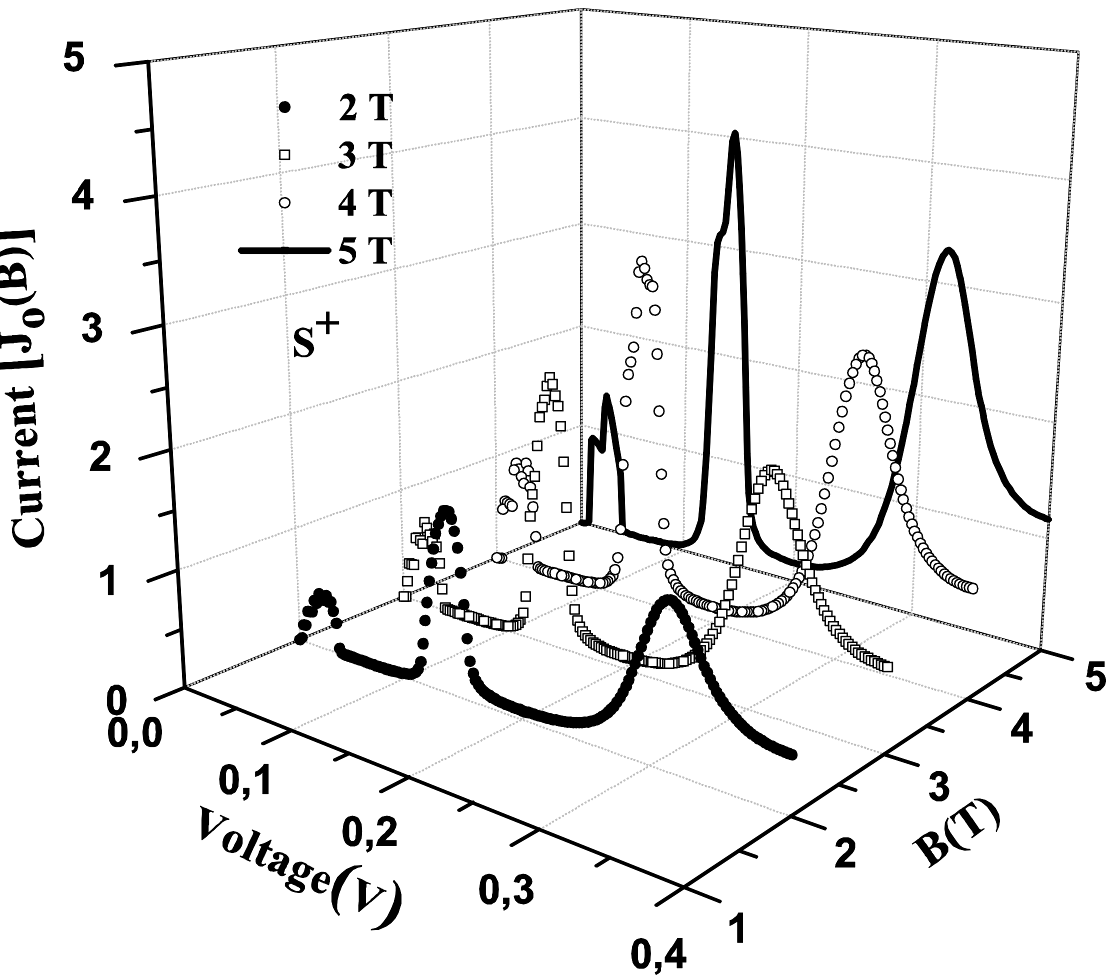
D
B = 5T
E_F = 5meV
S^T
S^-
S^+
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0,0
-0,1
Corrent(J_o(B))
0,000
0,005
0,010
0,015
0,020
0,025
0,030
0,035
V(V)



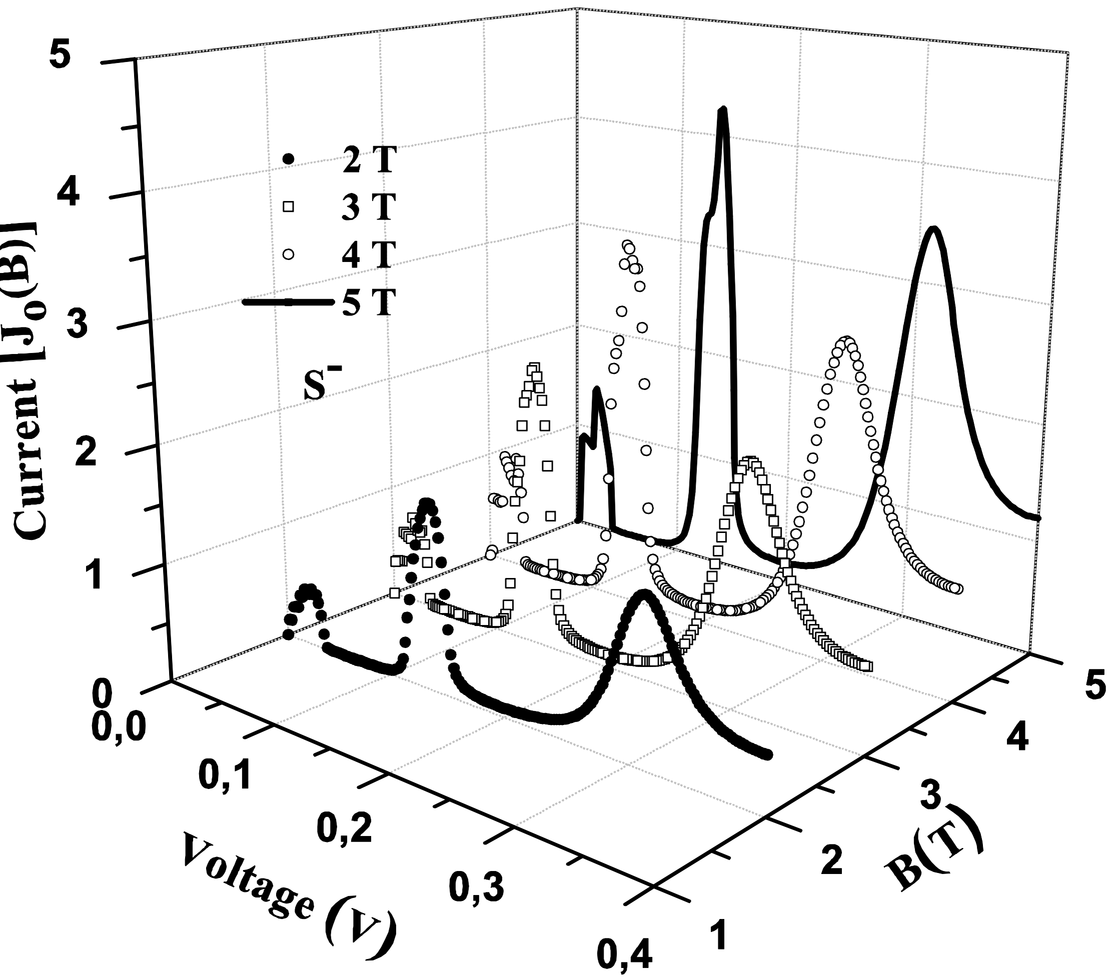
Corrent [Jo(B)]
B (T)
V = 30meV
V = 15meV
S-
S+
S-
S+
0
5
10
15
20
25
2
3
4
5
6
7
8
9



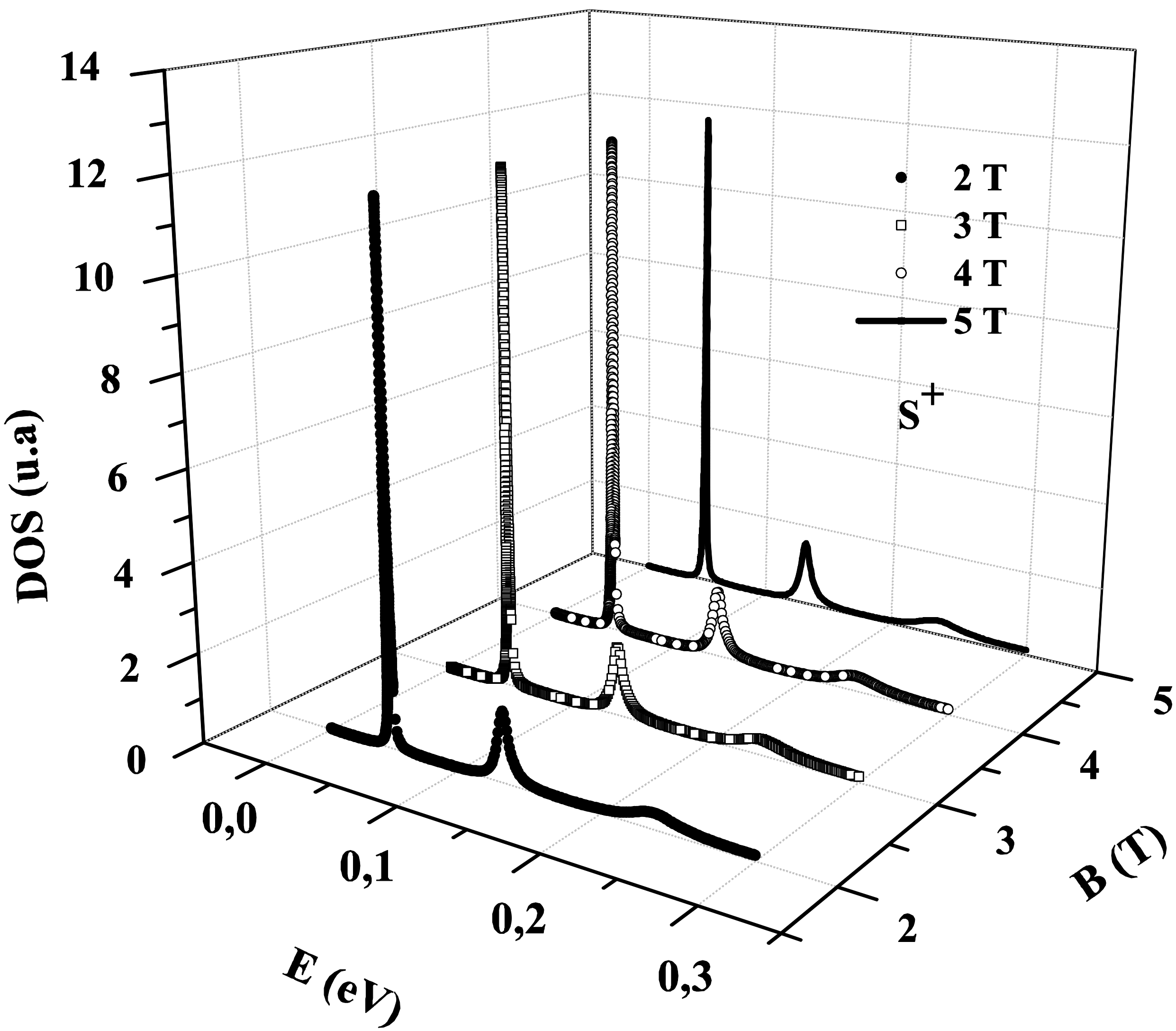
B = 15 T
B = 10 T
E_F = 22 meV
V = 150 meV
S = S^+
J[J_0(B)]
0
20
40
60
80
100
120
0
10
20
30
40
50
60
70



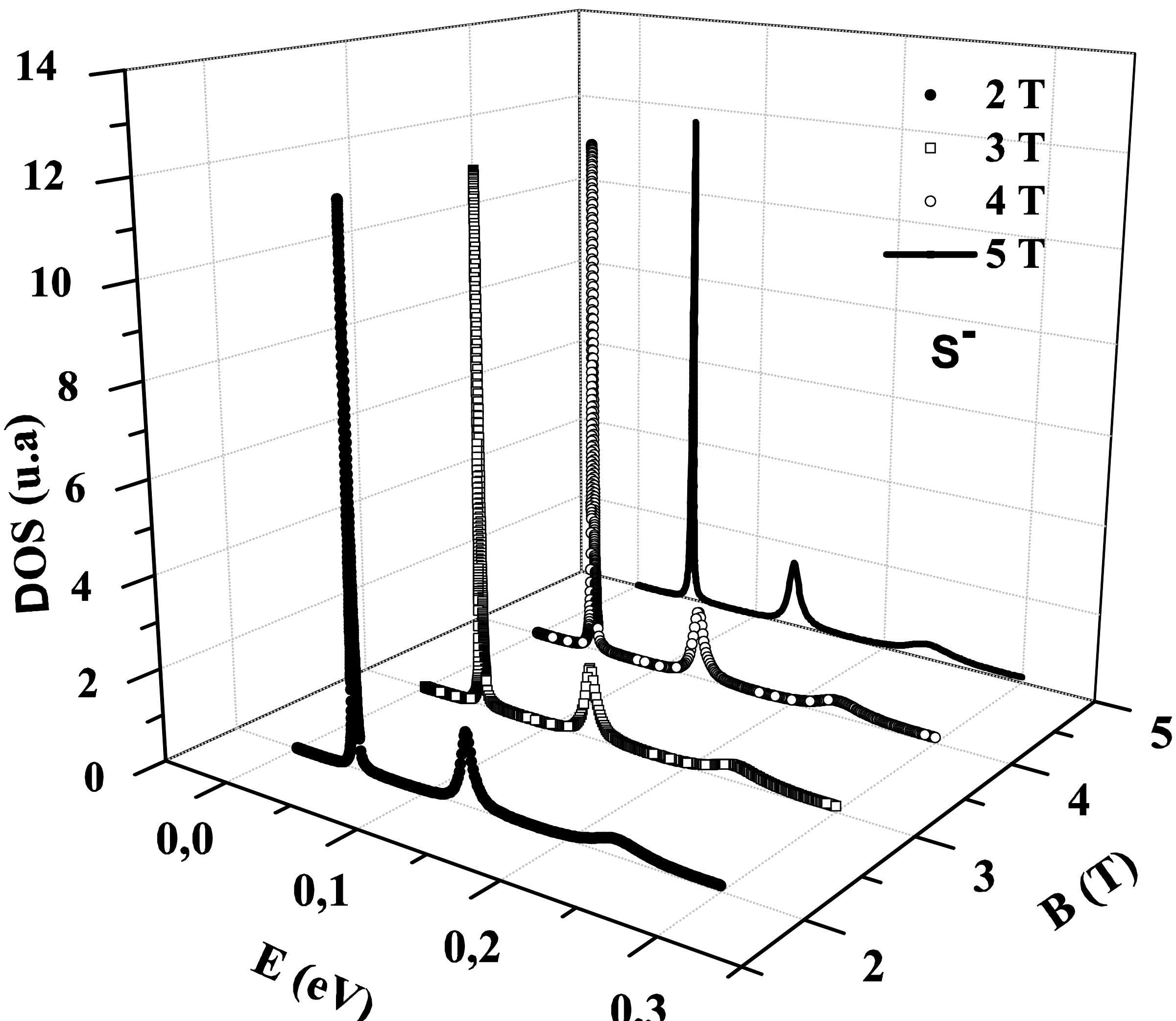
2 T
3 T
4 T
5 T
S$^+$
Current $[J_0(B)]$
Voltage(V)
B(T)
0
1
2
3
4
5
0,0
0,1
0,2
0,3
0,4
1
2
3
4
5



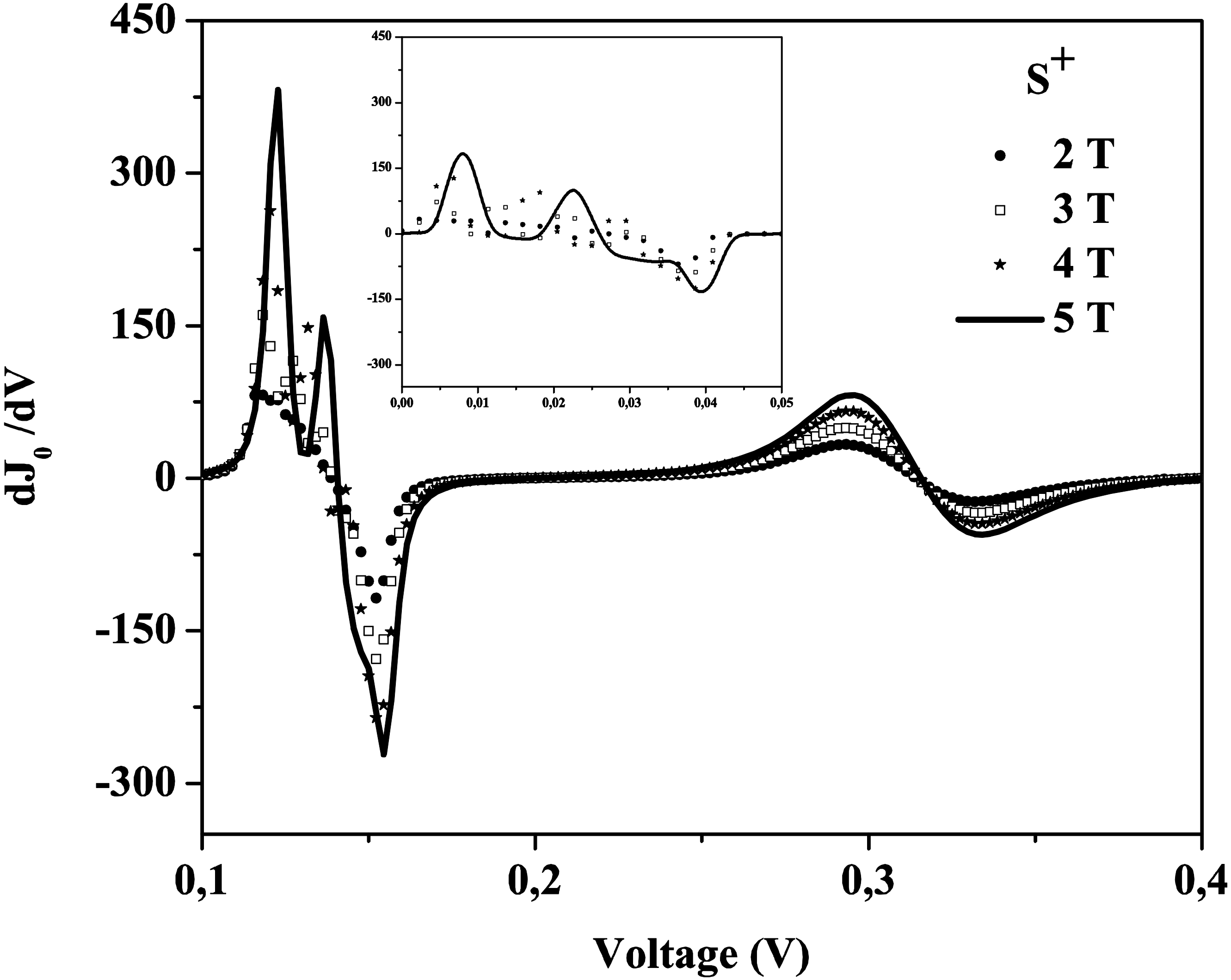
Current $[J_0(B)]$
Voltage (V)
B(T)
2 T
3 T
4 T
5 T
S^-
0
1
2
3
4
5
0,0
0,1
0,2
0,3
0,4
1
2
3
4
5



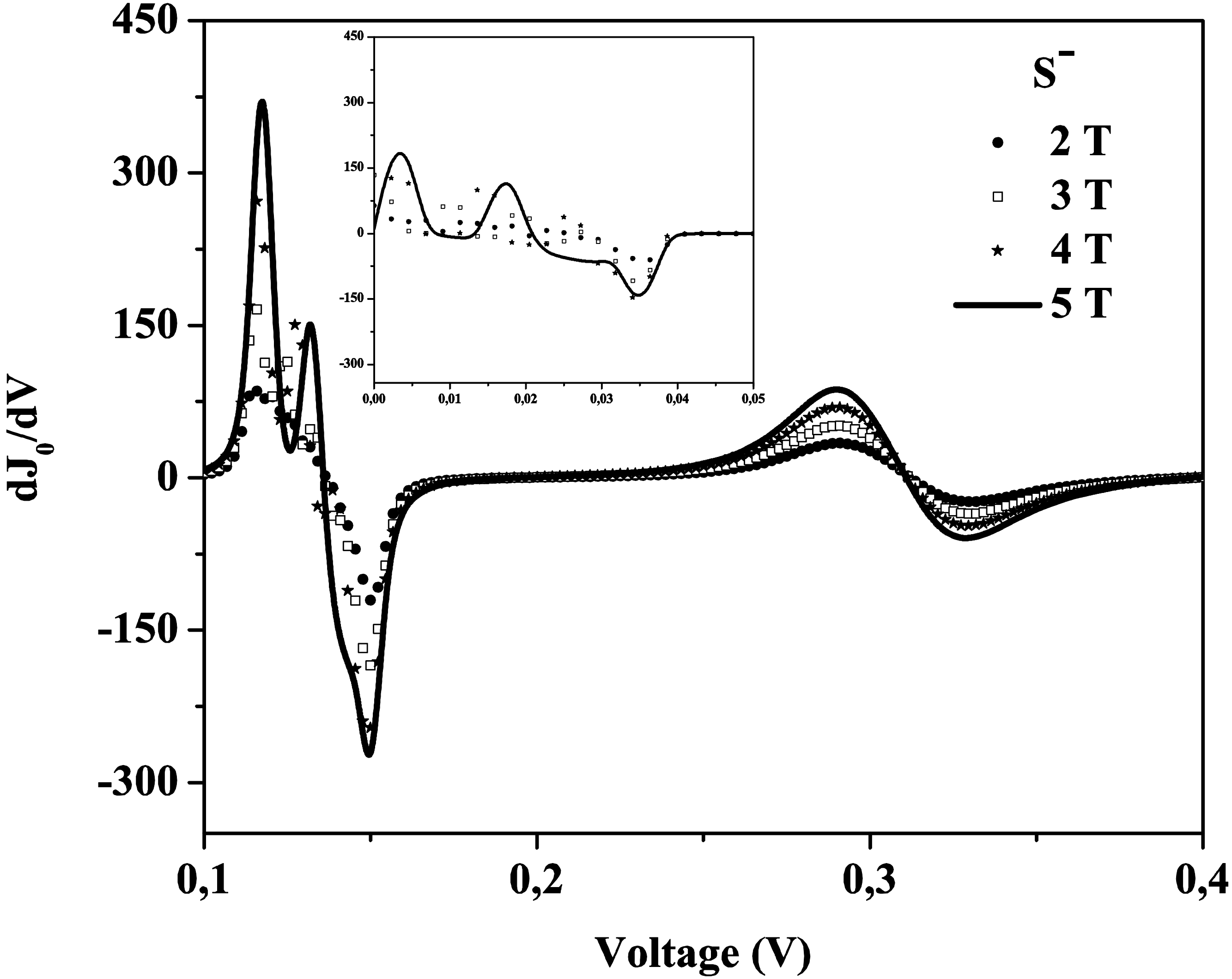
14
12
10
8
6
4
2
0
DOS (u.a)
0,0
0,1
0,2
0,3
E (eV)
2
3
4
5
B (T)
2 T
3 T
4 T
5 T
S^+



14
12
10
8
6
4
2
0
DOS (u.a)
0,0
0,1
0,2
0,3
E (eV)
2
3
4
5
B (T)
2 T
3 T
4 T
5 T
S⁻



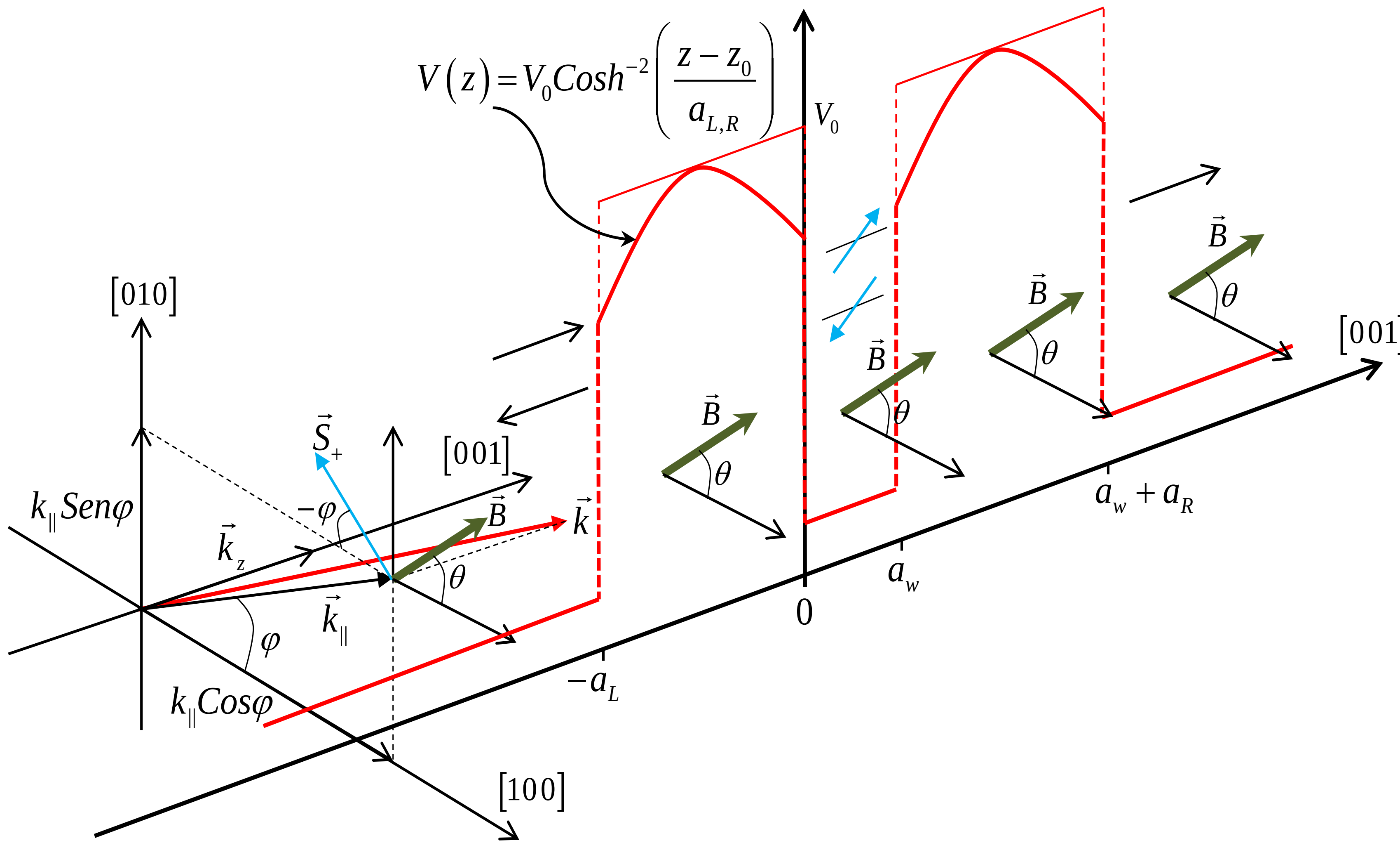
450
300
150
0
-150
-300
dJ0 /dV
0,1
0,2
0,3
0,4
Voltage (V)
S+
2 T
3 T
4 T
5 T
0,00
0,01
0,02
0,03
0,04
0,05



450
300
150
0
-150
-300
dJ$_0$/dV
0,1
0,2
0,3
0,4
Voltage (V)
S$^-$
2 T
3 T
4 T
5 T
450
300
150
0
-150
-300
0,00
0,01
0,02
0,03
0,04
0,05

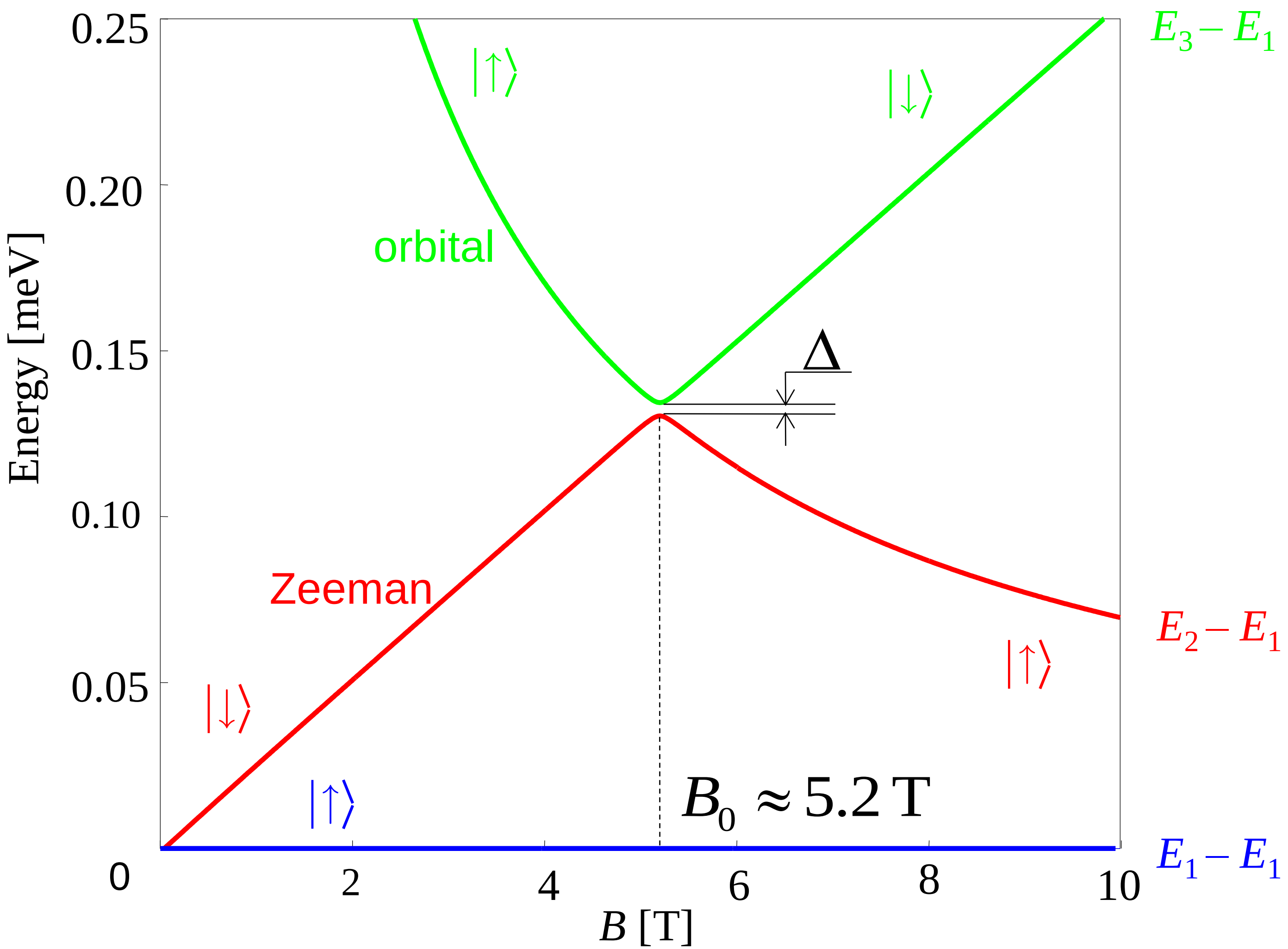
PÖSCHL-TELLER DOUBLE BARRIER POTENTIAL

RASHBA AND DRESSELHAUS EFFECTS



$V(z) = V_0 Cosh^{-2}\left(\frac{z - z_0}{a_{L,R}}\right)$
V_0
[010]
[001]
[001]
[100]
$k_{\|} Sen\varphi$
$k_{\|} Cos\varphi$
$\vec{S}_+$
$\vec{k}_z$
$\vec{k}_{\|}$
$\vec{k}$
$\vec{B}$
θ
$-\varphi$
φ
$-a_L$
0
a_w
$a_w + a_R$

Anticrossing due to Rashba coupling



$$\Delta = 2\hbar\omega_Z(l/\lambda_R) \approx 0.5\ \mu\mathrm{eV} = 6\ \mathrm{mK} = 0.02\ \mathrm{T} = 1.3\times 10^{-9}\ \mathrm{s}\ \left(\lambda_R = 8\ \mu\mathrm{m}\right).$$

$\mu\Phi$