Landau level formation in Graphene quantum dots

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Graphene Flakes

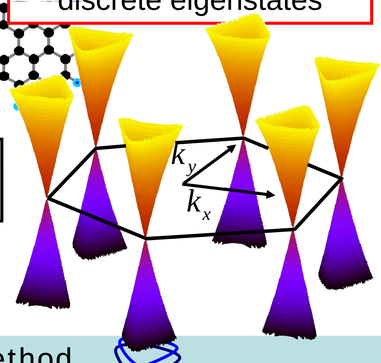
Eigenstates of graphene flakes are investigated[1]

C-atom
H-atom

Finite size flake: band structure collapses to discrete eigenstates

Hydrogen-terminated edges

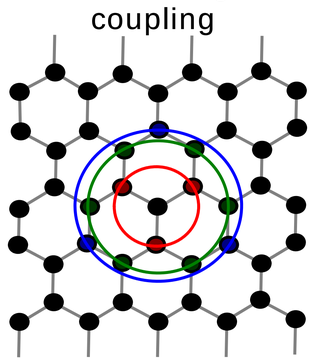
zigzag
armchair



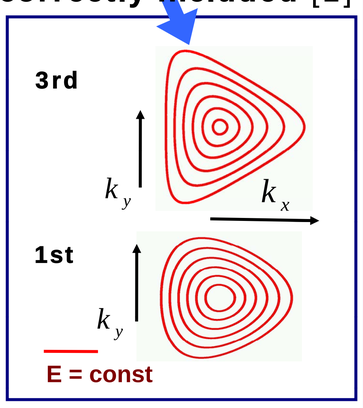
Method

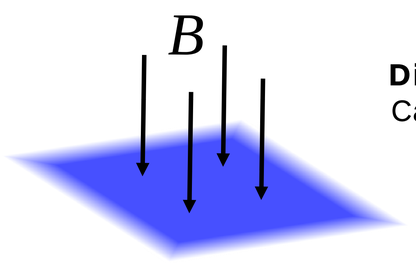
tight binding approximation

3rd nearest neighbour coupling



Triangular warping correctly included [2]





Lanzcos-Diagonalization [3]
Calculate parametric evolution of eienenergies as function of **perpendicular magnetic field** *B*

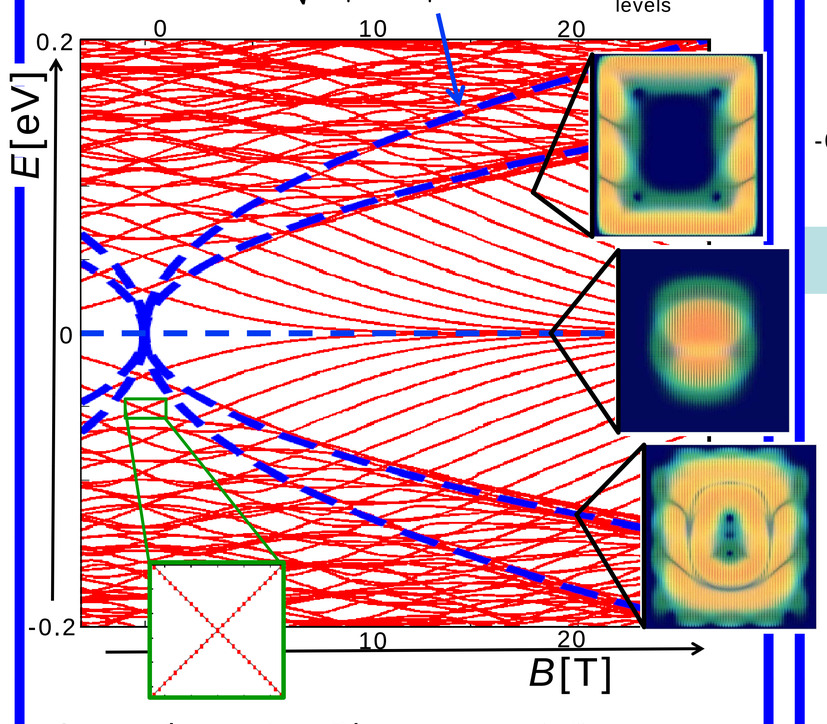
Linear dimension ***d*** between **50 and 100 nm (250000 – 1000000 carbon atoms)**

Ideal case

Landau level formation for Dirac fermions:

$$E_n = \mathrm{sgn}(n)\sqrt{2\left|enB\right|\hbar v_F^2}$$

Wavefunctions feauture characteristic patterns in different Landau levels



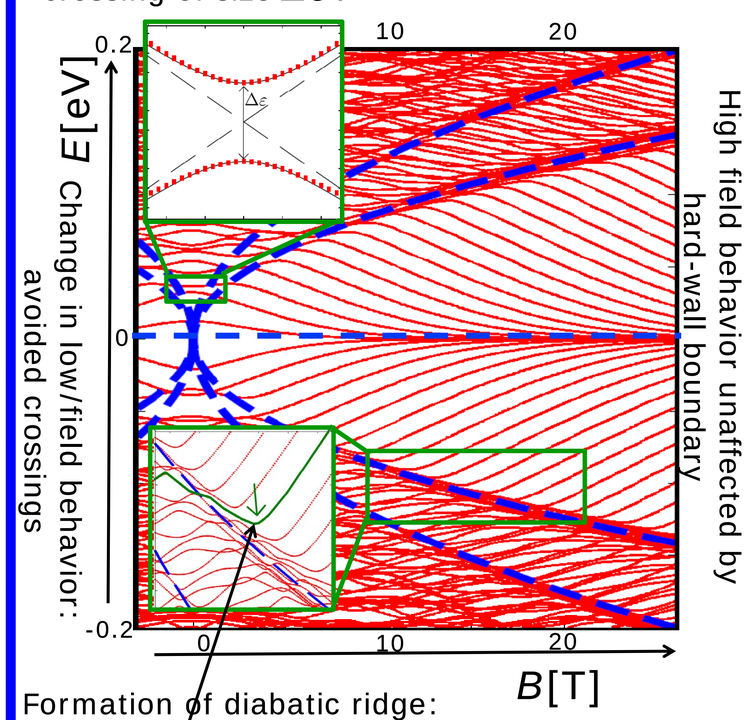
In graphene: two Dirac cones. *K*-*K*‘ degeneracy lifted by *B* field. If no *K*-*K*‘ scattering present: X-shaped crossing

Hard boundaries [4]

Rectangular geometry with zigzag / armchair boundaries

Reflections at hard-wall boundary couple K and K‘ cone!

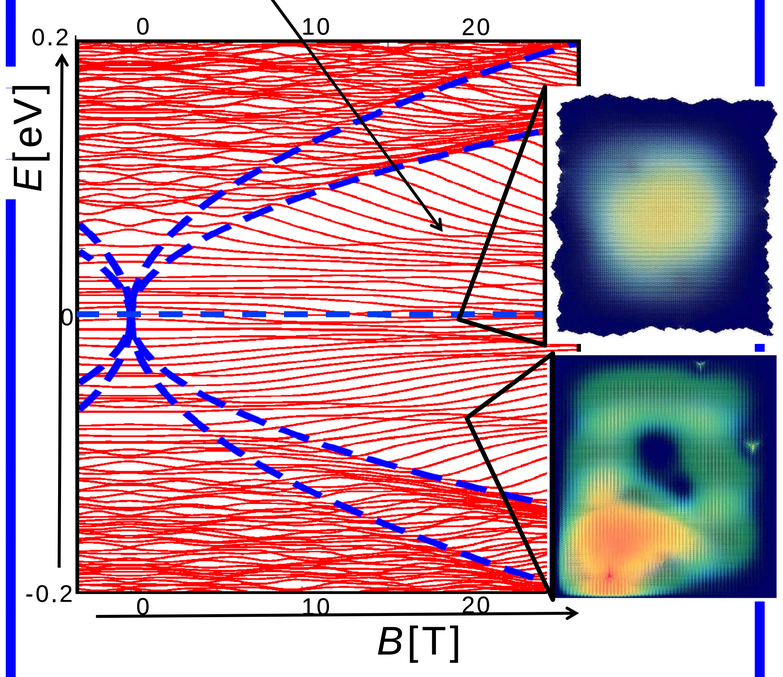
X-shaped crossing replaced by avoided crossing of size $\Delta\varepsilon$.



Formation of diabatic ridge:
Distinct kinks when crossing first Landau level
Pin down e-h crossover region in experiment [5]

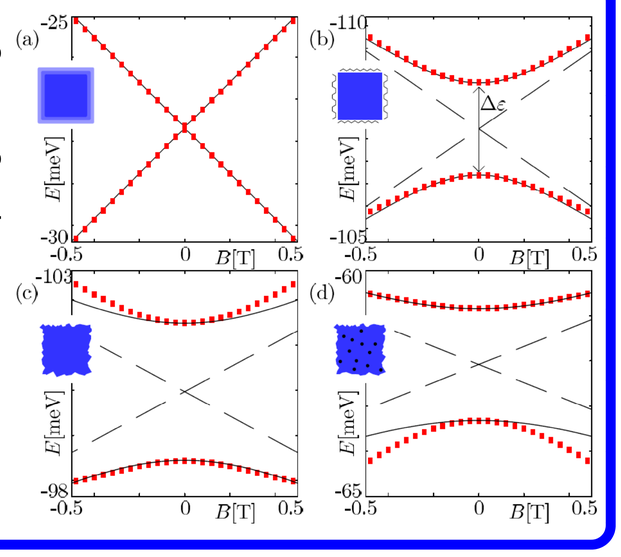
Disorder [4]

Localized states appear at defects / rough edges and persist to high *B* values

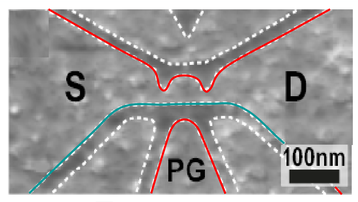


Avoided crossings

Size and symmetry of avoided crossings give quantitative stimate of K-Kä coupling strength

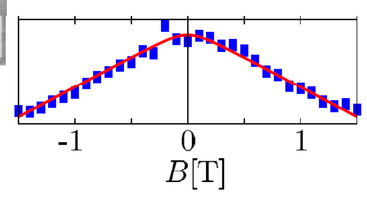


Experiment [4,5]



Transport measurements of 50nm graphene quantum dot

Measure parametric motion of Coulomb blockade peaks with *B*

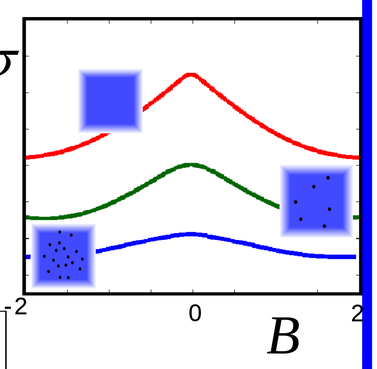


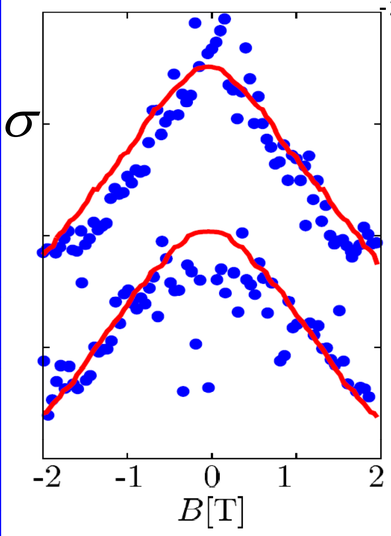
Assess K-K’ coupling

Variance of mean level spacing

$$\sigma = \sqrt{\left\langle \delta\varepsilon^2 \right\rangle - \left\langle \delta\varepsilon \right\rangle^2}$$

decreases with increasing K-K’ scattering





Experiment
Theory

Variance of mean level spacing: peak at B=0 due to K-K‘ symmetry: **quantitative measure of K-K‘ scattering in experiment**

Conclusions

- K/K‘ symmetry destrozed by zigzag & armchair boundaries
- Avoided crossing of states yields kink pattern
- Size of avoided crossings at B=0 allow estimate of K/K‘ coupling

Future directions

- Crossover from short to longe range disorder potential
- Magneto-transport properties

Acknowledgements

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References

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[5] F. Libisch, S. Rotter, J. Güttinger, C. Stampfer, and J. Burgdörfer, PRB **81**, 245411 (2010)