BIASED TWISTED BILAYER GRAPHENE: MAGNETISM AND GAP

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Presentation outline:

- General properties of twisted bilayers
- Effect of the bias: nested Fermi surface
- Exitonic gap + magnetism
Twisted bilayer graphene

System before rotation: AB bilayer graphene

“Commensurate” twist angle
Twisted bilayer graphene as seen on experiment

Moire superlattice is clearly seen

Scanning spectroscopy of twisted bilayer samples with different twist angles

Most of our knowledge about single-electron properties of twisted bilayers comes from calculations at “commensurate” angles

\[ \cos \theta = \frac{3m^2 + 3mr + r^2/2}{3m^2 + 3mr + r^2} \]

Here \( m \) and \( r \) are co-prime natural numbers.
Commensurate angles: superstructure
Commensurate angles: superstructure in the reciprocal space

Red dashed line – Brillouin zone of the unrotated layer

Blue dashed line – Brillouin zone of the rotated layer

Green solid line – Brillouin zone of the superstructure.
Why theorists like commensurate angles?

**Advantages**

1. Periodic structure emerges (one can study finite supercells)
2. Arbitrary incommensurate angle can be approximated
Calculation at a commensurate angle: single-particle dispersion

“Monolayer” Dirac cones

Renormalized Dirac cones at the corners of the supercell Brillouin zone

Inter-layer tunneling
Fermi velocity renormalization

G. Trambly de Laissardière et al., Nano Letters, 10, 804 (2010)
Bad new for phase transition: Dirac cones => vanishing DOS => no mean-field instability

\[ T_c \sim \exp\left(-\frac{1}{\rho(0)g}\right) \]
Biased twisted bilayer?

$E$ is transverse electric field
Biased twisted bilayer?

Bilayer spectrum at finite bias
Biased twisted bilayer?

Bilayer spectrum at finite bias

This is where Dirac cones are
Biased twisted bilayer?

Bilayer spectrum at finite bias

This is where Dirac cones are

One Dirac cone

Another Dirac cone

This is where Dirac cones are
Biased twisted bilayer?

Bilayer spectrum at finite bias

One Dirac cone

Another Dirac cone

Two more Dirac cones

This is where Dirac cones are
Biased twisted bilayer?

Bilayer spectrum at finite bias

This is where Dirac cones are
Biased twisted bilayer?

Bilayer spectrum at finite bias

This is where Dirac cones are
Fermi surface (Fermi curve)

Fermi surfaces near $K_1$ and $K_2$ points are doubly degenerate.
Fermi surface (Fermi curve) with nesting

Fermi surfaces near $\mathbf{K}_1$ and $\mathbf{K}_2$ points are doubly degenerate (perfect nesting between hole- and electron-like bands). This leads to exciton band gap opening.
Quality of nesting

Electron Fermi surface and hole Fermi surface are almost identical
Ordered state

Electron in one layer + hole in another + e-e repulsion = exciton

$\vec{E}$

Exciton
Ordered state: why nesting is important?

For any electron with low energy and momentum $p$ there is a hole with low energy and momentum $p$. 

$m=7 \ (\theta=4.408^\circ), \ V/t=0.2$

- **holes**
- **electrons**

$q_x$ vs. $q_y$
Some technical remarks

Model hamiltonian: \[ H = H_0 + H_{\text{int}} \]

Tight-binding part:

\[
\hat{H}_0 = \sum_{i,n,m} t(r_n^{is}, r_m^{js'}) \hat{d}_{nis\sigma}^{\dagger} \hat{d}_{mjs'\sigma} + \frac{V_b}{2} \sum_n (\hat{n}_{n1} - \hat{n}_{n2})
\]

Interaction part (\( U \) is screened Coulomb interaction):

\[
\hat{H}_{\text{int}} = \frac{1}{2} \sum_{i,n,m} u_{ijs\sigma} u_{js'\sigma'} (r_n^{is} - r_m^{js'}) \hat{d}_{njs\sigma}^{\dagger} \hat{d}_{mjs'\sigma'}^{\dagger}
\]
Some more technical remarks

Order parameter is of SDW type
two such order parameters (one per Dirac point)

One order parameter lives here

Another order parameter lives here
Results

Bias voltage: $V_{b/t} = 0.1$
Results

Bias voltage: $V_b/t = 0.037$

Effect of low Fermi velocity
Results
Results: magnetism

Two SDW order parameters (one per Dirac point) => interference
Conclusions

– Effect of the bias: nested Fermi surface
– Insulating gap + interference of 2 magnetic orders