Graphene, electronic properties and transport (L Levitov)

---------- Lecture I ----------

Background, brief history. Electronic properties overview
a) gate-tunable mobility
b) strong magnetic fields, QHE
c) locally gated systems, p-n junctions

I Massless Dirac fermions in D=2

1. Carbon 0D, 1D, 2D, 3D
2. Electron spectrum of carbon monolayer
   a) tight-binding model
   b) Dirac model at K,K' points
   c) smaller effects: trigonal warping; spin-orbital coupling
3. Carbon monolayer in magnetic field:
   a) Relativistic Landau levels;
   b) Experimental tests

II Dirac particles in external fields

4. Chiral dynamics in p-n junctions
   a) Klein tunneling, collimated transmission
   b) Interband tunneling, Landau-Zener transitions, Bloch-Zener tunneling
5. Confinement problem
   a) quasi-stationary states, finite lifetime
   b) graphene quantum dots (experiment)
6. Dirac electron in crossed E and B fields
   a) The electric and magnetic regimes;
   b) Collapse of Landau levels
   c) Tunneling in B field

---------- Lecture II ----------

III Between 2D and 1D: from flatland to edge-land, dream-land and pipe-land

7. Graphene boundary
   a) Structure: zigzag, armchair, etc
   b) Surface modes, tight-binding and Dirac models
   c) STM spectroscopy
8. Valley transport
   a)
   b)
   c)
9. Electron properties of carbon nanotubes
   a) slice and roll
   b) semiconducting and metallic NT (gaps and minigaps)

IV Graphene Quantum Hall effect

10. QHE basics:
    a) Landau levels, disorder (integer QHE)
    b) interactions (fractional QHE)
11. "Half-integer" QHE
    a) Berry phase
    b) field-theoretic anomaly
12. Edge states
    a) Construction; 1D model for QHE edge transport
    b) Nondissipative transport
    c) Dissipative QHE near Dirac point
13. QHE in graphene bilayers

---------- Lecture III ----------

V Transport properties, interactions

14. Mobility vs density
    a) Drude model
    b) Coulomb scattering
15. Minimal conductivity
    a)
    b)
    c)
16. Interaction effects
    a) Fine structure constant
    b) Renormalization of self-energy and vertex
    c) RG flow

VI Supercritical Coulomb impurities

17. Relativistic fall-down in QED
    a) atomic collapse, quasiclassical (Z>137,)
    b) QM: Z>170 (overview)
18. Quasi-Rydberg states at Q>1/2
    a) Bohr-Sommerfeld analysis
    b) Complex energies, Klein confinement
    c) Scattering phases
19. Polarization breakdown at Q>1/2
    a) Screening and Vacuum polarization
    b) Friedel sum rule argument, log-divergence for nonintercating particles
    c) RG for screening cloud
    d) Thomas-Fermi approach