RKKY Interaction In Bilayer Graphene

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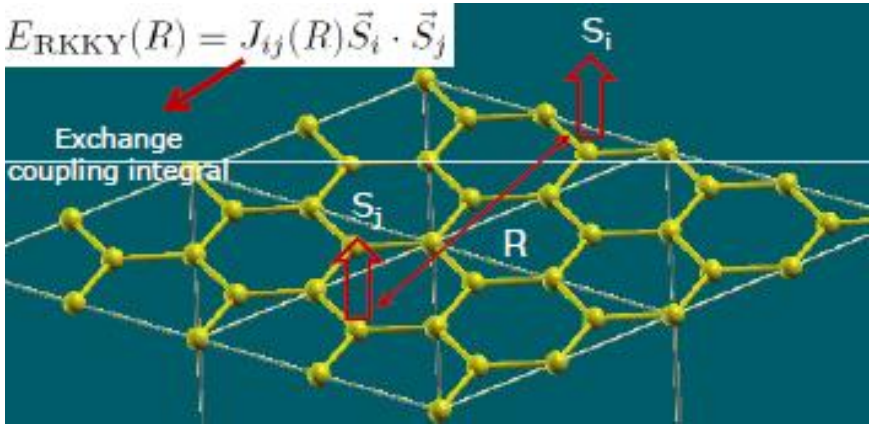
Outline

- RKKY Interaction
- Graphene & It's bilayer
- RKKY in 2D system
- RKKY in un-biased bilayer graphene
- RKKY in biased bilayer graphene

RKKY INTERACTION

Motivation

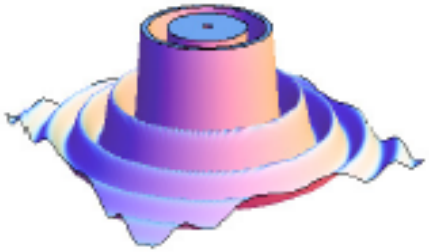
- RKKY: Indirect Exchange interaction between two magnetic impurities via host material electrons.

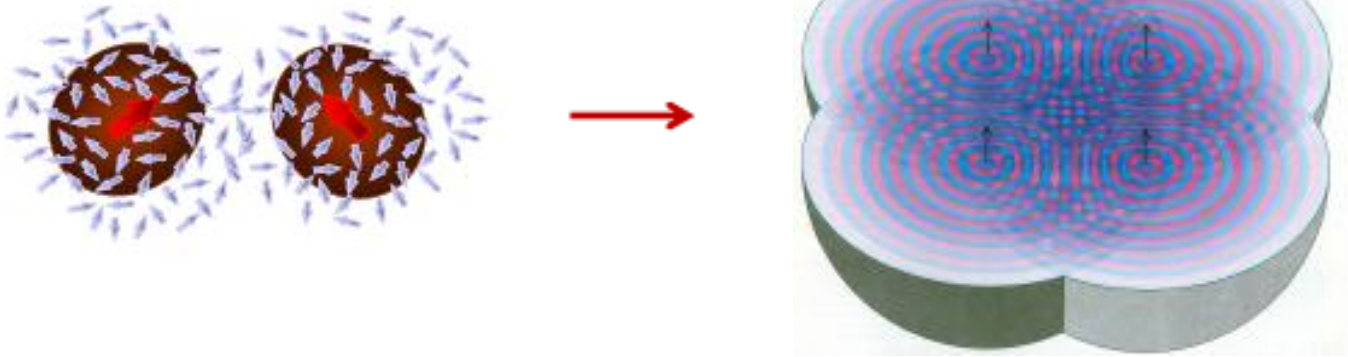


- Adatom properties
- Spintronic applications

Motivation

- Electron spin oscillation around magnetic impurity
- Ordering of impurities:

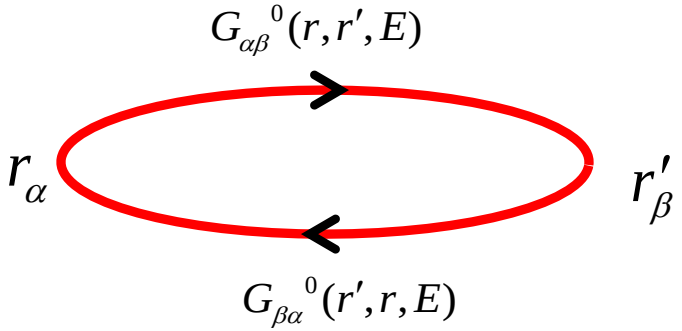




RKKY Interaction (Formalism)

$$H_{RKKY} = -\lambda^2 \sum_{ij} I_{1i} \chi_{ij}(R_1, R_2) I_{2j}$$

$$i, j = x, y, z$$

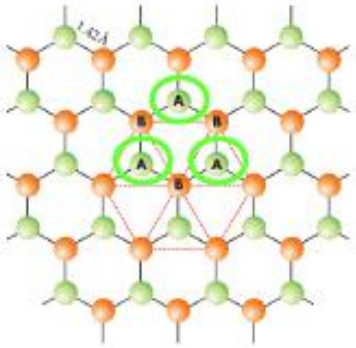


$$\chi_{ij}(R_1, R_2) = \mathrm{Im}[\int_{-\infty}^{\varepsilon_F} d\varepsilon Tr[\hat{\sigma}_i G^0(R_1, R_2, \varepsilon) \hat{\sigma}_j G^0(R_2, R_1, \varepsilon)]$$

GRAPHENE & IT'S BILAYER

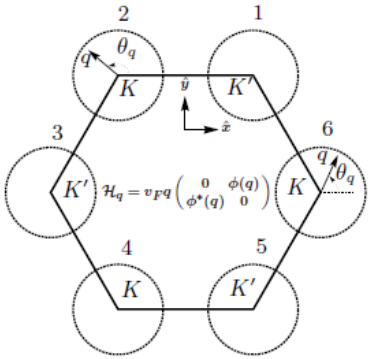
Graphene Structure

- Pseudo spin (A,B)



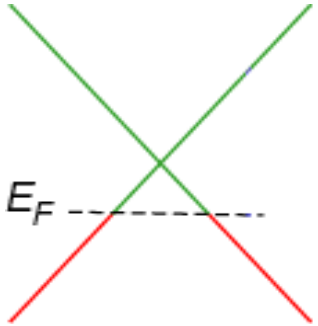
- Valley degeneracy

$$H_0 = \begin{pmatrix} 0 & v_F q \Phi_q \\ v_F q \Phi^*_q & 0 \end{pmatrix}$$

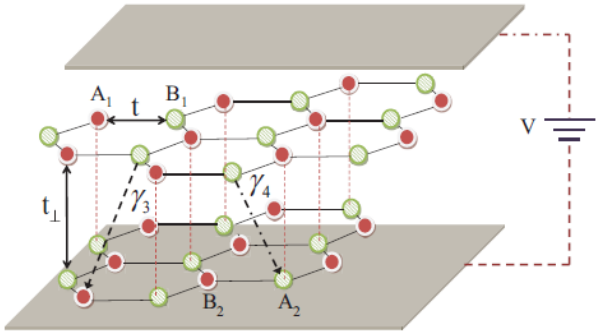


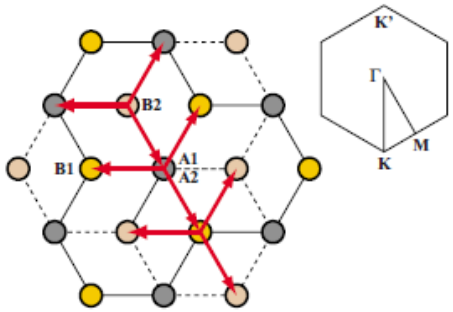
- Tunable Fermi energy

$$E(k) = \pm v_F k$$



Bilayer Graphene



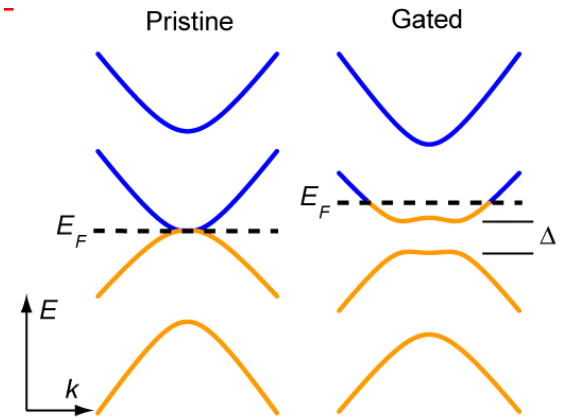


$$H = \sum_k \Psi^\dagger(k) \begin{pmatrix} \Delta & f(k) & t_\perp & \gamma_4 f^*(k) \\ f^*(k) & \Delta & \gamma_4 f^*(k) & \gamma_3 f(k) \\ t_\perp & \gamma_4 f(k) & -\Delta & f^*(k) \\ \gamma_4 f(k) & \gamma_3 f^*(k) & f(k) & -\Delta \end{pmatrix} \Psi(k)$$

Bilayer Graphene: Band Structure

- Dispersion relation:

$$\varepsilon^2 = v^2 p^2 + \frac{t_\perp{}^2}{2} + \frac{V^2}{4} - \sqrt{v^2 p^2 (V^2 + t_\perp{}^2) + t_\perp{}^4 / 4}$$

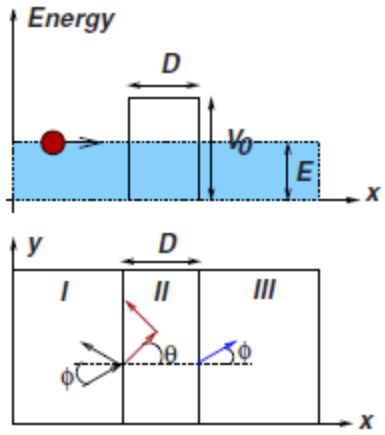


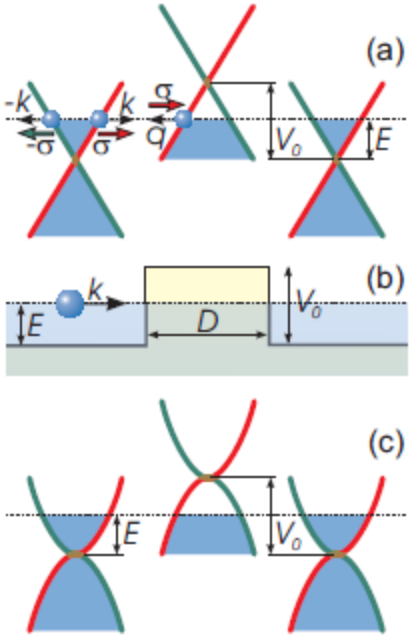
- 2Band effective model:

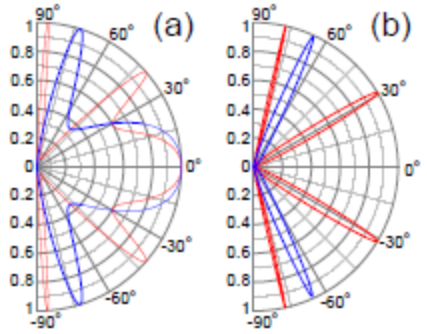
$$H_{low} = \frac{-1}{2m}\begin{pmatrix} 0 & (\pi^\dagger)^2 \\ (\pi)^2 & 0 \end{pmatrix} + \frac{V}{2}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

Klein Tunneling in Bilayer Graphene

$$H \propto \begin{pmatrix} 0 & (p_x - ip_y)^j \\ (p_x + ip_y)^j & 0 \end{pmatrix}$$







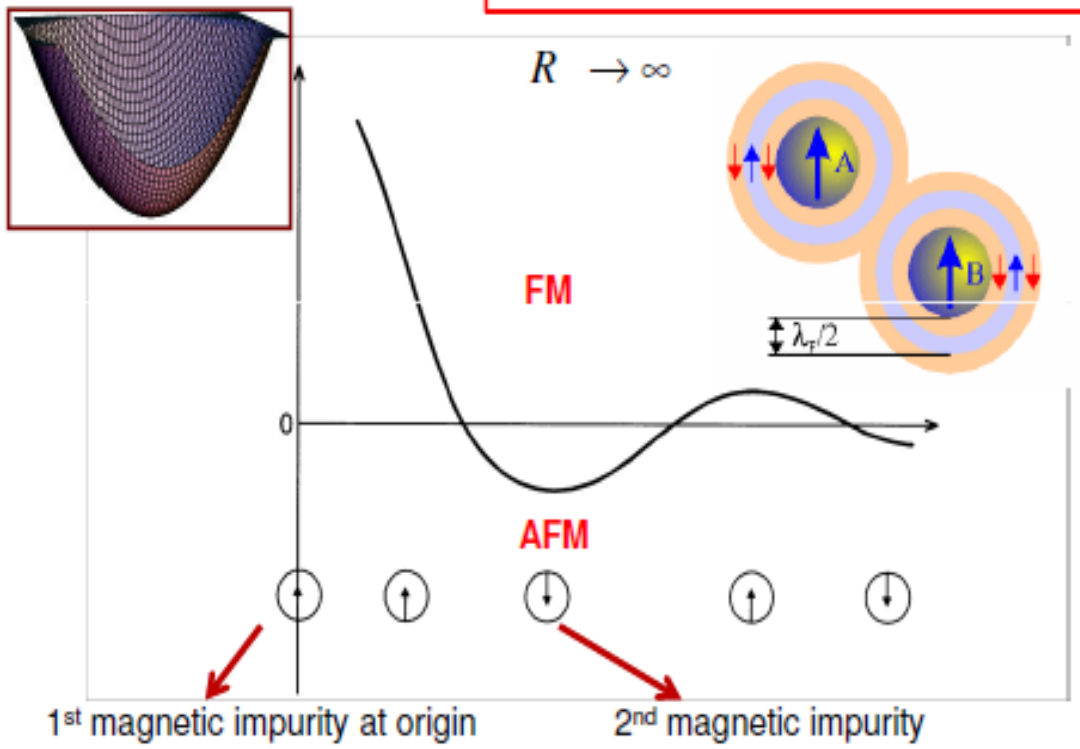
RKKY INTERACTION IN 2D SYSTEMS

RKKY in 2DEG

$$\hat{H}^{RKKY} = J\ S_1.S_2$$

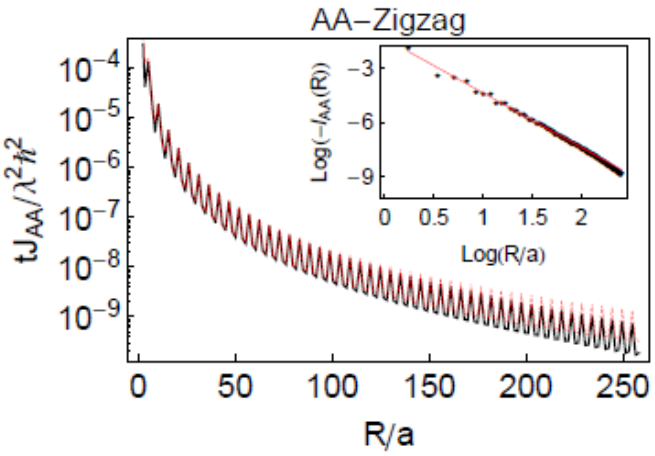
$\varepsilon(\vec{k}) \propto k^2$

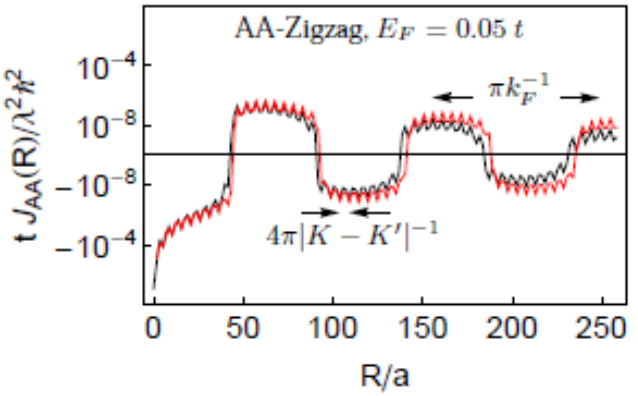
$$J \propto (2k_F R)^{-2} \sin(2k_F R)$$



B. Fisher, et al., Phys. Rev. B (1975)

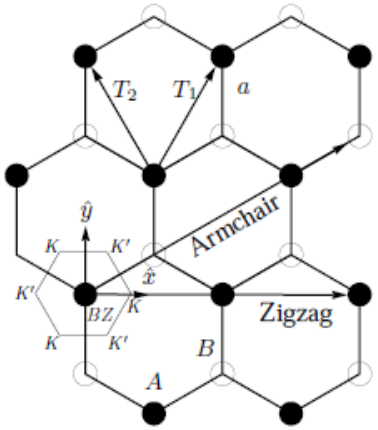
RKKY in Graphene





$$J_{AA} = C\frac{1+Cos((K-K').R)}{(R/a)^3}$$

$$J_{AA} = C\frac{1+Cos((K-K').R)}{(R/a)^2}Sin(2k_F R)$$

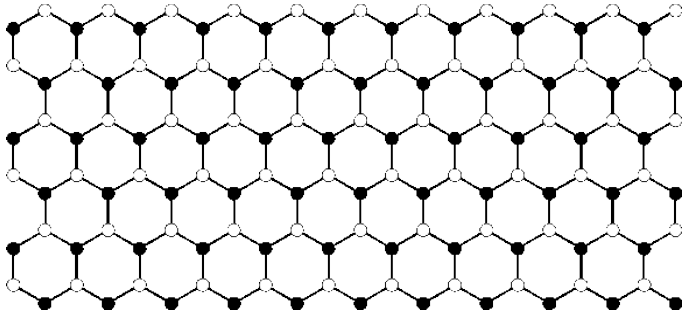


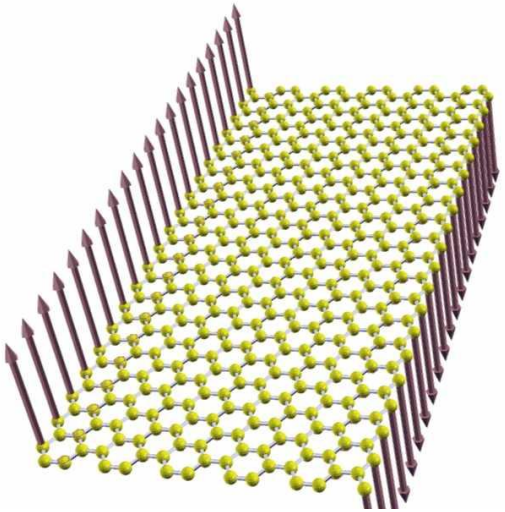
Sherafati et. al. PRB, 84, 125416

Sherafati et. al. PRB, 83, 165425

RKKY in spin polarized Graphene

$$H^{\alpha\beta}{}_{RKKY} = \frac{\lambda^2}{\pi}[J_x^{\alpha\beta}(S_{1x}S_{2x} + S_{1y}S_{2y}) + J_z^{\alpha\beta}(S_{1z}S_{2z}]$$



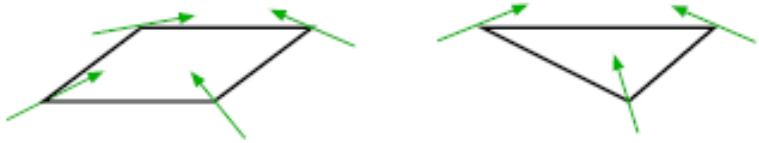


Parhizgar et. al. PRB, **87**, 125402

RKKY in Rashba spin orbit systems

$$\hat{H}^{RKKY} = J_H S_1 . S_2 + J_I S_1^z S_2^z + J_{DM} (S_1 \times S_2)_z$$

- Topological Insulators
- 2DEG + Rashba spin orbit
- MoS_2

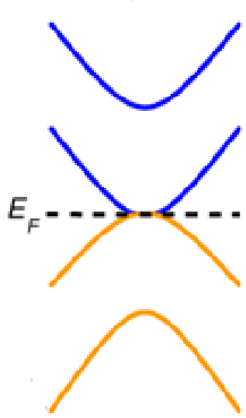


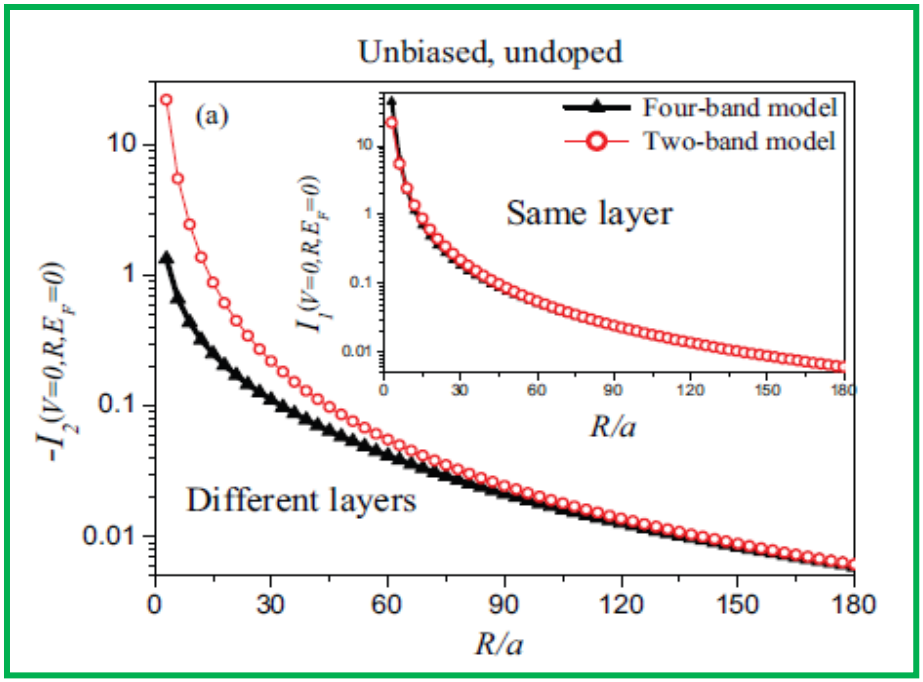
Parhizgar et. al. PRB, **87**, 125401

RKKY INTERACTION IN UN-BIASED BILAYER GRAPHENE

Un-biased, undoped

$$\hat{H}^{RKKY} = I(V, R, E_F)\phi_{\alpha\beta}$$

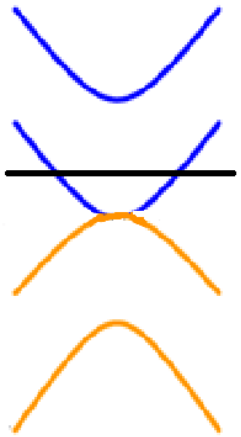


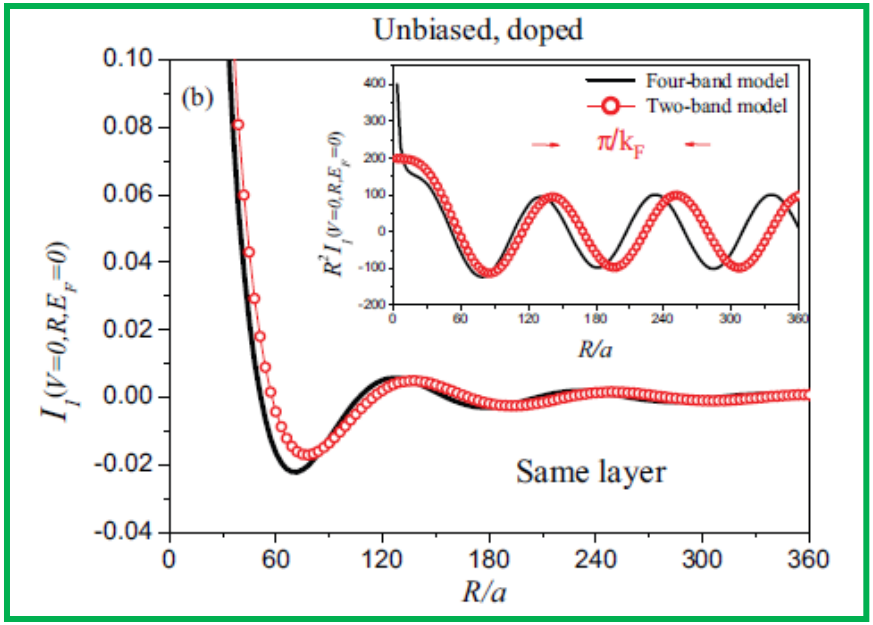


Parhizgar *et al.* Phys. Rev. B **87**,165429 (2013)

Un-biased, doped

$$J_{B1B1}(R) = \frac{-C\Phi_{B1B1}}{R^2} Sin(2k_F R)(e^{-k_F R} + C')$$





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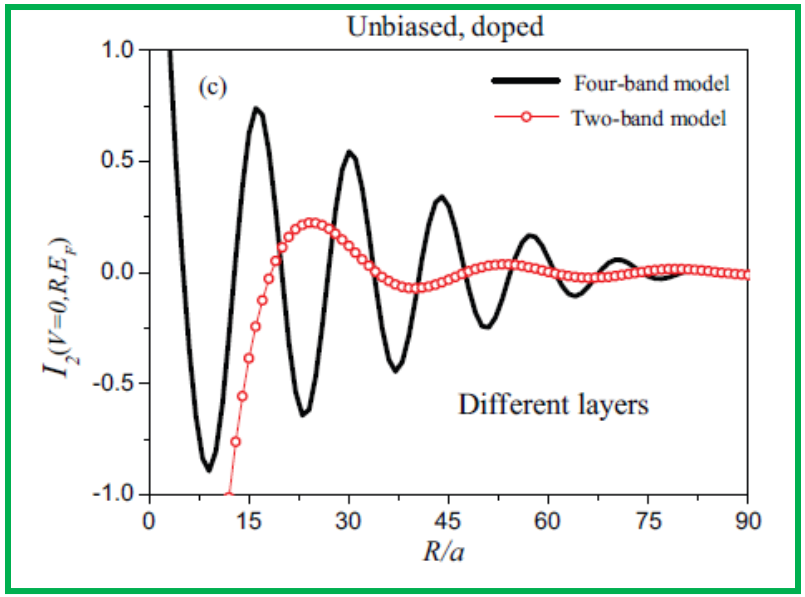
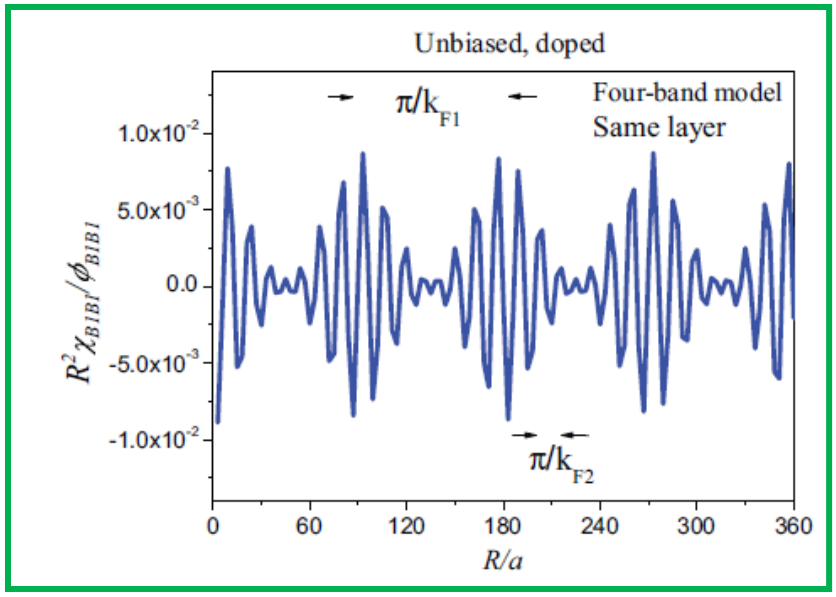
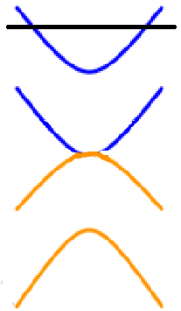
Necessity of 4-band model







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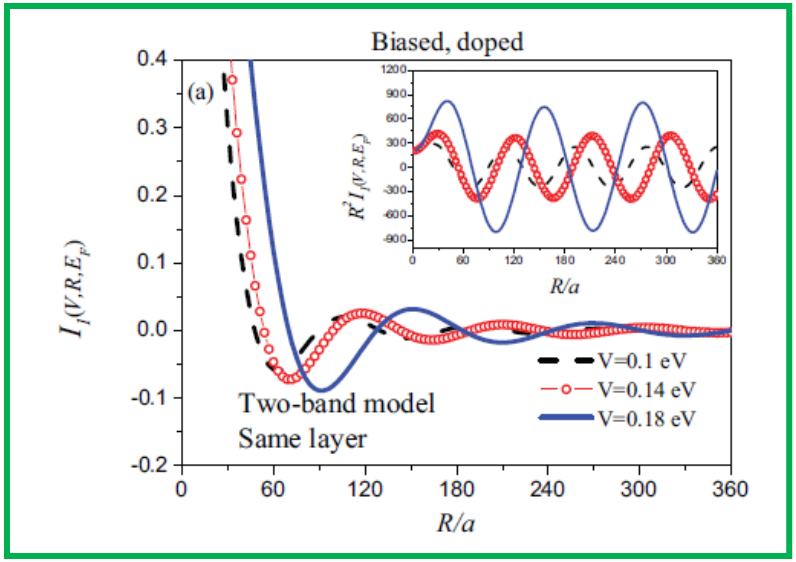
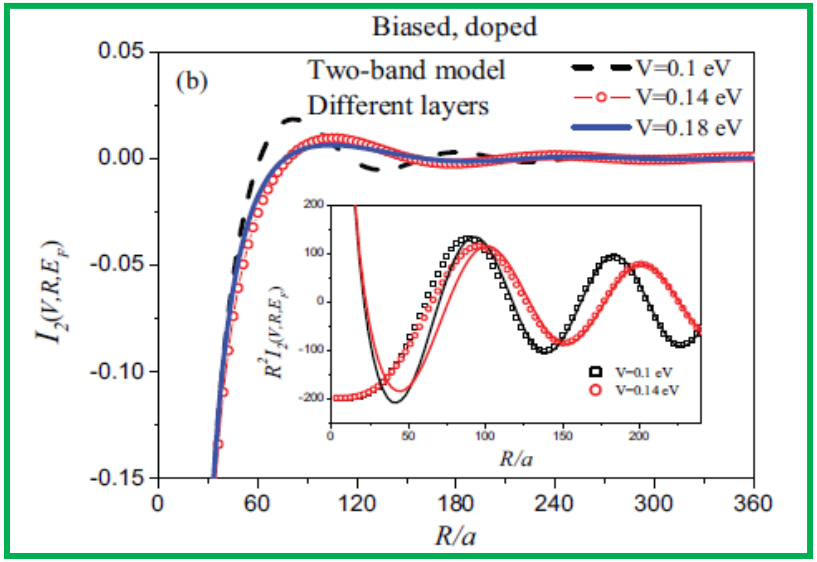
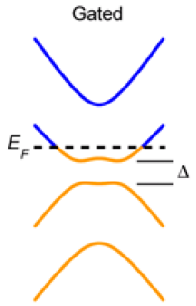
RKKY INTERACTION IN

BIASED BILAYER GRAPHENE

Biased, doped







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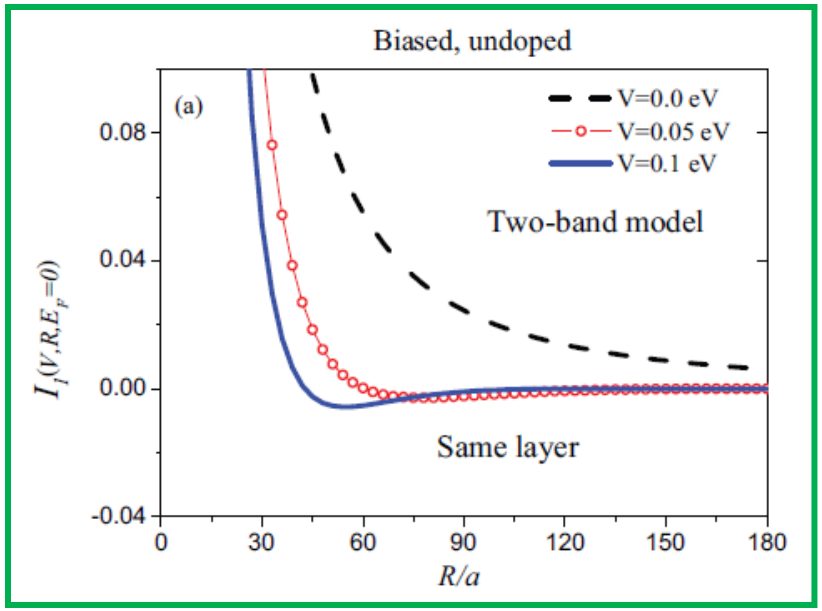
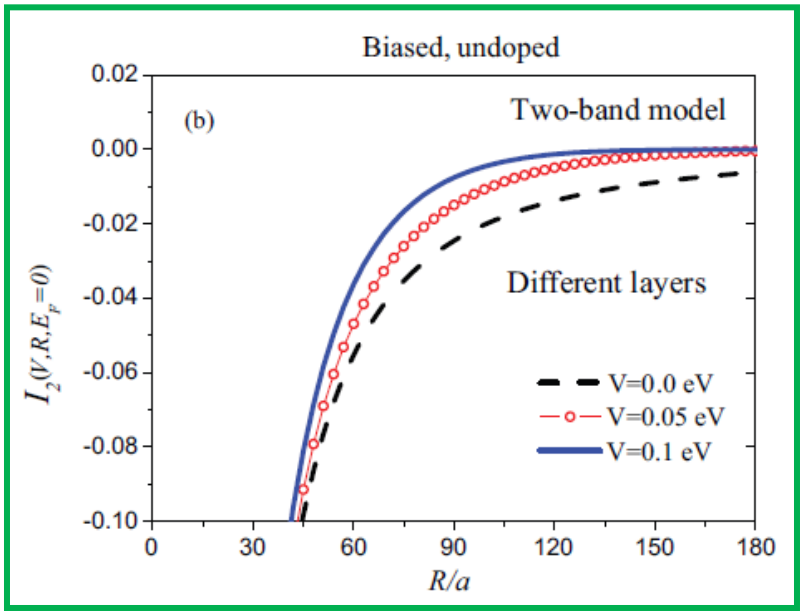
Biased, undoped





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Thanks For your Attention