

Electronic transport through two double quantum dot molecules embedded in an Aharonov–Bohm ring

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Abstract

We study transport through two quantum dot molecules embedded in an Aharonov–Bohm interferometer. We obtain analytically the conductance in equilibrium at zero temperature. As a result of quantum interference, this system exhibits up to two bound states in the continuum simultaneously, and remarkably maximum conductance occurs even when the molecules have both extremely weak interdot couplings.

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1. Introduction

Quantum interference effects in quantum dots have been an active subject of research in recent years. Particular interest has the Fano effect [1], which arises from the interference between a discrete state and the continuum. A simple system exhibiting this effect is a quantum dot embedded in an Aharonov–Bohm ring [2], being possible to control with the magnetic flux the position and widths of the Fano resonance. The study of a parallel-coupled double quantum dot molecule leads to another interesting effect: the existence of resonances of infinite lifetimes, or bound states in the continuum (BIC) [3]. In the double and triple molecules embedded in Aharonov–Bohm interferometers, the magnetic flux has a role in controlling the arising of these states [4]. In this article we study transport through two parallel quantum dot molecules embedded in an Aharonov–Bohm ring. Apart from Fano resonances and the existence of two simultaneous BICs, quantum interference allows perfect transmission when both molecules have very weak intramolecular couplings.

2. Model

The system under consideration is shown in Fig. 1. We model the system by a noninteracting Anderson Hamiltonian [3], and we work in the real-space picture. We assume up–down symmetry, and only one energy level relevant in each of the quantum dots. In the presence of a magnetic flux Φ , all the hoppings in the ring are modified by a phase factor $e^{i\phi/6}$ for a clockwise jump, and $e^{-i\phi/6}$ for a counterclockwise jump, where $\phi = 2\pi\Phi/\Phi_0$ is the Aharonov–Bohm phase, with $\Phi_0 = h/e$ the flux quantum.

We focus on the linear conductance at zero temperature. This is obtained from the Landauer formula $G = (2e^2/h)|t(\varepsilon = \varepsilon_F)|^2$, with $t(\varepsilon)$ the complex transmission amplitude [5].

3. Results and discussion

The transmission $t(\varepsilon)$, being proportional to $\cos \phi/2$, vanishes when ϕ is an odd multiple of π , whatever are the energies ε_A and ε_B , and the interdot and dot–leads couplings. An analogous behavior is found in two dots embedded in the arms of an Aharonov–Bohm interferometer, but the suppression of transmission occurs only when

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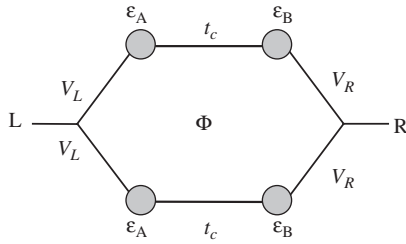


Fig. 1. Scheme of two quantum dot molecules embedded in parallel in an Aharonov–Bohm ring.

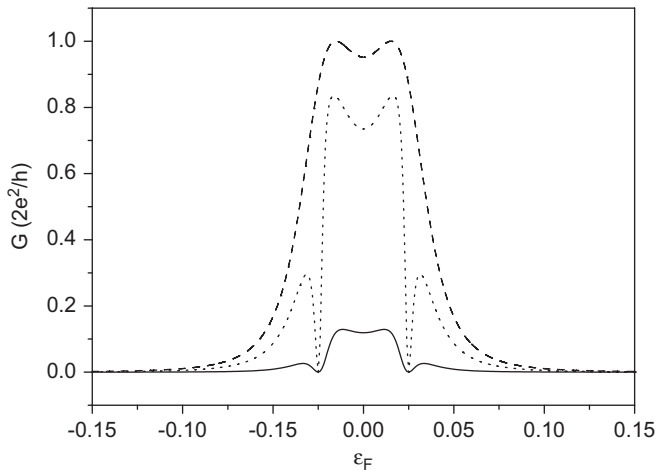


Fig. 2. Conductance versus Fermi energy for $V = 0.1$, $t_c = 0.025$ and $\phi = 0$ (solid line), $\phi = \pi/2$ (dash line), and $\phi = 6\pi/7$.

the energies of the quantum dot levels are equal [6]. In what follows, we express all the parameters in units of v , the hopping between sites in the leads. Results of the conductance G for $V_L = V_R \equiv V = 0.1$, $\varepsilon_A = \varepsilon_B = 0$, $t_c = 0.025$ and different values of ϕ are shown in Fig. 2. For arbitrary values of ϕ (dashed and dotted lines), $G(\varepsilon_F)$ exhibits in general four peaks, two Fano-type and two Breit–Wigner resonances, associated with the molecular states. The zeros in the conductance always occur at the bonding and antibonding energies. The Fano resonances disappear when ϕ is even multiple of π (solid line). For these values of the Aharonov–Bohm phase, two of the hybridized states decouple simultaneously of the leads, becoming BICs. These states correspond to antisymmetrical combinations of the states of the left dots and of the right dots, that is, $(|\psi_{A+}\rangle - |\psi_{A-}\rangle)/\sqrt{2}$ and $(|\psi_{B+}\rangle - |\psi_{B-}\rangle)/\sqrt{2}$, respectively. Interesting features arise when the quantum dots of both molecules are weakly coupled. In Fig. 3 it is plotted the conductance at the center of the band

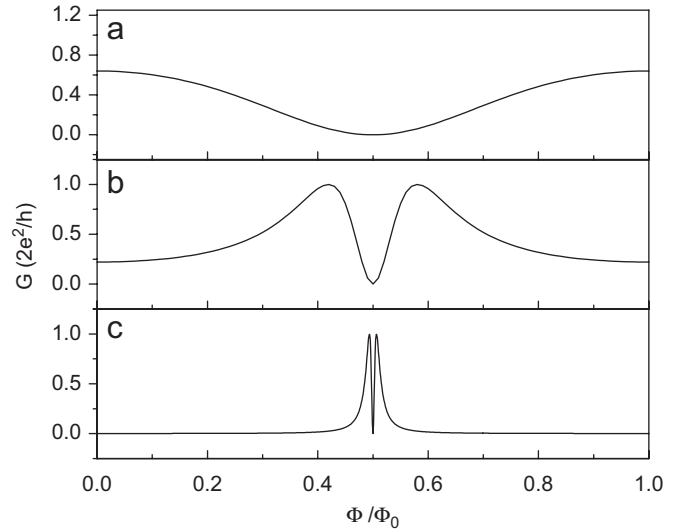


Fig. 3. Conductance versus magnetic flux at the center of the band for $V = 0.1$, and (a) $t_c = 0.04$, (b) $t_c = 5 \times 10^{-3}$ and (c) $t_c = 4 \times 10^{-4}$.

as a function of the magnetic flux for $V = 0.1$ and different values of t_c . Whenever t_c fulfills $|t_c^2 v^2 / 2V^4 - 1| \leq 1$ (as in Fig. 3b and c), the conductance reaches the unity for values of the flux given by $\Phi = \arccos(t_c^2 v^2 / 2V^4 - 1) \Phi_0 / 2\pi$.

As main results, due to quantum interference, this system exhibits up to two BICs simultaneously, and perfect transmission occurs even for very weak intramolecular couplings.

Acknowledgments

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