Corbino disk
In graphene & magneto transport properties

Zahra Khatibi
Outline:
Graphene review
Transport properties
  magneto transport
Corbino geometry
Magneto conductance in Corbino disk
Conclusion
Graphene review
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:

\[ -i v_F \mathbf{\sigma} \cdot \nabla \psi(\mathbf{r}) = E \psi(\mathbf{r}) \]

\[ v_F \approx 1 \times 10^6 \text{ m/s} \]

C. W. J. Beenakker, RevModPhys.80.1337
Transport properties
transport properties

Pseudodiffusive dynamics (ribbons)

an ideal strip of graphene (no impurities or defects)

\[ \frac{W}{L} \rightarrow \infty. \]

transmission via evanescent (exponentially decaying modes)

\[ G \propto \frac{W}{L} \]

disordered metals

minimum conductivity in the Dirac point (zero DOS):

\[ \sigma \rightarrow \frac{g_0}{\pi}. \]

\[ g_0 = \frac{4e^2}{h} \]

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: \[ A = B(-y, 0) \]

Landau levels: \[ E_{\pm}(N) = \pm \omega_c \sqrt{N} \]

\[ N = 0, 1, 2, \ldots \]

Cyclotron frequency: \[ \omega_c = \sqrt{2} \frac{v_F}{\ell_B} \]

Magnetic length: \[ \ell_B = \sqrt{\frac{c}{eB}} \]

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.

**Applications:**

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

Magneto conductance in Corbino disk
Magneto conductance in Corbino disk

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

\[ v_F = 10^6 \text{ m/s} \]

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

\[ \psi_j(r, \varphi) = e^{i(j-1/2)\varphi} \left( \begin{array}{c}
\chi_{j\uparrow}(r) \\
\chi_{j\downarrow}(r)e^{i\varphi}
\end{array} \right) \]

\[ j \] : 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:**

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

**Outer lead:**

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

**Disk area:**

\[ \chi_j^{(d)} = A_j \left( \begin{pmatrix} \xi_{j\uparrow}^{(1)} \\ \pm iz_j,1 \xi_{j\downarrow}^{(1)} \end{pmatrix} \right) + B_j \left( \begin{pmatrix} \xi_{j\uparrow}^{(2)} \\ \pm iz_j,2 \xi_{j\downarrow}^{(2)} \end{pmatrix} \right) \]

\[ k_\infty = \frac{|E - U_\infty|}{\hbar v_F} \]

\[ k_0 = \frac{|E - U_0|}{\hbar v_F} \]

\[ \xi_{js}^{(\nu)} \text{: confluent hypergeometric functions} \]
Magneto conductance in Corbino disk

**matching conditions on the boundaries:**

\[ \chi_j^{(o)}(R_o) = \chi_j^{(d)}(R_o) \]

\[ \chi_j^{(i)}(R_i) = \chi_j^{(d)}(R_i) \]

**Transmission probability:**

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

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

**Landauer-Büttiker formula:**

\[ G = g_0 \sum_j T_j \]
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

\[ \frac{\hbar \omega_c}{E_F} \]

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

\[ \frac{\mu_0 R_1}{\hbar \nu_F} \]

S. Souma et al., PRB 60 15 928 (1999)
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