Dirac Fermions in Newly Discovered Iron-Based Superconductors

The fourth Dirac Fermion in condensed matters

Takami Tohyama

in collaboration with
Takao Morinari and Eiji Kaneshita

T. Morinari, E. Kaneshita, T.T.,
The first Dirac fermions: GRAPHENE

Nobel Prize in Physics 2010

Andre Geim
Konstantin Novoselov

"for groundbreaking experiments regarding the two-dimensional material graphene"

Single layer Carbon:

- Ig nobel prize in 2000 “to make a frog levitate in a magnetic field"
- Invited speaker of YKIS2007

– the perfect atomic lattice

A thin flake of ordinary carbon, just one atom thick, lies behind this year’s Nobel Prize in Physics. Andre Geim and Konstantin Novoselov have shown that carbon in such a flat form has exceptional properties that originate from the remarkable world of quantum physics.

Dirac fermions
The first Dirac fermions: graphene

linear dispersion

$$E_{\pm}(p) = \pm \hbar v_F p, \quad p = \sqrt{p_x^2 + p_y^2}$$

$$H_p = \hbar v_F \left( p_x \sigma_x + p_y \sigma_y \right) = \hbar v_F \begin{pmatrix} 0 & p_x - ip_y \\ p_x + ip_y & 0 \end{pmatrix}$$

wavefunction

$$\Psi_p^{(e)} = \frac{1}{\sqrt{2}} \begin{pmatrix} +e^{-i\theta/2} \\ e^{i\theta/2} \end{pmatrix}, \quad \Psi_p^{(h)} = \frac{1}{\sqrt{2}} \begin{pmatrix} -e^{-i\theta/2} \\ e^{i\theta/2} \end{pmatrix} \quad \left( \tan \theta = \frac{p_y}{p_x} \right)$$

chirality helicity operator:

$$\hat{h} = \frac{p \cdot \sigma}{p}$$

$$\hat{h}\Psi_p^{(e)} = +\Psi_p^{(e)}, \quad \hat{h}\Psi_p^{(h)} = -\Psi_p^{(h)}$$

Pseudo-spins

A, B sublattices in honeycomb structure

Dirac point = Fermi level
The second Dirac fermions: $\alpha-(\text{BEDT-TTF})_2\text{I}_3$

Tilted Dirac dispersions

Pseudo-spins

A, B sublattices in BEDT-TTF layer

Dirac point = Fermi level
The third Dirac fermions: topological insulator

On the surface of Bi$_2$Se$_3$

Pseudo-spins

Real spins of electrons in surface layer

Dirac point ≠ Fermi level
The fourth Dirac fermions

Antiferromagnetic metallic phase of iron-based high-temperature superconductors

Pseudo-spins

Two orbitals ($zx$ and $yz$) on Fe

Dirac point $\neq$ Fermi level
Along a symmetric direction in the momentum space, the degeneracy of the two atomic orbitals $zx$ and $yz$ on Fe are lifted.

Y. Ran et al., PRB 79, 014505 (2009)
Complication

Not only *Dirac electrons* but also standard *hole carriers*

New possibility of Dirac physics
Hall Coefficient $R_H$, Thermoelectric Power $S$

Small number of electron carriers but small scattering rate due to Dirac electrons