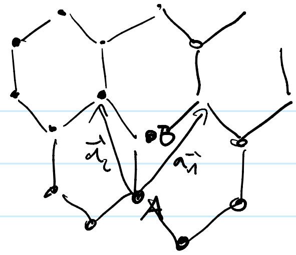
Nanofizika - grafen

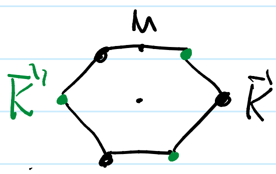
ponedeljek, 23. marec 2020 14:51

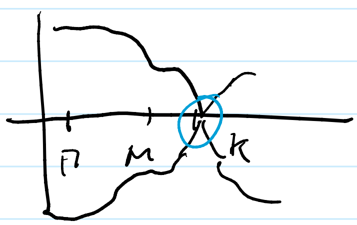


grafen: atomi C na mreži satovja (2d - kristal, blago upognjen v z-smeri)

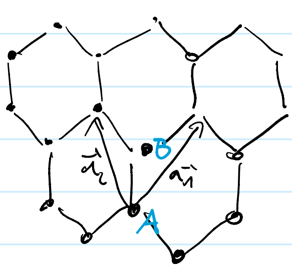
Geim, Novoselov (Nobel '10) '04

- zanimiv tehnološko (trden, lahek)
  0,77 mg/m², 4kg obremenitve, ...
- lahko ga dopiramo z elektrodami
- nizkoenergijska stanja imajo Diracovo disperzijo $E = \pm |k| c \hbar$





- relativistični Hallov pojav

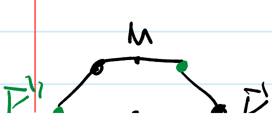


$$\vec{a}_1 = a\left(\tfrac{1}{2}, \tfrac{\sqrt{3}}{2}\right)$$

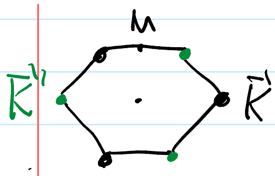
$$\vec{a}_2 = a\left(-\tfrac{1}{2}, \tfrac{\sqrt{3}}{2}\right)$$

$$\vec{b}_1 = \frac{2\pi}{a}\left(1, \tfrac{1}{\sqrt{3}}\right)$$

$$\vec{b}_2 = \frac{2\pi}{a}\left(-1, \tfrac{1}{\sqrt{3}}\right)$$



$$\vec{K} = \tfrac{1}{3}\left(\vec{b}_1 - \vec{b}_2\right)$$



$$\vec{K} = \frac{1}{3}(\vec{b}_1 - \vec{b}_2)$$

$$\vec{K}' = \frac{1}{3}(\vec{b}_2 - \vec{b}_1)$$

$$H = -t\sum_{\vec{R}}\Big(|\psi^B_{\vec{R}-\vec{a}_1}\rangle\langle\psi^A_{\vec{R}}| + |\psi^B_{\vec{R}-\vec{a}_2}\rangle\langle\psi^A_{\vec{R}}| + |\psi^B_{\vec{R}}\rangle\langle\psi^A_{\vec{R}}| + h.c.\Big)$$

$$|\psi^A_{\vec{k}}\rangle = \frac{1}{\sqrt{N}}\sum_{\vec{R}} e^{i\vec{k}\cdot\vec{R}}|\psi^A_{\vec{R}}\rangle \quad ; \text{ isto za } B$$

$$|\psi^A_{\vec{R}}\rangle = \frac{1}{\sqrt{N}}\sum e^{-i\vec{k}\cdot\vec{R}}|\psi^A_{\vec{k}}\rangle$$

$$H(\vec{k}) = \begin{bmatrix} & e^*(\vec{k}) \\ e(\vec{k}) & \end{bmatrix}$$

$$e(\vec{k}) = -t\,(1 + e^{i\vec{k}\cdot\vec{a}_1} + e^{i\vec{k}\cdot\vec{a}_2})$$

$$\det(H(\vec{k}) - E) = 0 \quad E^2 - |e|^2 = 0 \quad E = \pm|e|$$

$$\vec{k} = \vec{K} + \vec{q}$$

$$\vec{K}\cdot\vec{a}_1 = 2\pi/3 \quad ; \quad \vec{K}\cdot\vec{a}_2 = -\frac{2\pi}{3}$$

$$e(\vec{k}) = -t\left(1 + e^{i2\pi/3}(1 + i\vec{q}\cdot\vec{a}_1) + e^{-i2\pi/3}(1 + i\vec{q}\cdot\vec{a}_2)\right)$$

$$= -t\left(\cos\frac{2\pi}{3}\,\vec{q}\cdot(\vec{a}_1 + \vec{a}_2)\,i - \sin\frac{2\pi}{3}\,\vec{q}(\vec{a}_1 - \vec{a}_2)\right)$$

$$= -t\left(i - \tfrac{1}{2}\sqrt{3}\,q_y a - \tfrac{1}{2}\sqrt{3}\,q_x a\right) = +t\frac{\sqrt{3}}{2}(q_x a + i q_y a)$$

$$H(k) = t\frac{\sqrt{3}}{2}\begin{pmatrix} 0 & q_x - iq_y \\ q_x + iq_y & 0 \end{pmatrix} a = \vec{q}\cdot\vec{\sigma}\; t\frac{\sqrt{3}}{2}a = c^*\hbar\,\vec{q}\cdot\vec{\sigma}$$

$$c^* = \frac{t\sqrt{3}}{2}a \approx 10^6\,m/s$$

$$c^* = \frac{t\sqrt{3}}{2}\frac{a}{\hbar} \approx 10^6\, m/s$$

$$\boxed{H(\vec{q}) = c^* \hbar (\vec{\sigma}\cdot\vec{q})}$$ Diracova / Weylova

$$\boxed{c^* \hbar\, \vec{\sigma}\cdot\vec{q}\, \psi = E\psi}$$ enačba

$\vec{\sigma}\cdot\vec{p}$ − projekcija (pseudo−) spina na moment : ročnost

$\vec{p} = \hbar\vec{q}$

$$(\gamma_\mu p^\mu \psi) = mc\,\psi$$

$$\gamma_0 \gamma^\mu p_\mu \psi = 0$$

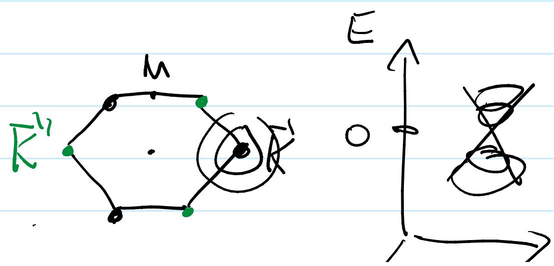
$$\gamma_0 \gamma^i p_i \psi = E\psi$$

razvoj okoli K'

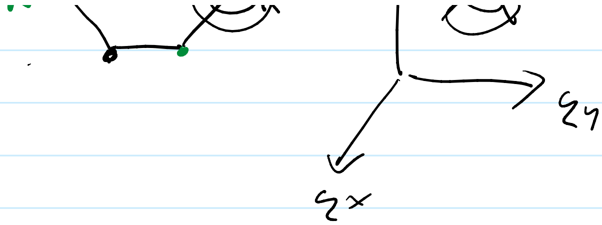
$$c^* \hbar (-\vec{\sigma}^*)\cdot\vec{q}\, \psi = E\psi$$

$\vec{\sigma}^* = (\sigma_x, -\sigma_y)$ redefiniramo $q_y \to -q_y$ (okoli K')

$$\boxed{c\begin{bmatrix} \vec{\sigma}\cdot\vec{p} & \\ & -\vec{\sigma}\cdot\vec{p} \end{bmatrix}\begin{pmatrix}\psi_K \\ \psi_{K'}\end{pmatrix} = E\begin{pmatrix}\psi_K \\ \psi_{K'}\end{pmatrix}}$$



Diracova relativistična disperzija



relativistična disperzija
za $m = 0$.