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Modulation of the energy gap in carbon nanotubes threaded by magnetic field

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Carbon nanotubes are molecules that have an atomic lattice equivalent to the hexagonal lattice of a single layer of graphite, seamlessly rolled into a cylinder. Their electronic properties are determined by the chirality or wrapping angle. Depending on the chirality, the molecule may have a gap in the electronic spectrum and behave as a semiconductor, or it may have zero gap and exhibit properties of a one-dimensional metal. Although, practically, it is impossible to change the chirality of a given molecule, it is possible to achieve an equivalent effect by applying a strong magnetic field along the axis of the nanotube. This behavior arises from Aharonov-Bohm coupling of the magnetic vector-potential, which is determined by the magnetic flux threading the nanotube, to the orbital motion of the electrons. In particular, the energy gap is predicted to oscillate periodically with magnetic flux, with a period of h/e. This effect, known as Ajiki-Ando (AA) splitting [1], offers the possibility of interconversion of metallic tubes into semiconducting ones and vice-versa, via a magnetic field. Our recent experiments[2] provide an experimental evidence for the AA energy-gap modulation. These measurements were performed on single electron tunneling (SET) transistors based on multiwall carbon nanotubes, in the quantum dot regime. Multiwall nanotubes are unique molecules in that they allow an application of a full magnetic flux quantum, due to their large diameter. The SET transistors used in this study showed the usual pattern of Coulomb diamonds and signatures of resonant tunneling and Zeeman splitting. Therefore the observed pattern of Coulomb peaks and their displacements with the magnetic field could be interpreted as a pattern of single-electron energy levels and was used to study their response to the magnetic flux. Spectroscopic measurements at higher bias showed an energy gap, which was induced and modulated by the magnetic flux. The period of the observed modulation was h/e, as expected for the AA splitting, while the modulation amplitude was lower than expected. [1] H. Ajiki, T. Ando, J. Phys. Soc. Jpn., Vol.62, p.1255 (1993). [2] U.C. Coskun, T.-C. Wei, S. Vishveshwara, P. M. Goldbart, and A. Bezryadin, Science, Vol.304 p.1132 (2004).