Shell filling and trigonal warping in graphene quantum dots

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The investigation of the quantum dot ground states, excited states and addition spectra led to a complete understanding of the orbital and spin degeneracies of quantum dots in traditional semiconductors like InGaAs, GaAs and silicon, and hence made these quantum dots interesting as solid-state qubits. For vertical quantum dots etched into a circular geometry shell filling and Hund's rule spin filling was observed [1]. Another promising material for solid state qubits is graphene [2]. Graphene offers an environment with few nuclear spins (reducing hyperfine interactions compared to III-V semiconductors) and it is a light element (reducing spin-orbit effects even compared to silicon). Compared to other conventional semiconductors, electrons in bilayer graphene possess an additional valley degree of freedom and a non-trivial minivalley band-structure due to trigonal warping [3]. Applying a displacement field perpendicular to the bilayer graphene sheet opens a bandgap and forms three shallow minivalleys around the K and K' points, this allows to electrostatically define and control quantum dots [4]. However, the formation and relevance of the minivalleys for low-energy quantum dot states can be tuned by the band gap and the size of the quantum dot.

Here, we experimentally investigate shell filling effects in a nearly circular quantum dot in bilayer graphene [5]. Starting from the empty quantum dot we observe a successive bunching of four, eight and twelve conductance resonances, which becomes visible in the addition energy as shown in Fig. 1. We describe this observation in terms of a transition from a level scheme given by two-dimensional s- and p-shells for the first electrons to a level scheme dominated by mini-valleys with three-fold degeneracy.

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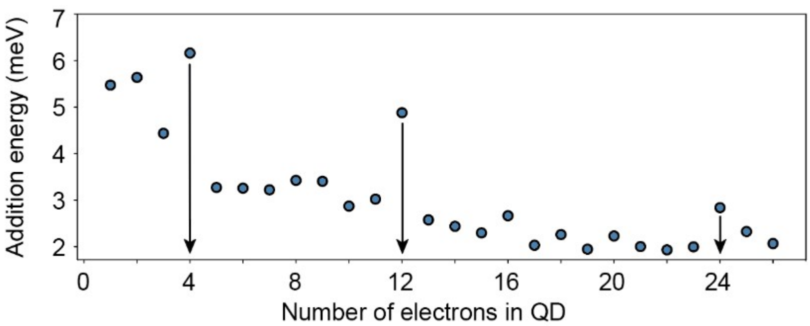

Figure 1: Addition energy for an extra electron versus number of electrons in the dot extracted from the separation between Coulomb resonances in a conductance trace.