Toroidal order in metals without local inversion symmetry

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A toroidal moment, which is represented by vector products of electric and magnetic moments [Fig. 1(a)], is a source of cross correlations between electric and magnetic responses. Recently, a toroidal order has gained interest because it leads to exotic phenomena, such as magnetoelectric effects and nonreciprocal directional dichroism [1]. The study of such toroidal ordering has been mostly restricted to magnetic insulators thus far, although it may bring about richer physics in metallic systems owing to their conducting nature [2]. In order to examine the effect of toroidal ordering in metals, we investigate the spontaneous ferroic toroidal ordering in systems where the spatial-inversion symmetry is preserved globally but broken intrinsically at each magnetic site [3]. Considering an effective Hubbard-type model with a site-dependent antisymmetric spin-orbit coupling on a stacked honeycomb lattice as shown in Fig. 1(b), we find that the toroidal ordered state exhibits the highly anisotropic Hall effect and two different types of magnetoelectric effects. Moreover, we propose that the toroidal magnetic order induces an intrinsic off-diagonal magnetotransport response even without an external magnetic field. We will also discuss the relevance of our results to a candidate compound for the toroidal metal, UNi\(_4\)B.

Figure 1: (a) Schematic picture of the toroidal moment, which is defined by vector products of the position from the inversion center and the magnetic moment. (b) Schematic picture of the layered honeycomb lattice. The red (blue) arrows in the \(z\) direction (\(xy\) plane) represent the toroidal (magnetic) moments.