1 Aoki Group

Subject: Theoretical condensed-matter physics

Our main interests are many-body and topological effects in electron and cold-atom systems, i.e., **superconductivity, magnetism and topological phenomena**, for which we envisage **materials design** and novel **non-equilibrium** phenomena should be realised. Studies around the 2021 academic year include:

- **Superconductivity/superfluidity**
  - — Superconductivity in a new cuprate $Ba_2CuO_{3+\delta}$ [1], see Fig.1.1.1
  - — Superconductivity in a nickelate (Nd,Sr)NiO_2[2], see Fig.1.1.2
  - — Design of flat bands and flat-band superconductivity[3, 4, 5], see Fig.1.1.3
  - — Nematicity-enhanced superconductivity[5], see Fig.1.1.4
  - — BCS-BEC crossover in superconductivity/superfluidity in incipient 2-band systems[6], see Fig.1.1.5
- **Topological systems**
  - — Zero modes in Kekule-ordered honeycomb systems[7]
  - — Valley and spin polarisation in bilayer graphene and transition-metal dichalcogenides[8], see Fig.1.1.6
- **Non-equilibrium phenomena**
  - — Nonequilibrium-induced topological superconductivity[9], see Fig.1.1.7
  - — Imprinting topological states by spatially-periodic circularly-polarised light[10]

[1] Kimihiro Yamazaki, Masayuki Ochi, Daisuke Ogura, Kazuhiko Kuroki, Hiroshi Eisaki, Shinichi Uchida, and Hideo Aoki: Superconducting mechanism for a new-type cuprate $Ba_2CuO_{3+\delta}$ based on a multiorbital Lieb lattice model, *Phys. Rev. Research* **2**, 033356 (2020).

[2] Hirofumi Sakakibara, Hidetomo Usui, Katsuhiro Suzuki, Takao Kotani, Hideo Aoki, and Kazuhiko Kuroki: Model construction and a possibility of cuprate-like pairing in a new d^9 nickelate superconductor (Nd,Sr)NiO_2, *Phys. Rev. Lett.* **125**, 077003 (2020) (Editors' suggestion).

[3] Sharareh Sayyad, Edwin W. Huang, Motoharu Kitatani, Mohammad-Sadegh Vaezi, Zohar Nussinov, Abolhassan Vaezi and Hideo Aoki: Pairing and non-Fermi liquid behavior in partially flat-band systems, *Phys. Rev. B* **101**, 014501 (2020).

[4] Hideo Aoki: Theoretical possibilities for flat-band superconductivity, *Journal of Superconductivity and Novel Magnetism* **33**, 2341 (2020).

[5] Sharareh Sayyad, Motoharu Kitatani, Abolhassan Vaezi, and Hideo Aoki: Nematicity-enhanced superconductivity in systems with a non-Fermi liquid behavior, arXiv:2110.14268.

[6] Kazunari Ochi, Hiroyuki Tajima, Kei Iida, and Hideo Aoki: Resonant pair-exchange scattering and BCS-BEC crossover in a system composed of dispersive and heavy incipient bands: a Feshbach analogy, *Phys. Rev. Research* **4**, 013032 (2022).

[7] Tohru Kawarabayashi, Yuya Inoue, Ryo Itagaki, Yasuhiro Hatsugai and Hideo Aoki: Robust zero modes in disordered two-dimensional honeycomb lattice with Kekulé bond ordering, *Annals of Physics*, doi.org/10.1016/j.aop.2021.168440 (Proc. "Localization 2020").

[8] P. A. Maksym and H. Aoki: Complete spin and valley polarization by total external reflection from potential barriers in bilayer graphene and monolayer transition metal dichalcogenides, *Phys. Rev. B* **104**, 155401 (2021).

[9] Sota Kitamura and Hideo Aoki: Floquet topological $d + id$ superconductivity induced by chiral many-body interactions, to be published in *Communications Physics* (arXiv:2108.13626).

[10] Hwanmun Kim, Hossein Dehghani, Hideo Aoki, Ivar Martin, and Mohammad Hafezi: Optical imprinting of superlattices in 2D materials, *Phys. Rev. Research* **2**, 043004 (2020).

Gallery

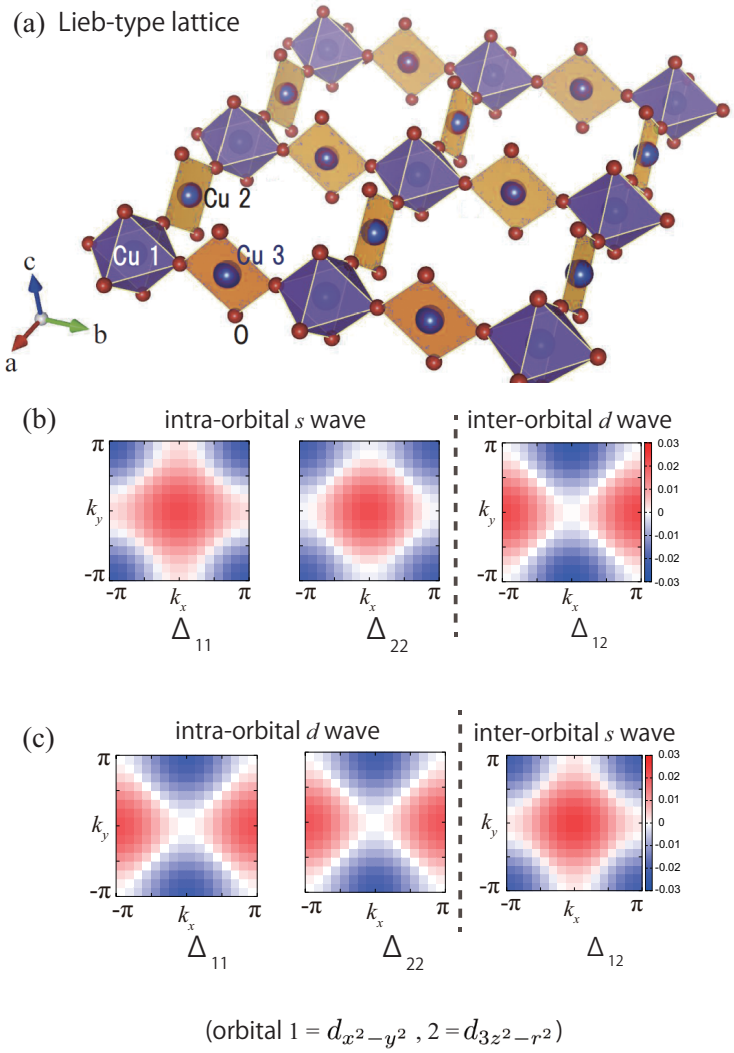


図 1.1.1: (a) A theoretically proposed Lieb-lattice type crystal structure for a new cuprate superconductor $Ba_2CuO_{3+\delta}$. (b) Gap function Δ_{ij} in the orbital (i, j) representation is shown for the intra-orbital s-wave, inter-orbital d-wave pairing, and (c) the intra-orbital d-wave, inter-orbital s-wave.[1]

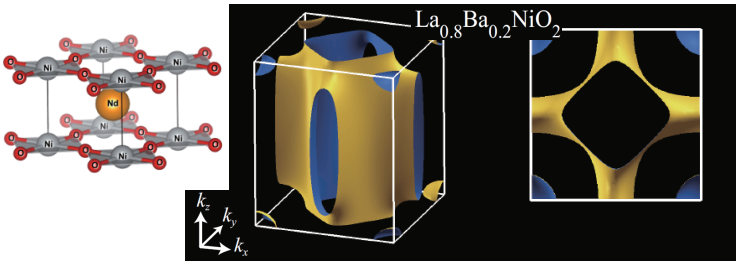


図 1.1.2: A theoretical Fermi surface in the nickelate superconductor, with a crystal structure in the left inset.[2]

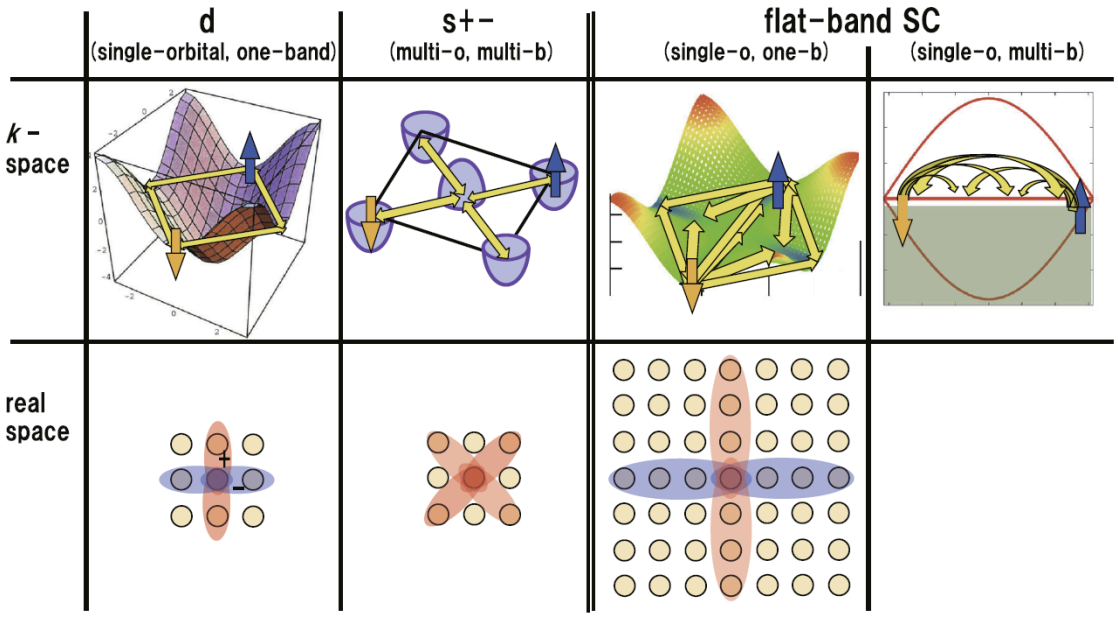


図 1.1.3: Schematic models for superconductivity. [4] Left column: Ordinary one-orbital, one-band systems, as exemplified here for a d-wave pairing. Second from left: Ordinary multi-orbital, multi-band systems, here for an $s_{\pm}$-wave pairing. Yellow arrows represent main pair-scattering channels with nesting vectors between the "hot spots". These are contrasted with flat-band systems — Second from right: one-orbital, one-band flat-band systems. Right: one-orbital, multi-band flat-band systems. In the flat-band systems the pair scattering occurs over a "bunch" of nesting vectors. The bottom panels depict the pairs in real space.

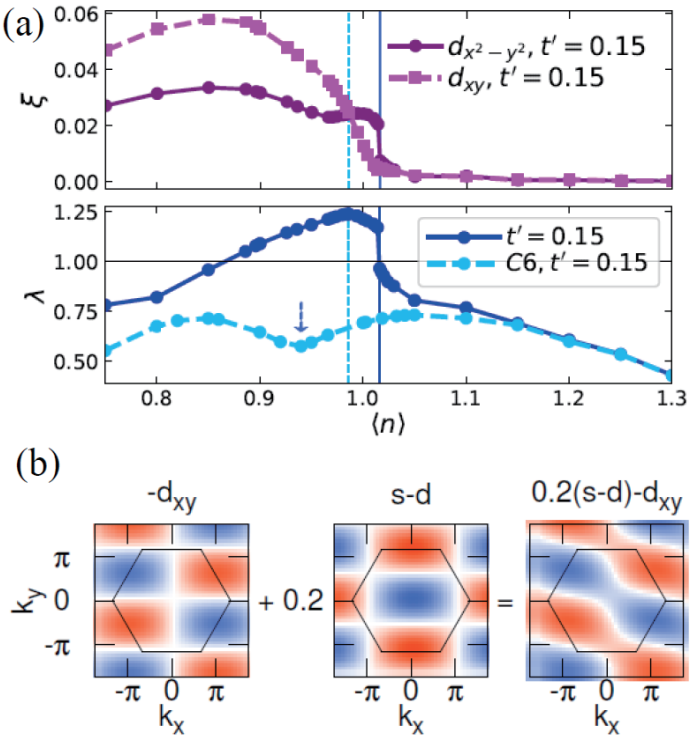


図 1.1.4: Superconductivity in repulsively-interacting electron systems on a triangular lattice.[5] (a) Electron nematicity (ξ) and eigenvalue of the Eliashberg equation (λ) are plotted against the band filling $\langle n \rangle$. For ξ, $d_{x^2-y^2}$ wave is represented by a solid curve, d_{xy} by a dashed curve. For λ, the solid curve represents the case in which the electron nematicity (Pomeranchuk instability) is allowed, while the dashed curve the case is which the nematicity is forbidden. (b) The gap function in the presence of the electron nematicity (right-hand side) comprises d_{xy} and $s_{x^2+y^2} - d_{x^2-y^2}$ components (left-hand side).

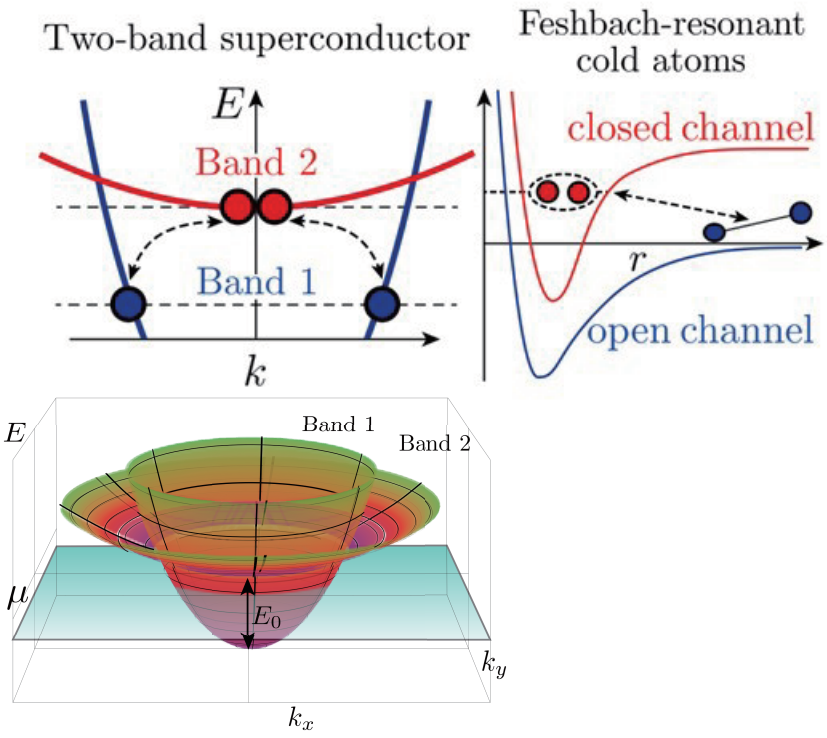


図 1.1.5: Left: Pair scattering in an electron system comprising light-mass (blue) and heavy-mass (red) bands. Right: Feshbach resonance in a cold-atom system comprising open (blue) and closed (red) channels.[6]

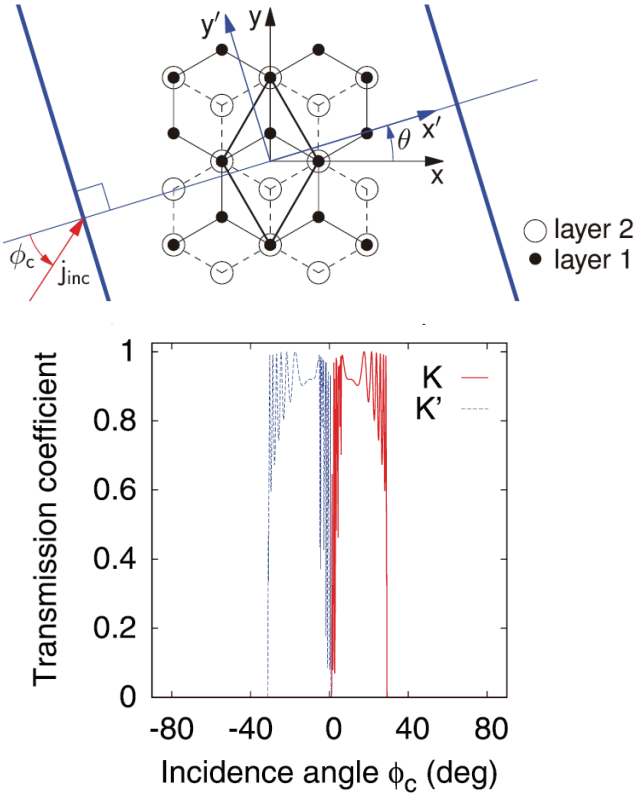


図 1.1.6: Top: Electron transmission through a potential barrier (with its perimeters depicted by blue lines) in a bilayer graphene. Bottom: Tranmission coefficient as function of the incidence angle ϕ_c of the electron. Solid curve represents K-valley, dashed curve K' valley.[8]

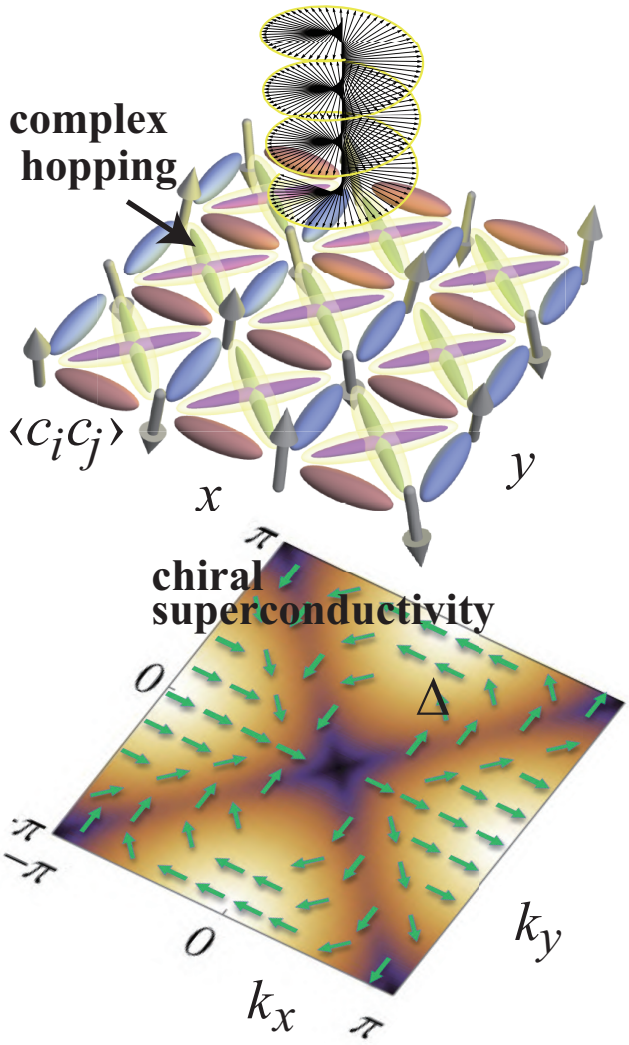


図 1.1.7: When a circularly-polarised light is illuminated on a d-wave superconductor in a repulsively-interacting electron system on square lattice (top panel), a new pairing component is induced due to a Floquet physics, and a topological ($d + id$ wave) superconductivity with a broken time-reversal emerges (bottom panel depicting the gap function in k-space).[9]