Corbino disk

In graphene & magneto transport properties

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1 January 2012

Outline:

Graphene review

Transport properties

- magneto transport

Corbino geometry

Magneto conductance in Corbino disk

Conclusion

Graphene review

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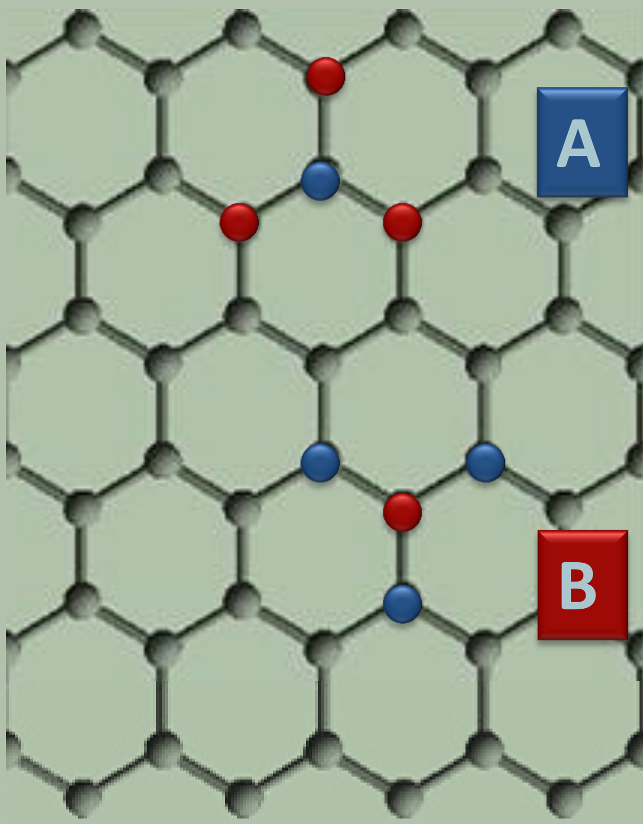
A two dimensional atomic crystal of carbon

With two sub lattices



- One atom thick crystal
- Hard, flexible, rippled
- Variety of applications

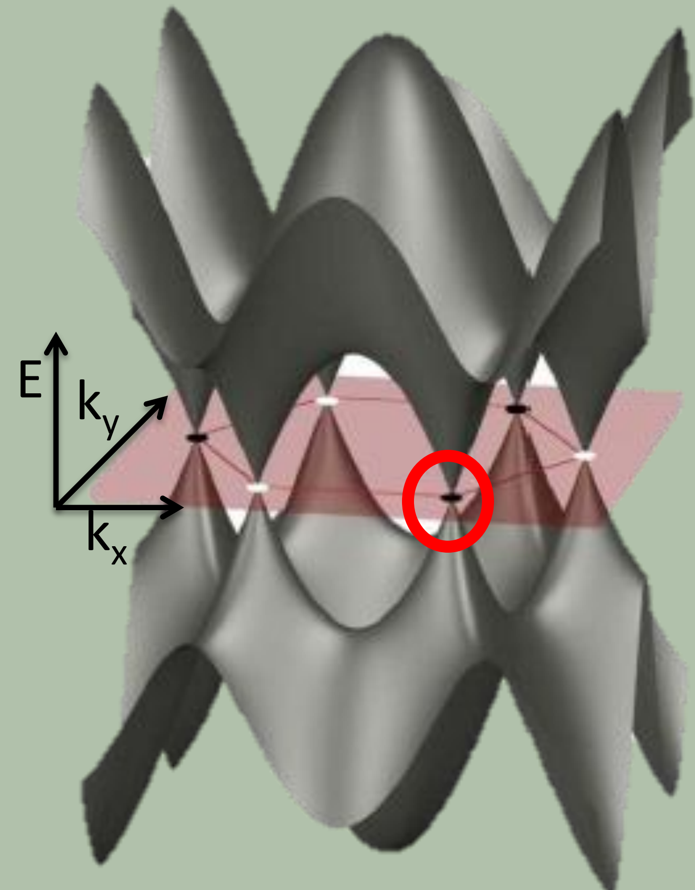
Two dimensional Dirac fermions

at the six corners of the BZ

Expansion of energy around a Fermi point :

$$-iv_F\boldsymbol{\sigma}\cdot\nabla\psi(\mathbf{r})=E\psi(\mathbf{r})$$

$$v_F\simeq 1\times 10^6\ \mathrm{m/s}$$



Band structure of a carbon monolayer

C. W. J. Beenakker, RevModPhys.80.1337

Transport properties

Pseudodiffusive dynamics (ribbons)

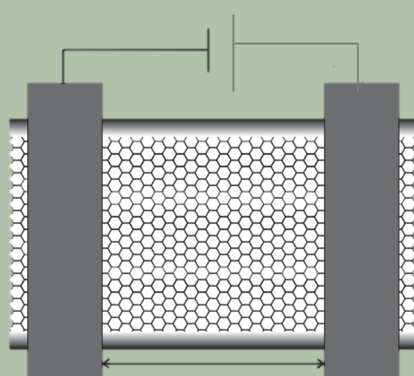
an ideal strip of graphene (no impurities or defects) $W/L \to \infty.$

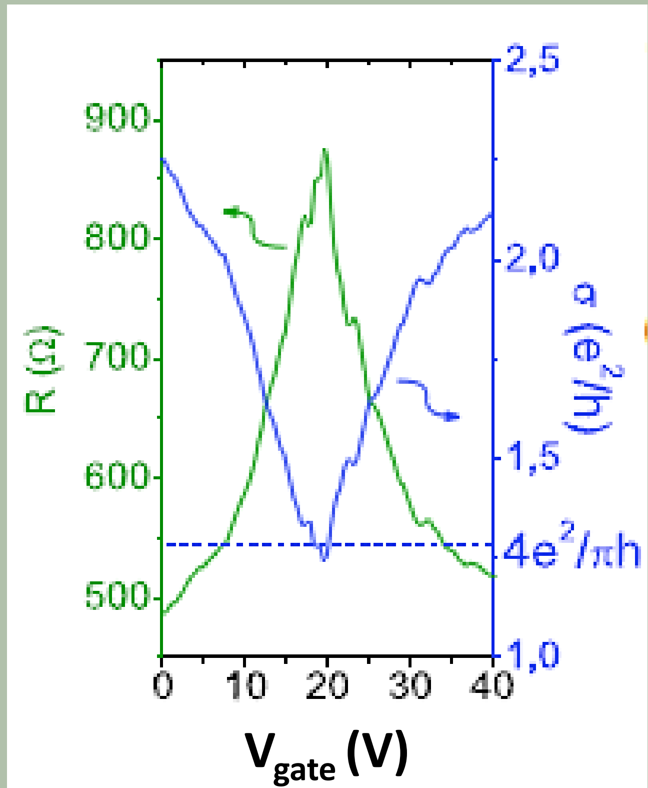
→ transmission via evanescent (exponentially decaying modes) $G \propto W/L$ ← disordered metals

minimum conductivity in the Dirac point (zero DOS):

$$\sigma \to g_0/\pi,$$

$$g_0 = 4e^2/h$$





J. Tworzydło et al., PRL 96, 246802 (2006)
R. Danneau et al., PRL 100, 196802 (2008)

Magneto transport

transport properties in presence of a external magnetic field

Dirac fermions in a perpendicular magnetic field

Landau gauge: $\mathbf{A} = B(-y, 0)$

Landau levels: $E_{\pm}(N) = \pm\,\omega_c\sqrt{N}$

$N = 0, 1, 2, \ldots$

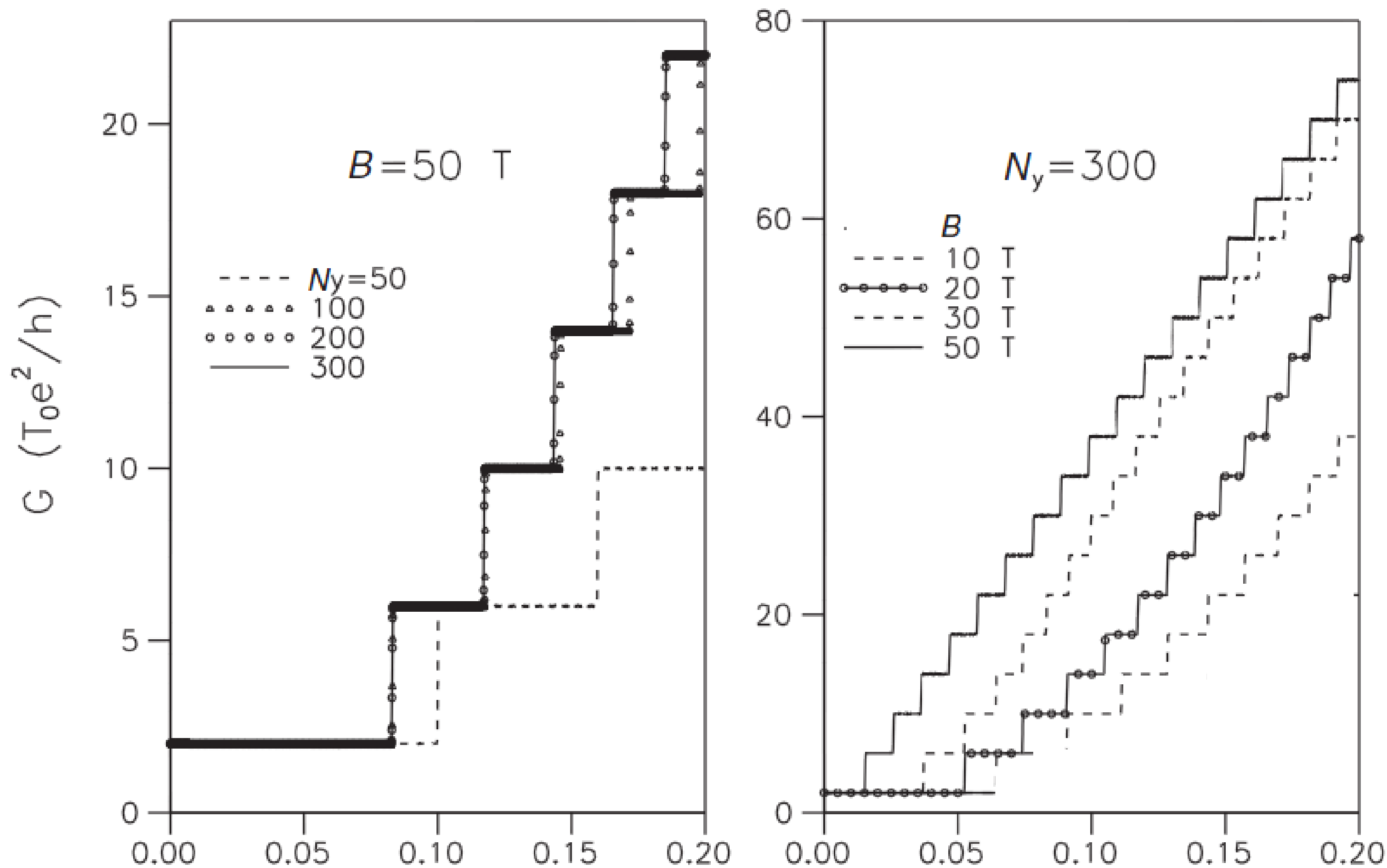
Cyclotron frequency: $\omega_c = \sqrt{2}\dfrac{v_F}{\ell_B}$

Magnetic length: $\ell_B = \sqrt{\dfrac{c}{eB}}$

A. H. Castro Neto et al., RevModPhys.81.109 (2009)

Magneto transport (ribbons)

magnetic confinement and the size effect in a competition



Conductance as a function of chemical potential

T. S. Li et al., Philos. Mag. **89**, 697 (2009)

Corbino geometry

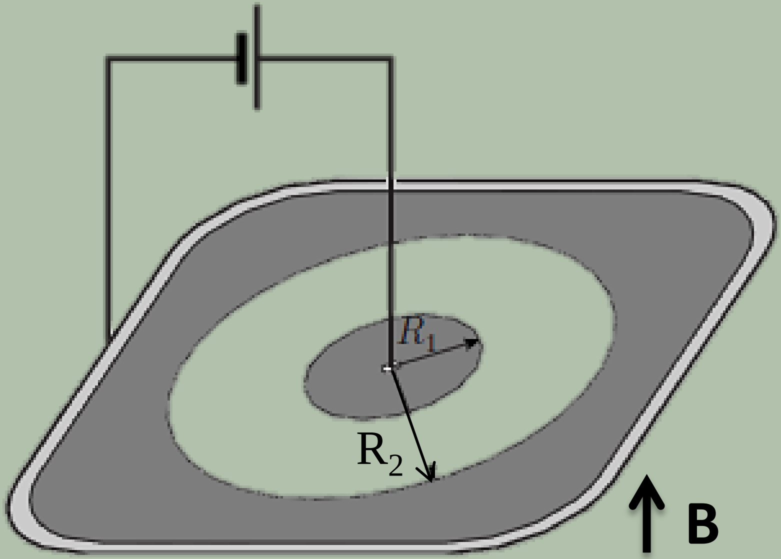
What is Corbino geometry?

disk-shaped sample with coaxial contacts with
No edge influence
which was used as experimental setup (1911) by
Orso Mario Corbino
For magneto resistance measurements.

O. M. Corbino
(1876-1937)

Applications:

- a good rectifier and voltage regulator
- expellant or amplifier of external field (detector of weak fields)
- microwave Spectroscopy



D. A. Kleinman et al., J. Appl. Phys. **31**, 2176 (1960)

Magneto conductance in Corbino disk

Magneto conductance in Corbino disk

$$H = v_F(p + eA)\cdot \sigma + U(r)$$

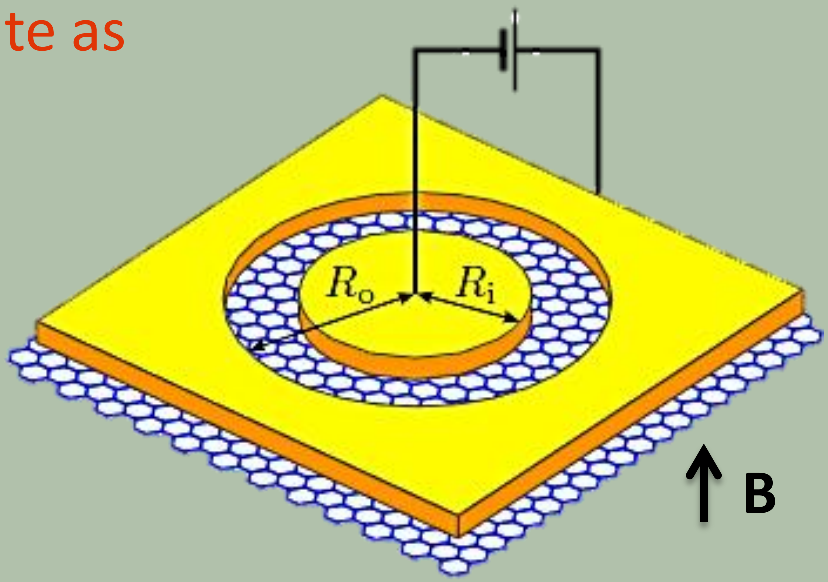
$$v_F = 10^6 \ \ \mathrm{m/s}$$

Electrostatic potential

$$\begin{cases} U(r) = U_0 & (R_i < r < R_o) \\ U(r) = U_\infty & \text{otherwise} \end{cases}$$

A two spinor component eigen state as a result of two sub lattice

$$\psi_j(r,\varphi) = e^{i(j-1/2)\varphi}\begin{pmatrix} \chi_{j\uparrow}(r) \\ \chi_{j\downarrow}(r)e^{i\varphi} \end{pmatrix}$$



j :Total angular momentum

$s = \uparrow, \downarrow$:lattice pseudospin

Magneto conductance in Corbino disk

$$\psi_j(r,\varphi) = e^{i(j-1/2)\varphi}\begin{pmatrix} \chi_{j\uparrow}(r) \\ \chi_{j\downarrow}(r)e^{i\varphi} \end{pmatrix}$$

Inner lead:

$$\chi_j^{(\mathrm{i})} = \frac{e^{\pm ik_\infty r}}{\sqrt{r}}\begin{pmatrix} 1 \\ 1 \end{pmatrix} + r_j \frac{e^{\mp ik_\infty r}}{\sqrt{r}}\begin{pmatrix} 1 \\ -1 \end{pmatrix}$$

Outer lead:

$$\chi_j^{(\mathrm{o})} = t_j \frac{e^{\pm ik_\infty r}}{\sqrt{r}}\begin{pmatrix} 1 \\ 1 \end{pmatrix}$$

$$k_\infty \equiv |E - U_\infty| / (\hbar v_F)$$

Disk area:

$$\chi_j^{(\mathrm{d})} = A_j \begin{pmatrix} \xi_{j\uparrow}^{(1)} \\ \pm iz_{j,1}\xi_{j\downarrow}^{(1)} \end{pmatrix} + B_j \begin{pmatrix} \xi_{j\uparrow}^{(2)} \\ \pm iz_{j,2}\xi_{j\downarrow}^{(2)} \end{pmatrix}$$

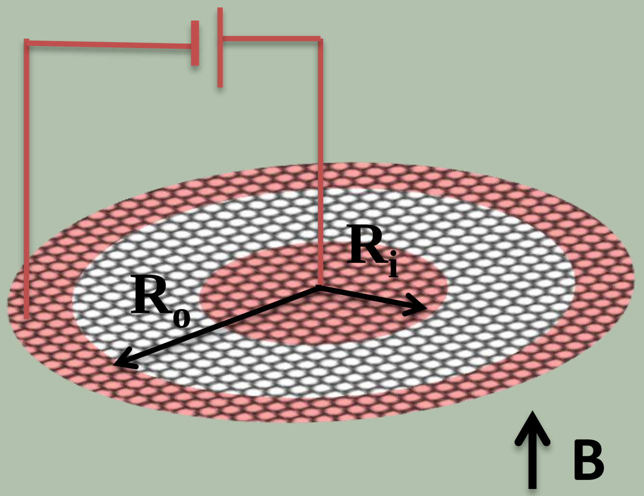
$$k_0 \equiv |E - U_0| / (\hbar v_F)$$

$\xi_{js}^{(\nu)}$:confluent hypergeometric functions

matching conditions on the boundaries:

$$\chi_j^{(\mathrm{o})}(R_\mathrm{o}) = \chi_j^{(\mathrm{d})}(R_\mathrm{o})$$

$$\chi_j^{(\mathrm{i})}(R_\mathrm{i}) = \chi_j^{(\mathrm{d})}(R_\mathrm{i})$$



Transmission probability:

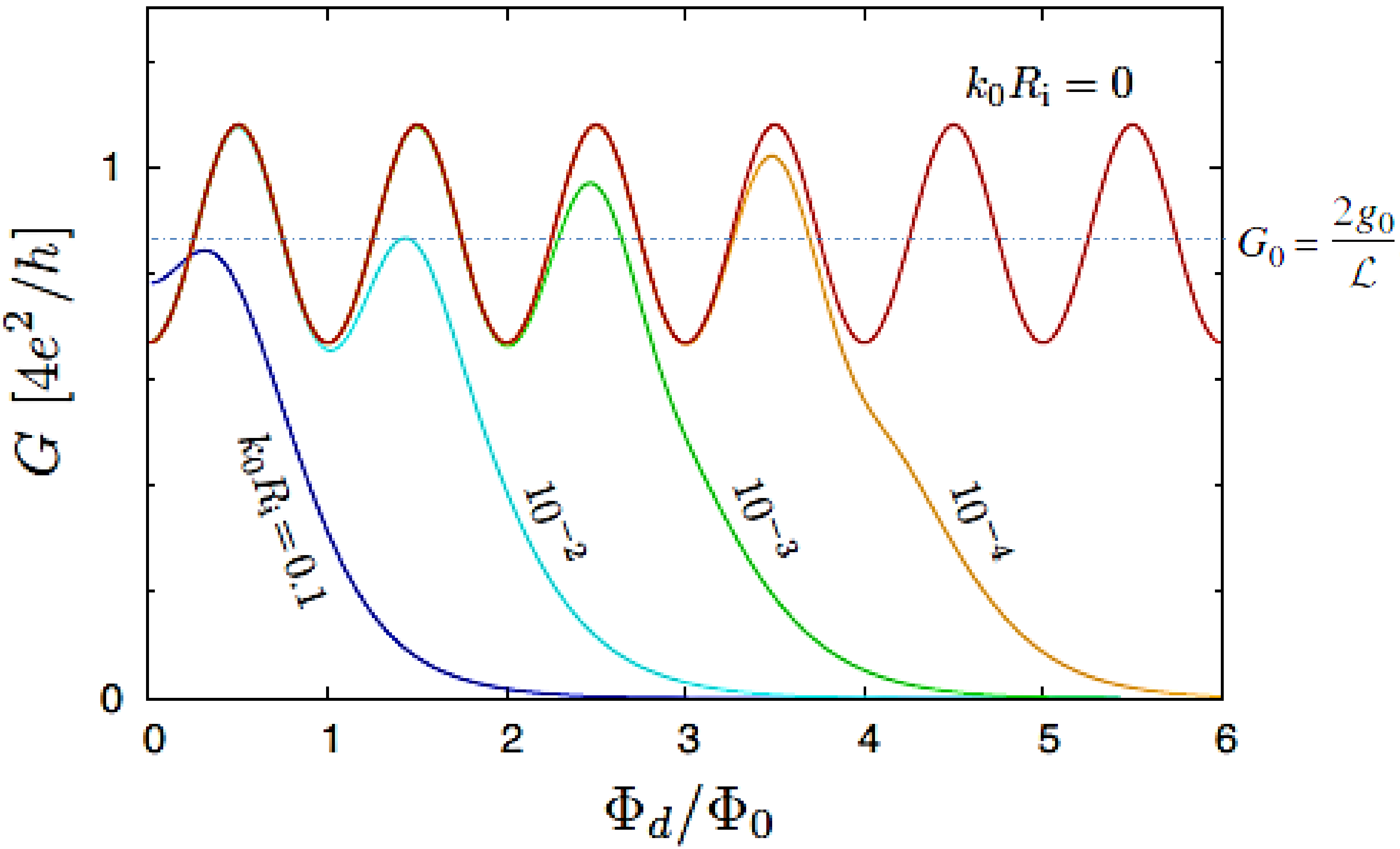
$$T_j = |t_j|^2 = \frac{16(k_0^2/\beta)^{|2j-1|}}{k_0^2 R_\mathrm{i} R_\mathrm{o}(X_j^2 + Y_j^2)} \left[\frac{\Gamma(\gamma_{j\uparrow})}{\Gamma(\alpha_{j\uparrow})}\right]^2$$

$Y_j \propto \xi_{js}^{(\nu)}$ $\quad X_j \propto \xi_{js}^{(\nu)}$ $\quad \alpha_{js}(j, k_0^2)$

Landauer-Büttiker formula:

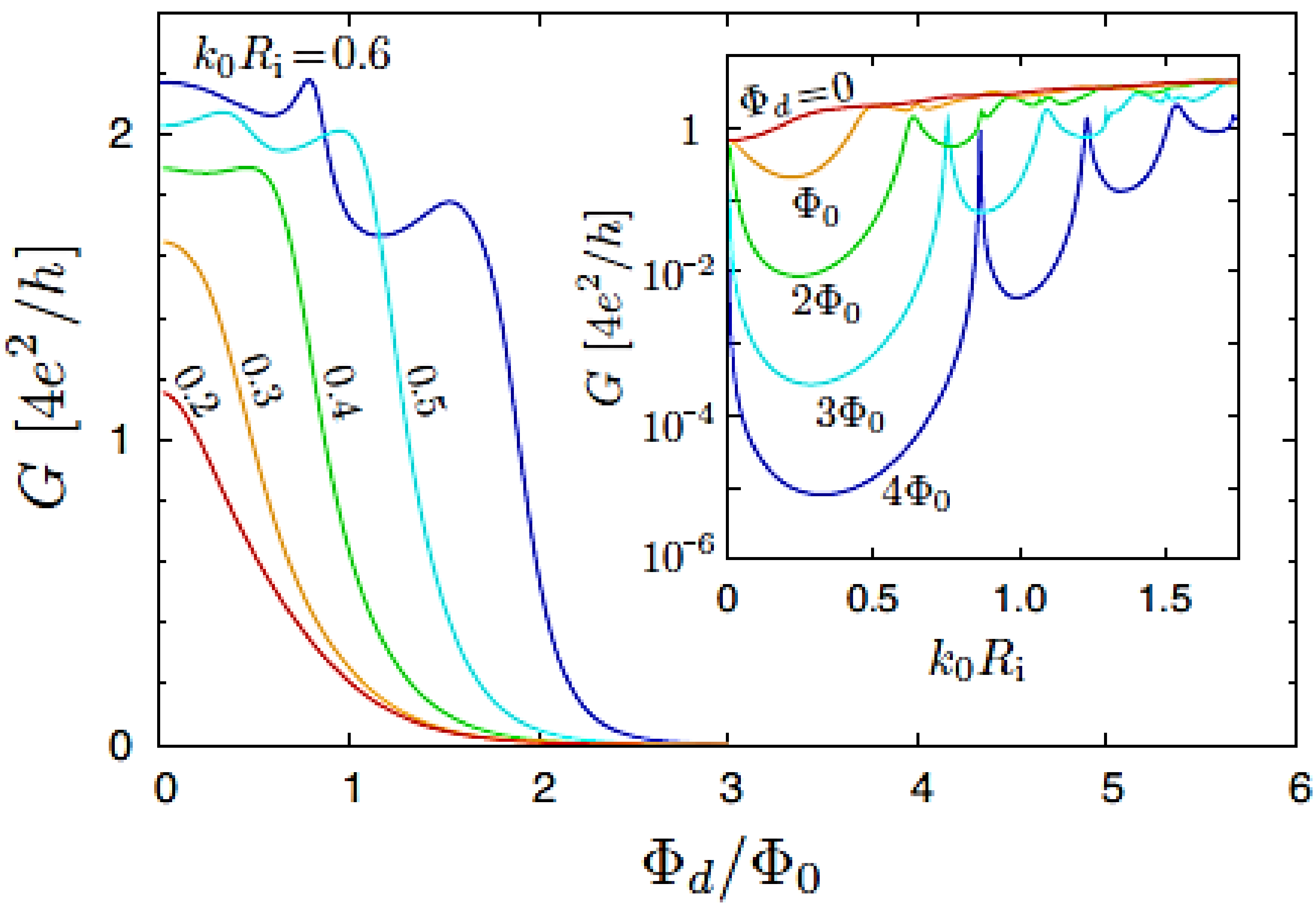
$$G = g_0 \sum_j T_j$$

Magneto conductance in Corbino disk



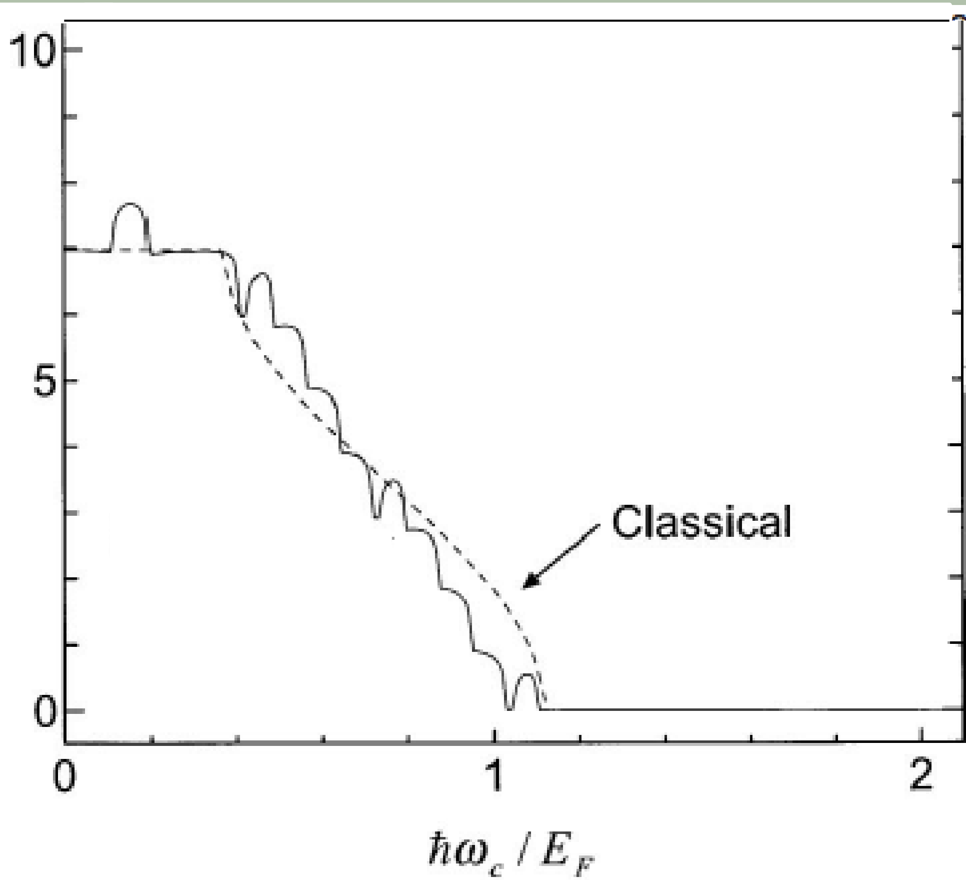
Conductance as a function of the magnetic field for (R_o / R_i =10)
Zero and weak doping

Magneto conductance in Corbino disk

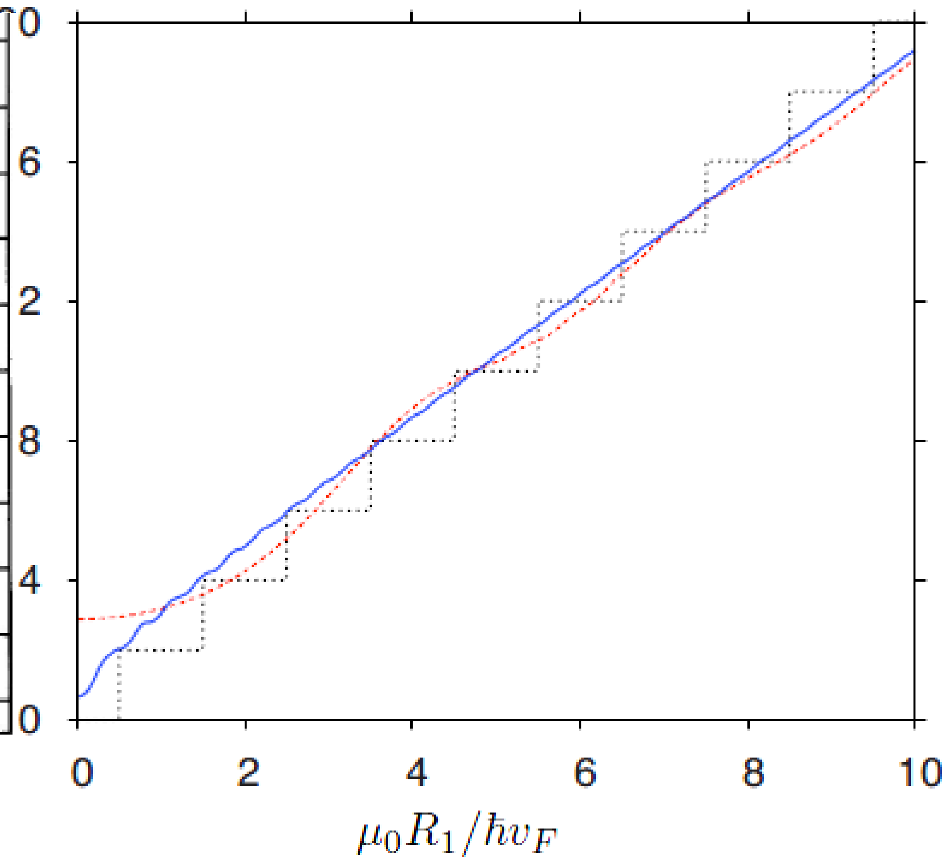


Conductance as a function of the magnetic field and doping for (R_o / R_i =10)

Classical approach and zero field correspondence



Conductance as a function of the magnetic field for 2DEG



Conductance as a function of chemical-potential (B=0)

S. Souma et al., PRB 60 15 928 (1999)
A. Rycerz et al., PhysRevB.81.121404 (2010)

Conclusion

- strongly dependence of conductance on the field strength.
- conductance oscillations observable at Dirac point.

Pictures were adapted from

Adam Rycerz, PRB **81**, 121404R (2010)

Thank you