Edge states in graphene quantum dots: Fractional quantum Hall effect analogies and differences at zero magnetic field

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We investigate the way that the degenerate manifold of midgap edge states in quasicircular graphene quantum dots with zig-zag boundaries supports, under free-magnetic-field conditions, strongly correlated many-body behavior analogous to the fractional quantum Hall effect (FQHE), familiar from the case of semiconductor heterostructures in high magnetic fields. Systematic exact-diagonalization (EXD) numerical studies are presented for the first time for 5 <= N <= 8 fully spin-polarized electrons and for total angular momenta in the range of N(N-1)/2 <= L <= 150. We present a derivation of a rotating-electron-molecule (REM) type wave function based on the methodology introduced earlier [C. Yannouleas and U. Landman, Phys. Rev. B 66, 115315 (2002)] in the context of the FQHE in two-dimensional semiconductor quantum dots. The EXD wave functions are compared with FQHE trial functions of the Laughlin and the derived REM types. It is found that a variational extension of the REM offers a better description for all fractional fillings compared with that of the Laughlin functions (including total energies and overlaps), a fact that reflects the strong azimuthal localization of the edge electrons. In contrast with the multiring arrangements of electrons in circular semiconductor quantum dots, the graphene REMs exhibit in all instances a single (0,N) polygonal-ring molecular (crystalline) structure, with all the electrons localized on the edge. Disruptions in the zig-zag boundary condition along the circular edge act effectively as impurities that pin the electron molecule, yielding single-particle densities with broken rotational symmetry that portray directly the azimuthal localization of the edge electrons.

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