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The topological phase of matter is one of the intriguing fields in condensed matter physics. One breakthrough in the topological phase of matter is the theoretical proposal for the two-dimensional topological insulator. While the bulk is an insulator, its edge is metallic and protected by a topological number. The concept of topology in the topological insulator is extended to a gapless phase, which is the topological semimetal. One example of the topological semimetal is the nodal line semimetal having line-node degeneracy in the momentum space known as nodal lines. The nodal lines are protected by topological and symmetry reasons. For example, the nodal line is characterized by the quantized Berry phase in spinless systems with inversion symmetry and time-reversal symmetry. Otherwise, the nodal line is protected by symmetry such as mirror symmetry in spinless and spinful systems. Through a continuous change of the system, such as pressure, the nodal lines are deformed and can change their topology.

In this thesis, we systematically classify the topology changes of nodal lines in systems with inversion and time-reversal symmetries. It is a nontrivial problem and has not been studied before in general. We solve this problem by regarding the nodal line as the two-dimensional manifold in four dimensions by adding a one-dimensional parameter space. Then the topology change of nodal lines is related to the shape of the manifold around critical points. We use the Morse theory to classify its shape at critical points to understand the topology changes of nodal lines. We reveal that only three types of topology changes, creation, reconnection, and annihilation of nodal lines, are allowed and related to the index in the Morse theory. Therefore, we can predict the topology changes of nodal lines by calculating the index without following the complicated deformation of nodal lines.

Moreover, we extend our approach to systems with additional crystallographic symmetries and disclose possible topology changes of nodal lines. In these cases, the Morse theory cannot be directly applied, and the index is not defined in these cases with additional crystallographic symmetry. Here, we find that in such cases the coefficient functions in the Hamiltonian are always “factorized,” and after the factorization one can apply the Morse theory to define the index and to classify the events of topology changes of nodal lines. We start with cases of simple point group symmetries, such as rotational symmetry and mirror symmetry. We disclose the topology changes of nodal lines with all possible pairs of irreducible representations under these symmetries. In particular, in some point groups the reconnection of nodal lines is prohibited because of symmetry constraints. Systems with more complicated point groups can be studied similarly, based on the factorization under the rotational symmetries and the mirror symmetry. Then, we find rich varieties of topology changes of nodal lines in those point groups. Through this study, we exhaust all the possible events of topology changes of nodal lines in most of the point groups.