Spectral Properties of Incommensurate Double-walled Carbon Nanotubes

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Carbon nanotubes are of immense fundamental and technical interest. While many theoretical and experimental studies have demonstrated that single-walled nanotubes (SWNTs) exhibit ballistic electron conduction, the transport properties of multi-walled nanotubes (MWNTs) are not well understood and even still controversial; conductance measurements using scanning probe microscope showed ballistic behavior, while magneto-resistances measured for MWNTs on top of metallic gate indicated diffusive conduction.

Instead of directly investigating transport properties, we consider here the spectral properties of incommensurate double-walled nanotubes (DWNTs) which are the most simple system among MWNTs. If concentric carbon shells are especially incommensurate, the Bloch theorem is no longer valid, and the Landauer formula for conductance is not applicable because it is difficult to count the number of conducting channels of nanotubes in micron size without information on their electronic band structure. The spectral statistics has proven to be a useful tool to get insight on the dynamics of systems when it is hopeless to investigate individual quantum states.

We investigate the spectral properties of incommensurate double-walled nanotubes using the tight-binding method, and find that the spectral statistics follows the Poisson, Gaussian orthogonal ensemble (GOE) of random-matrix theory, or semi-Poisson (SP) distribution, depending on the energy window, while the overall states are well described by the SP distribution, as shown in Fig. 1.

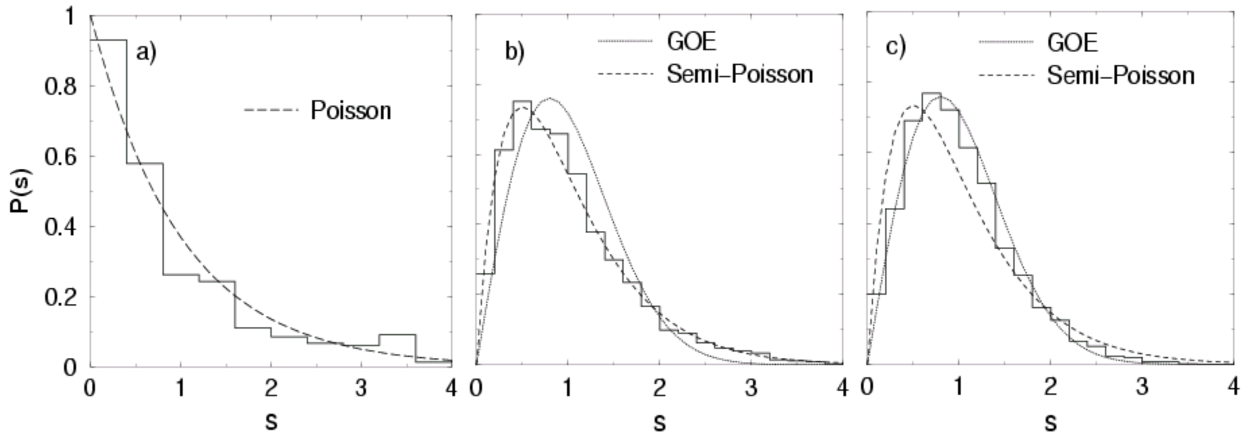

FIG. 1. The nearest energy spacing distribution P(s) of the (16,5)/(23,8) DWNT on the energy windows of (a) (0.08,1.3eV) with 511 levels, (b) (1.0,2.5eV) with 1872 levels, and (c) (2.5,3.5eV) with 2696 levels.

When the Fermi energy is close to the charge neutral point, the interwall coupling is so weak that the electron conduction essentially takes place in each layer of nanotubes. Our result indicates that the electron dynamics in incommensurate double-walled nanotubes can be either ballistics or diffusive, depending on the location of the Fermi energy. The appearance of three different spectral statistics is robust to the helicities of double-walled nanotubes provided they are incommensurate. We also discuss the dependence of the spectral statistics on nanotube length, diameter, and inter-wall interaction strength, considering many types of incommensurate DWNTs.