Ground state construction of Bilayer Graphene

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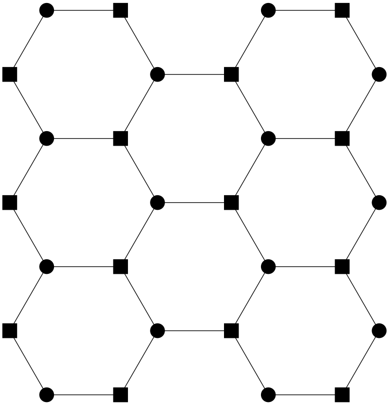
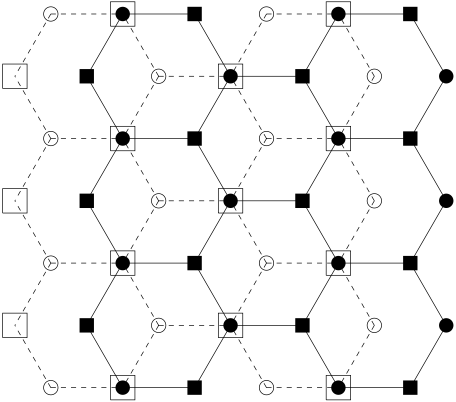
Monolayer graphene

- 2D crystal of carbon atoms on a honeycomb lattice.



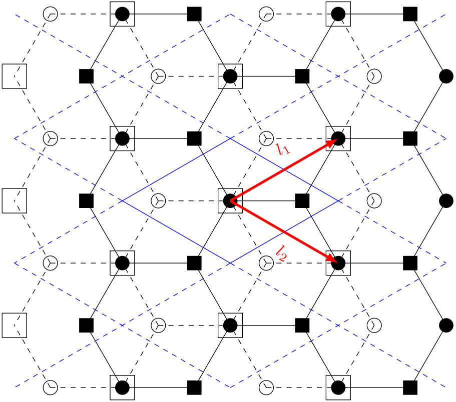
Bilayer graphene

- 2 graphene layers in AB stacking.



Bilayer graphene

- Rhombic lattice $\Lambda \equiv \mathbb{Z}^2$, 4 atoms per site.

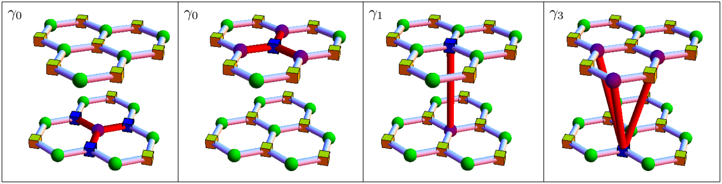


Hamiltonian

- Hamiltonian:

$$\mathcal{H} = \mathcal{H}_0 + UV$$

- Non-interacting Hamiltonian: hoppings



- Interaction: weak, short-range (screened Coulomb).

Non-interacting Hamiltonian

$$\mathcal{H}_0 = \sum_{k \in \hat{\Lambda}} \begin{pmatrix} \hat{a}_k^\dagger \\ \hat{\tilde{b}}_k^\dagger \\ \hat{\tilde{a}}_k^\dagger \\ \hat{b}_k^\dagger \end{pmatrix}^T \hat{H}_0(k) \begin{pmatrix} \hat{a}_k \\ \hat{\tilde{b}}_k \\ \hat{\tilde{a}}_k \\ \hat{b}_k \end{pmatrix}$$

$$\hat{H}_0(k) := \begin{pmatrix} 0 & \gamma_1 & 0 & \gamma_0 \Omega^*(k) \\ \gamma_1 & 0 & \gamma_0 \Omega(k) & 0 \\ 0 & \gamma_0 \Omega^*(k) & 0 & \gamma_3 \Omega(k) e^{3ik_x} \\ \gamma_0 \Omega(k) & 0 & \gamma_3 \Omega(k) e^{-3ik_x} & \end{pmatrix}$$

$$\Omega(k) := 1 + 2e^{-\frac{3}{2}ik_x} \cos(\tfrac{\sqrt{3}}{2} k_y)$$

Non-interacting Hamiltonian

- Hopping strengths:

$$\gamma_0 = 1, \quad \gamma_1 = \epsilon, \quad \gamma_3 = 0.33 \times \epsilon$$

- Experimental value $\epsilon \approx 0.1$, here, $\epsilon \ll 1$.

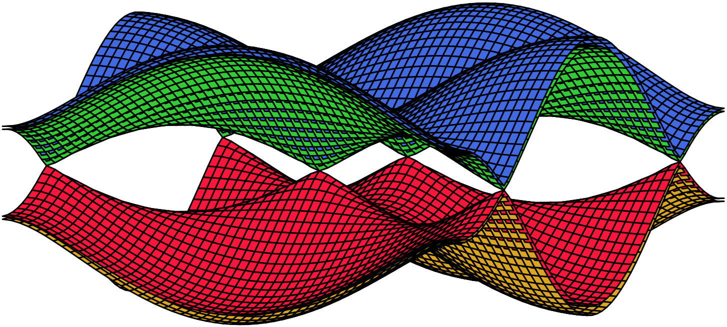
Interaction

$$V = \sum_{x,y} v(|x-y|) \left(n_x - \frac{1}{2}\right) \left(n_y - \frac{1}{2}\right)$$

- $\sum_{x,y}$: sum over pairs of atoms
- $v(|x-y|) \leqslant e^{-c|x-y|}$, $c > 0$
- $-\frac{1}{2}$: *half-filling.*

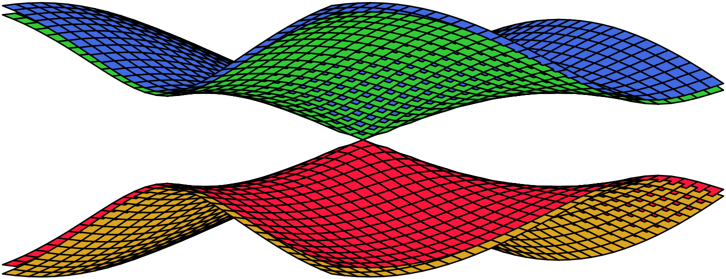
Non-interacting Hamiltonian

- Eigenvalues of $\hat{H}_0(k)$:



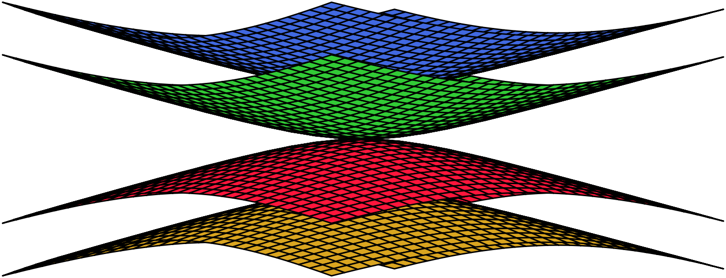
Non-interacting Hamiltonian

- $|k| \gg \epsilon$



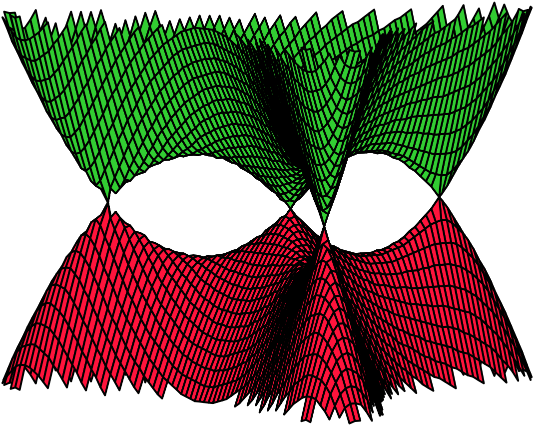
Non-interacting Hamiltonian

- $\epsilon^2 \ll |k| \ll \epsilon$



Non-interacting Hamiltonian

- $|k| \ll \epsilon^2$



Theorem

$\exists U_0, \epsilon_0 > 0$, independent, such that, for $\epsilon < \epsilon_0$, $|U| < U_0$,

- the free energy

$$f := -\frac{1}{|\Lambda|\beta} \log \mathrm{T}r(e^{-\beta\mathcal{H}})$$

is analytic in U, uniformly in β and $|\Lambda|$,

- the two-point Schwinger function

$$s_2(x-y) := \frac{\mathrm{T}r(e^{-\beta\mathcal{H}} a_x a_y^\dagger)}{\mathrm{T}r(e^{-\beta\mathcal{H}})}$$

is analytic in U, uniformly in β and $|\Lambda|$.

Renormalization group flow