Carbon Materials [Le Hu]

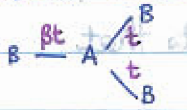
close in energy

- Atomic shell: $1s^2\,2s^2\,2p^2$

- Various pure element forms: fullerene, graphene, graphite, nanotube, dian
  sp² hybridization — trigonal planer; sp³ hyb — tetrah

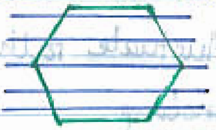
- Graphene can be described by tight-binding model of π-orbital
  $\Longrightarrow$ 2 inequivalent Dirac cones for nearest-neighbor tight-binding
  ▲ Introducing next-nearest-neighbor t' can break particle-hol symmetry. But still have 2 cones at half-filling.

- Dirac node also survive when NN-bonds vary in strength:

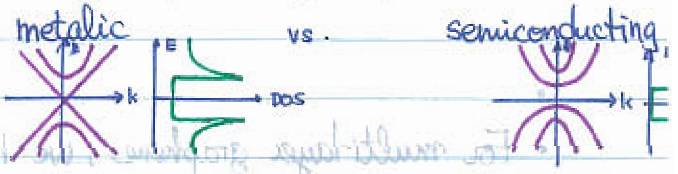


$\Longrightarrow$ Dirac nodes as long as $\beta < 2$.

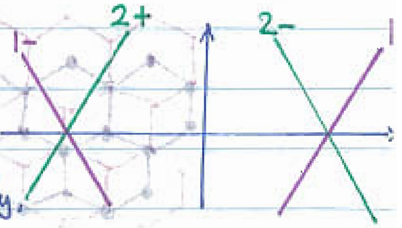
- Nanotubes are obtained by rolling graphene sheet along certain direction. In Brillouin zone e^- are restricted to certain lines



▲ Thus there are 2 cases: metalic vs. semiconducting,

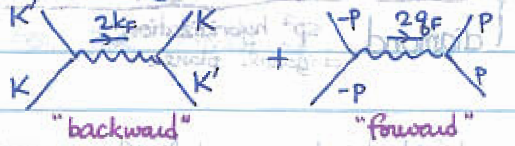


- Put in interaction, using previous techniques
  $\rightarrow \mathcal{H}_{int} = e^2 \ln(R_s/R) \int dx\, \rho_{tot}^2(x)$
  The interaction couples to total charge mode only.
  3 neutral modes are NOT affected.
  For charged mode, $g = \left[1 + \frac{8e^2}{v_F \pi \hbar} \ln(R_s/R)\right]^{-1/2}$

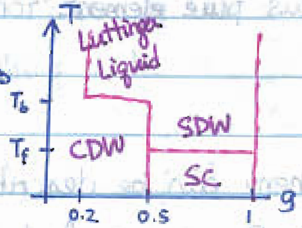


- From tunneling experiment, $g \approx 0.22$.

- In addition to long-ranged Coulomb, one can also put in short-ranged interaction:



$\Longrightarrow$

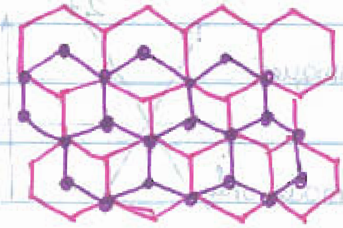


- Now consider two-dimensional graphene
  - ▲ Klein paradox: perfect transmittion through classically forbidden region

- In graphene, the "fine structure const." is $\alpha = \frac{e^2}{\epsilon_0 v_F}$. The <u>bare</u> value is $\alpha \sim 1$. But RG predicts that α is marginally irrelevant.
  - ▲ However, when $k_B T \gg \underset{\approx 0}{\underline{\mu}}$ the system is still a non-Fermi liquid, where $\tau^{-1} \sim \alpha^2 T$

- In real sample, graphene spatial density fluctuate rather strongly, possibly caused by graphene sheet bending.

- For multi-layer graphene, we have specific stacking pattern:



$$\mathcal{H} = \begin{array}{c} \\ \\ \\ \\ \end{array}\begin{array}{cccc|c} A & \tilde{B} & \tilde{A} & B & \\ \hline & & & v\pi^{\dagger} & A \\ & & v\pi & & \tilde{B} \\ & v\pi^{\dagger} & & \gamma_1 & \tilde{A} \\ v\pi & & \gamma_1 & & B \end{array}$$

$\Longrightarrow$