Strain Induced Quantum Hall Phenomena of Excitons in Graphene

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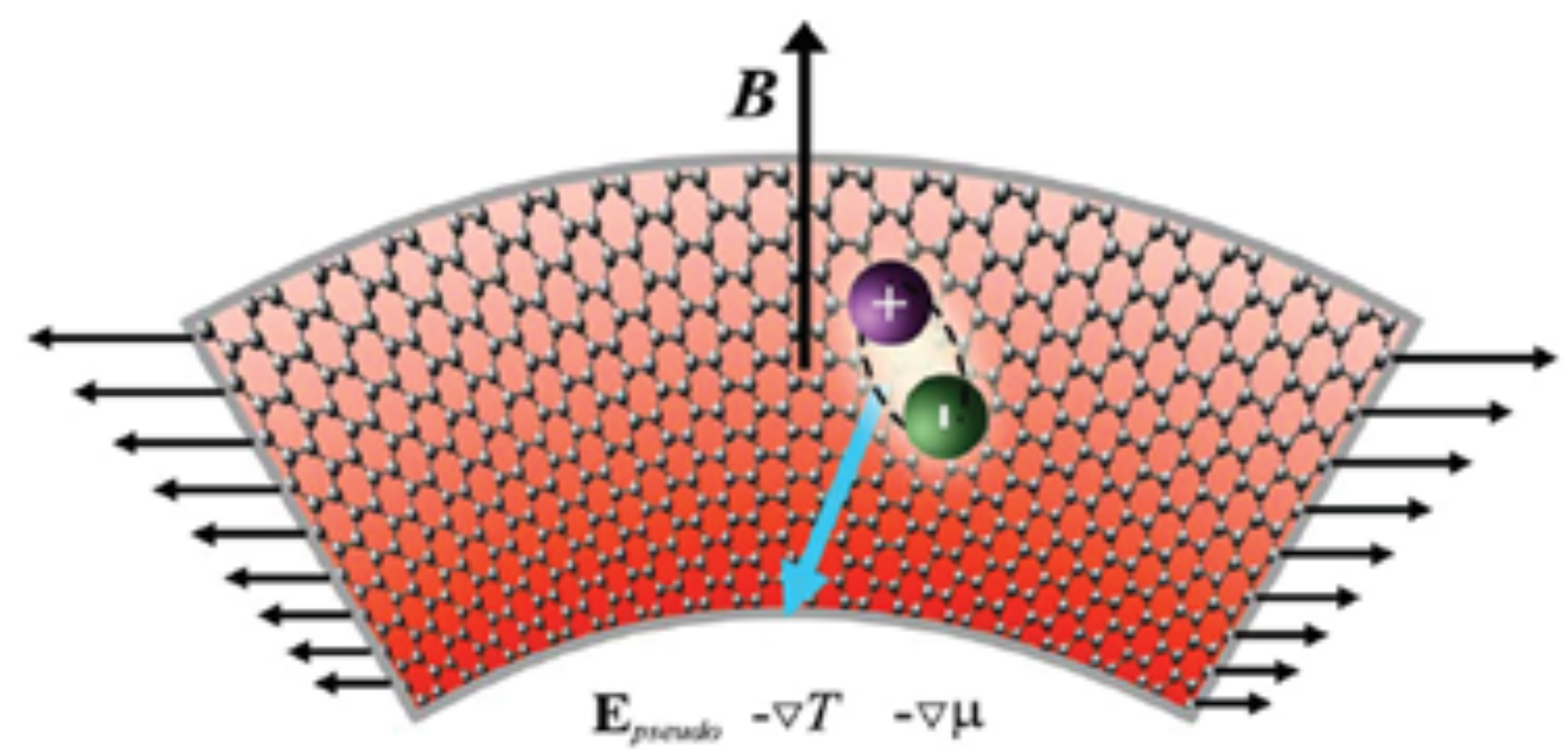
Summary

1. We predict quantum Hall phenomena for excitons in a mono and double layer of gapped graphene under strain induced gauge pseudomagnetic field (PMF).
2. When electrons and holes are excited only in one valley of the honeycomb lattice of gapped graphene, the strain induced pseudomagnetic field acts on electrons and holes the same way.
3. Wave functions and the energy spectrum of direct and indirect pseudomagnetoexcitons (PMEs) in a mono and double layer of gapped graphene are obtained.
4. The valley Hall flows of direct and indirect PME's, similar to Hall currents of charged particles, can be excited in a mono or double layer of gapped graphene, respectively.
5. The predicted quantum Hall phenomena for the PMEs are important, since they imply that the quantum Hall physics and valleytronics phenomena can be observed in the novel system of neutral bosons without magnetic field.

Conceptual picture of quantum Hall effect of PMEs in graphene.



Dirac equation for a pair of an electron and a hole

$$(H_0 + V(|\mathbf{r}_1 - \mathbf{r}_2|))\Psi = \mathcal{E}\Psi$$

$$H_0 = v_F \sum_{j=1}^{2} \begin{pmatrix} 2\Delta/v_F & i\hbar\partial_{x_j} + A_x(\mathbf{r}_j) + \hbar\partial_{y_j} - iA_y(\mathbf{r}_j) \\ i\hbar\partial_{x_j} + A_x(\mathbf{r}_j) - \hbar\partial_{y_j} + iA_y(\mathbf{r}_j) & -2\Delta/v_F \end{pmatrix}, \quad \Psi = \begin{pmatrix} \psi_1(\mathbf{r}_1, \mathbf{r}_2) \\ \psi_2(\mathbf{r}_1, \mathbf{r}_2) \end{pmatrix}$$

In stark contrast to the vector potential of the electromagnetic field, the strain induced effective vector potentials A(r1) and A(r2), acting on an electron and a hole, forming PME, are not coupled to the charges of the particles and have the same sign in the Hamiltonian, and these potentials act on e and h the same way, and the quasi-Lorentz force due to PMF can be exerted on a moving PME.

Total energy of a direct magnetoexciton

$$\mathcal{E}_{n,\tilde{n},\tilde{m}} = \mathcal{E}_{0n,\tilde{n}} + E'_{\tilde{n},\tilde{m}},$$

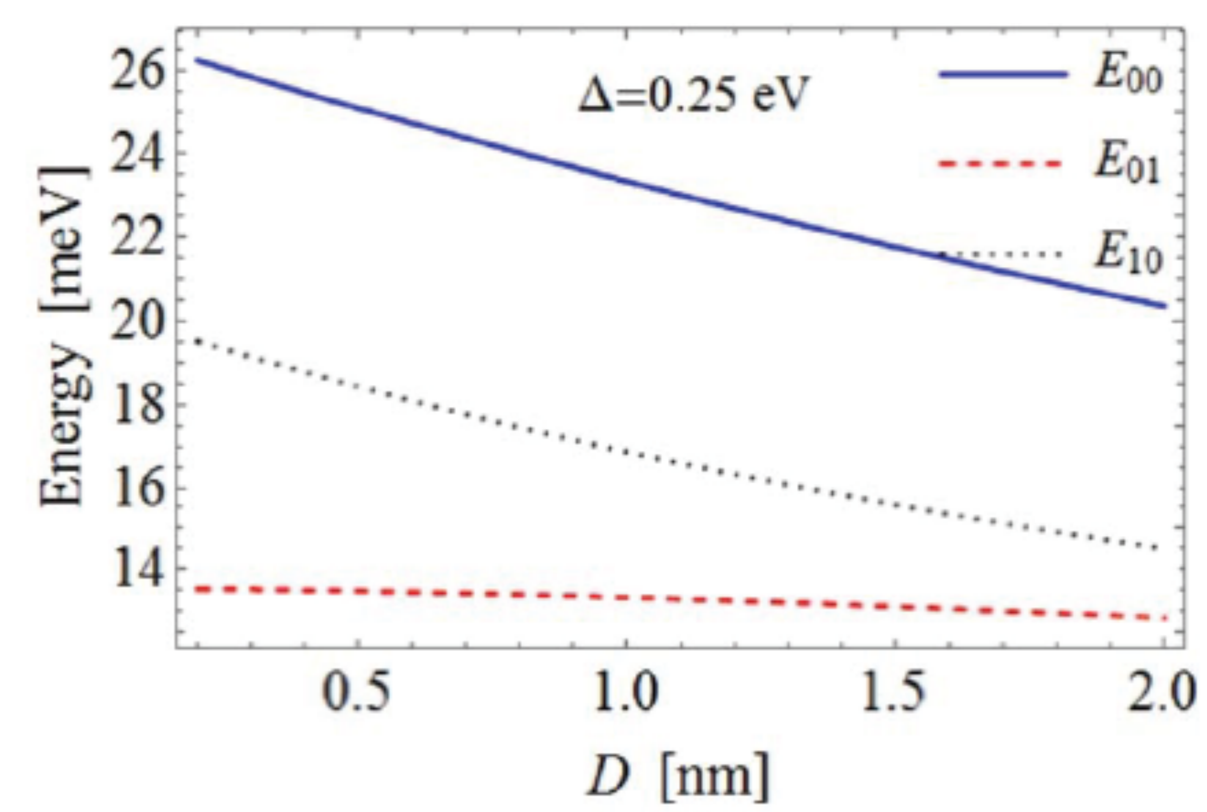
$$\mathcal{E}_{0n,\tilde{n}} = \sqrt{4\hbar v_F^2 B_z n + 16\Delta^2} + \sqrt{\hbar v_F^2 B_z \tilde{n} + \Delta^2}$$

V (r) is the electron-hole attraction potential

The first-order perturbation theory:

$$E'_{\tilde{n},\tilde{m}} = \langle \Psi_{n,m,\tilde{n},\tilde{m}}(\mathbf{R},\mathbf{r}) | V(r) | \Psi_{n,m,\tilde{n},\tilde{m}}(\mathbf{R},\mathbf{r}) \rangle = \left\langle \tilde{\varphi}^{(0)}_{\tilde{n},\tilde{m}}(\mathbf{r}) | V(r) | \tilde{\varphi}^{(0)}_{\tilde{n},\tilde{m}}(\mathbf{r}) \right\rangle$$

The dependence of energies $E'_{\tilde{n},\tilde{m}}$ of indirect PMEs on the separation D between gapped graphene layers. Calculations performed for the value of magnetic length l that corresponds to $B/e = 50$ T.



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