Topological electronic states in microscopic gyroids

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The gyroid is a three-dimensional periodic structure that has been realized in various systems and scales [1]. It has been demonstrated that the photonic gyroid crystal exhibits topologically nontrivial band structures, including Weyl points and line nodes, which reflect the high symmetry of the structure [2]. In this study, we focus on the electronic properties of the microscopic gyroid structure to explore the unique topological features arising from the symmetry of the crystal structure.

The chiral crystal structure known as the "single gyroid" has a configuration where each lattice point is connected by three bonds [Fig. 1(a)]. This single gyroid structure is one of the structures with the highest symmetry, referred to as "strong isotropy," along with honeycomb and diamond structures [3]. Due to its high symmetry, the higher-spin Dirac points can appear at the Γ point in the electronic band structure of the single gyroid [4]. Although the synthesis of a single gyroid with carbon atoms has not been successful to date, the synthesis of a single gyroid structure using organic molecules has been achieved, and the realization of a spin liquid has been confirmed [5].

In the present study, we focus on the nested crystal structure consisting of two single gyroids, known as the "double gyroid" [Fig. 1(a)]. Figure 1(b) shows the electronic band structure based on the tight-binding approximation considering only a single orbital at each site. Unlike the single gyroid, the double gyroid exhibits accidental degeneracy between the conduction band and the valence band. A detailed analysis of this degeneracy revealed that the bands degenerate continuously within the three-dimensional momentum space, forming what is known as a "Dirac line node" [Fig. 1(c)]. The Dirac line nodes in the double gyroid, unlike the loop-like line nodes previously discovered, are open across the Brillouin zone and form a total of 12 line nodes within the Brillouin zone [Fig. 1(d)]. In the presentation, we will further discuss the topological properties associated with these unique band structures.

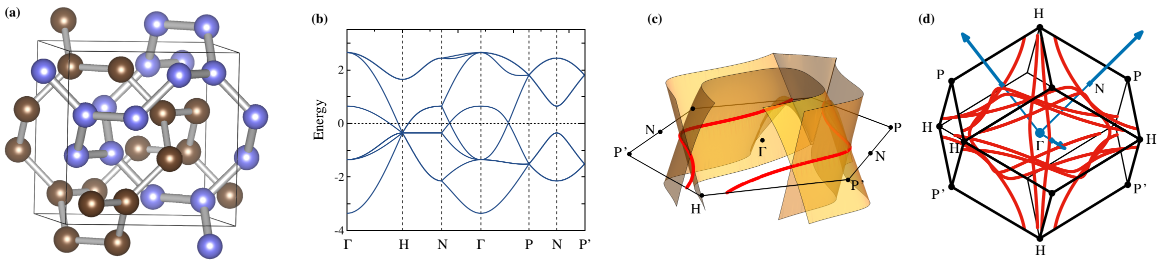

Figure 1 (a) Double gyroid structure. The space group is $Ia\bar{3}d$ (No. 230). The brown and purple structures represent single gyroid structures. (b) Band structure of the double gyroid structure. The nearest-neighbor hopping is set to t_0=0.5 and the next-nearest-neighbor hopping is set to t_1=1. (c) Dispersion relation of the Dirac line nodes. (d) Dirac line nodes in the Brillouin zone.

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