Zero modes, energy gaps, and the quantum Hall effect of the graphene

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Recently, monolayer graphite (graphene) was fabricated, and unconventional quantum Hall effect $\sigma_{xy} = 2(2n+1)\frac{e^2}{h}$ (n: integer) has been observed [1,2]. At the same time, Hall plateau $\sigma_{xy} = 0$ has been reported experimentally [3].

We investigate zero modes and energy gaps of the graphene in a uniform magnetic field.

We change the value of the hopping integral t as a parameter, and examine the structure of zero modes and energy gaps systematically.

Zero modes always exist below $t = 1$ (the usual graphene state), but they begin to disappear at $t \gtrsim 1$. This means that the usual graphene state corresponds to a kind of quantum phase transition point. We have another quantum phase transition point at $t = 2$. For $t \leq 2$, we have zero modes for some value of the magnetic flux, but for $t > 2$, we always have gaps around zero energy.

On the basis of the energy spectra, we discuss the quantum Hall effect in terms of the topological number (Chern number). Zero Hall conductance is obtained by gaps around zero energy.

[1] K.S.Novoselov et.al., Nature **438**, 197 (2005).

[2] Y.Zhang et.al., Nature **438**, 201 (2005).

[3] Y.Zhang et.al., Phys. Rev. Lett **96**, 136806 (2006).