FUNDAMENTALS OF NANOELECTRONICS

B. Quantum Transport

1. Schrodinger Equation

2. Contact-ing Schrodinger

3. Advanced Examples

4. Spin Transport

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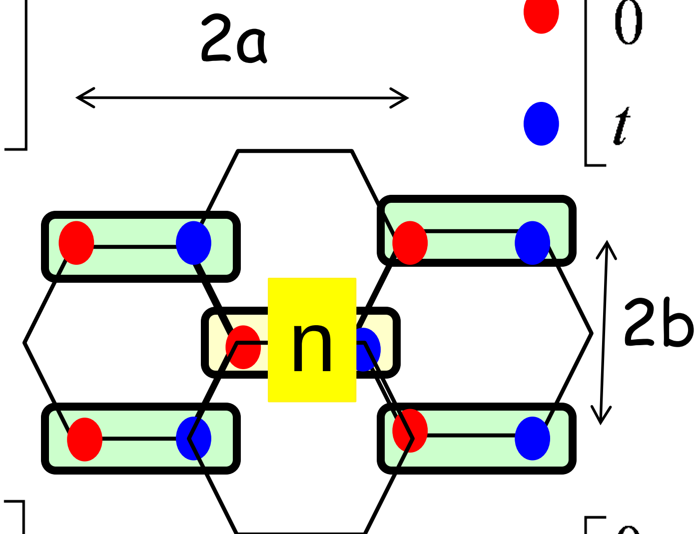
http://nanohub.org/groups/lnebook

$$\left[h(\vec{k})\right] = \sum_m \left[H_{nm}\right] e^{i\vec{k}.(\vec{r}_m - \vec{r}_n)}$$

1.8a Graphene

$$e^{i\vec{k}.(-a\hat{x}+b\hat{y})}\begin{bmatrix} 0 & t \\ 0 & 0 \end{bmatrix} \qquad \begin{bmatrix} 0 & 0 \\ t & 0 \end{bmatrix} e^{i\vec{k}.(a\hat{x}+b\hat{y})}$$

$\uparrow$ y



$x \rightarrow$

$$e^{i\vec{k}.(-a\hat{x}-b\hat{y})}\begin{bmatrix} 0 & t \\ 0 & 0 \end{bmatrix} \qquad \begin{bmatrix} 0 & 0 \\ t & 0 \end{bmatrix} e^{i\vec{k}.(a\hat{x}-b\hat{y})}$$

$$\begin{bmatrix} \varepsilon & t \\ t & \varepsilon \end{bmatrix}$$

1.8b Graphene

$$\boxed{\left[h(\vec{k})\right] = \sum_m \left[H_{nm}\right] e^{i\vec{k}.(\vec{r}_m - \vec{r}_n)}}$$

$$h(\vec{k}) = \begin{bmatrix} \varepsilon & h_0^* \\ h_0 & \varepsilon \end{bmatrix}$$

$$h_0 \equiv t\left(1 + e^{ik_x a + ik_y b} + e^{ik_x a - ik_y b}\right)$$

$$= t\left(1 + 2e^{ik_x a}\cos k_y b\right)$$

$$+ e^{i\vec{k}.(-a\hat{x}+b\hat{y})}\begin{bmatrix} 0 & t \\ 0 & 0 \end{bmatrix}$$

$$+ \begin{bmatrix} 0 & 0 \\ t & 0 \end{bmatrix} e^{i\vec{k}.(a\hat{x}+b\hat{y})}$$

$$+ e^{i\vec{k}.(-a\hat{x}-b\hat{y})}\begin{bmatrix} 0 & t \\ 0 & 0 \end{bmatrix}$$

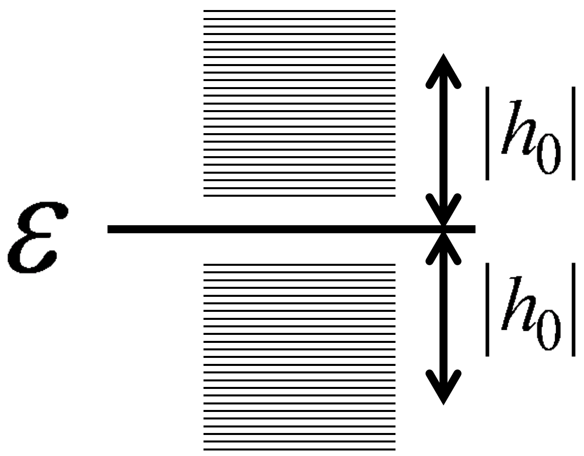
$$+ \begin{bmatrix} \varepsilon & t \\ t & \varepsilon \end{bmatrix}$$

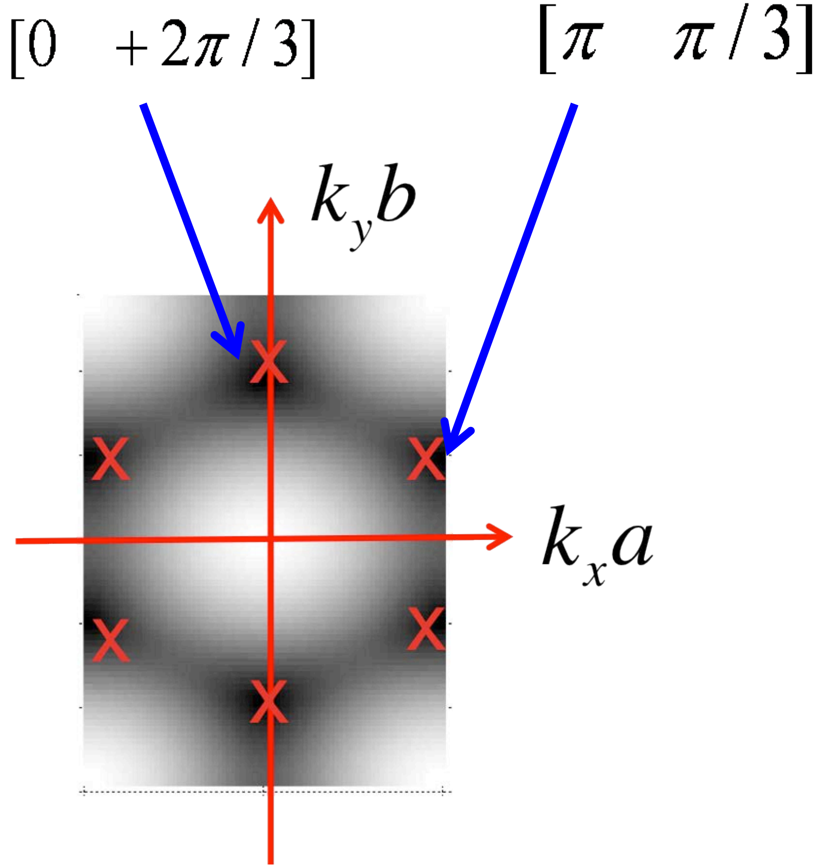
$$+ \begin{bmatrix} 0 & 0 \\ t & 0 \end{bmatrix} e^{i\vec{k}.(a\hat{x}-b\hat{y})}$$

1.8c Graphene

$$h(\vec{k}) = \begin{bmatrix} \varepsilon & h_0^* \\ h_0 & \varepsilon \end{bmatrix} \quad , \quad h_0 = t\left(1+2e^{ik_x a}\cos k_y b\right)$$

$$E = \varepsilon \pm |h_0|$$



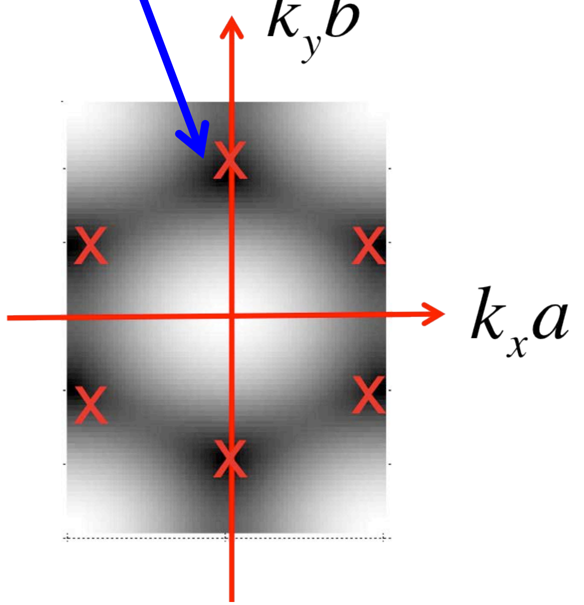


1.8d Graphene

$$h(\vec{k}) = \begin{bmatrix} \varepsilon & h_0^* \\ h_0 & \varepsilon \end{bmatrix} \qquad E = \varepsilon \pm |h_0|$$

$[0 \quad +2\pi/3]$

$$h_0 = t\left(1 + 2e^{ik_x a}\cos k_y b\right)$$

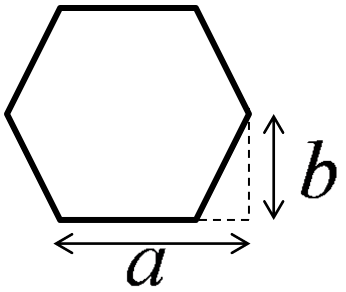


$$\approx \left[\frac{\partial h_0}{\partial k_x}\right]_{0,\frac{2\pi}{3}} (k_x - 0) + \left[\frac{\partial h_0}{\partial k_y}\right]_{0,\frac{2\pi}{3}} \left(k_y - \frac{2\pi}{3}\right)$$

$$= -\,iat\;k_x \;-b\sqrt{3}\,t\;\beta_y$$

$$\approx -\,iat\;(k_x + i\,\beta_y)$$

$$\left[2ia\,e^{ik_x a}\cos k_y b\right]_{0,\frac{2\pi}{3}} \qquad \left[-2b\,e^{ik_x a}\sin k_y b\right]_{0,\frac{2\pi}{3}}$$



1.8e Graphene

$$h(\vec{k}) = \begin{bmatrix} \varepsilon & h_0^* \\ h_0 & \varepsilon \end{bmatrix}$$

$$\nu = \frac{1}{\hbar}\frac{\partial E}{\partial k} = \frac{a\,t}{\hbar}$$

$$a \approx 0.2\ nm$$

$$\sim 10^6\ m/\sec$$

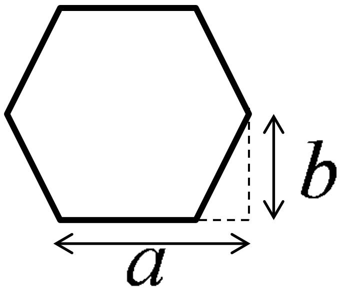
$$t \approx 3\ eV$$

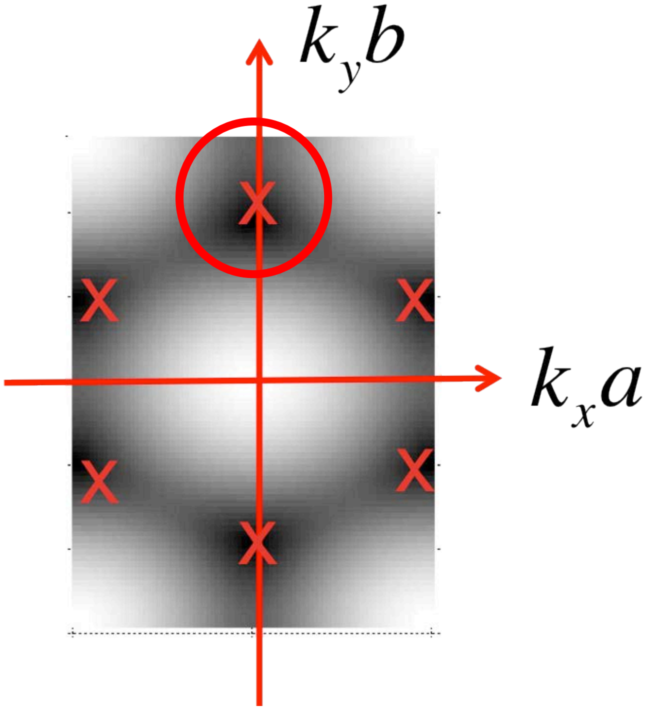
$$E = \varepsilon \pm |h_0|$$

$$= \varepsilon \pm at\sqrt{k_x^2 + \beta_y^2}$$

$$h_0 = t\left(1 + 2e^{ik_x a}\cos k_y b\right)$$

$$\approx -iat\,(k_x + i\,\beta_y)$$





Coming up next ..

How many valleys are there?