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Making Axion Dynamical in Non-Centrosymmetric Magnetic Topological Insulators

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"Axion" was predicted as a hypothetical elementary particle to resolve the strong conjugation-parity problem in particle physics,[1] and it is also an attractive candidate for the as-yet-unobserved dark matter in cosmology.[2] While the detection of axions still remains elusive in particle physics and cosmology, it was recently proposed that the elegant physics of axions, known "axion electrodynamics",[3] can emerge in certain condensed matter systems, particularly topological insulator materials,[4] in which a variety of exotic physical phenomena (e.g. topological magnetoelectric effect) have been theoretically predicted.[5,6] The recent discovery of magnetic topological insulators in $MnBi_2Te_4$ family of materials[7,8] provides an excellent platform to explore these physical phenomena induced by axion electrodynamics.[9–13] Current research mainly focuses on the phenomena related to a static quantized axion field (also called θ field), of which the parameter θ is independent of time. This is because the axion field is normally fixed to a quantized value ($\theta = \pi$) by certain symmetry in $MnBi_2Te_4$ family of materials. On the other hand, several intriguing phenomena, such as axionic polariton[14] and axion instability induced by nonlinear electromagnetic effect,[15] relies on the dynamics of axion field. Therefore, the ability of controlling the θ value of the axion field and inducing a large fluctuation of θ is of great importance for the experimental test of axion electrodynamics, as well as the potential applications. More recently, it was suggested that the phason mode of the charge density wave in Weyl semimetal $(TaSe_4)_2I$ can also play the role of dynamical axion field.[16] However, since $(TaSe_4)_2I$ is non-magnetic and respects time reversal, it remains challenging to induce a large fluctuation of the axion field for the experimental probe of axionic polariton and axion instability.

The paper by Zhang *et al.*[17] provides a guiding principle to search for materials with a large dynamical axion field, based on which they identify a series of van der Waals layered $Mn_2Bi_2Te_5$-related topological materials as the candidates. The key insight is that the parameter θ is fixed to a quantized value by either time reversal T or inversion P, and thus breaking both T and P is required to drive θ away from the quantized value for the fluctuation. It is further noticed that θ can rapidly vary between the values of 0 and π when the system is close to a topological phase transition. Therefore, a non-centrosymmetric magnetic topological insulator with a small gap (close to topological phase transition) is preferable for a large dynamical axion field. Based on this guiding principle, Zhang *et al.* propose that a large dynamic axion field can exist in a variation of the $MnBi_2Te_4$ compounds, namely $X_2A_2B_5$, X = Mn/Eu, A = Sb/Bi, B = Se/Te, through the first-principles calculations. A systematic study on the variation of the gap as a function of element substitution (Bi/Sb and Te/Se) is also carried out in order to guide the optimization of the material compounds experimentally to maximize the effect of dynamical axion field.

Zhang *et al.* also explore the possible experimental detection of dynamical axion field. It is interesting to notice that they predict a double frequency signature induced by dynamical axion field in nonlinear optical spectroscopy. Current efforts in topological nonlinear optics[18–21] mainly focus on the phenomena related to Berry phase and Berry curvature, while nonlinear optical response induced by axion electrodynamics remains largely unexplored. If these proposed phenomena can be observed in $Mn_2Bi_2Te_5$ family of materials, this may also pave the way to a new generation of axion-based devices for the applications of electronics, optronics and spintronics.

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