Designer curved-space geometry for relativistic fermions in Weyl metamaterials

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Simulating relativistic phenomena in table-top systems has become a major theme in condensed matter physic. Topological materials, exhibiting a myriad of connections to high-energy physics, have been a significant inspiration for these developments. An important source of fascination has also been provided by semimetals which display emergent relativistic dynamics at low energies. This has given rise to a wide-spread interest in engineering artificial gauge fields in graphene and 3d Dirac and Weyl semimetals. The phenomenology of general rel- ativity and curved-space dynamics has also penetrated into condensed-matter research. In addition to fundamental interest, curved-space physics may also have striking practical applications as electromagnetic metamaterials and transformation optics demonstrate.

Weyl semimetals are recently discovered materials supporting emergent relativistic fermions in the vicinity of band-crossing points known as Weyl nodes. The positions of the nodes and the low-energy spectrum depend sensitively on the time-reversal (TR) and inversion (I) symmetry breaking in the system. We introduce the concept of Weyl metamaterials where the particles experience a 3d curved geometry and gauge fields emerging from smooth spatially varying TR and I breaking fields. The Weyl metamaterials can be fabricated from semimetal or insulator parent states where the geometry can be tuned, for example, through inhomogeneous magnetization. We derive an explicit connection between the effective geometry and the local symmetry-breaking configuration. This result opens the door for a systematic study of 3d designer geometries and gauge fields for relativistic carriers. Particle motion in Weyl metamaterials results from an interplay of classical and quantum geometric effects. The general theory is illustrated by proposing simple magnetic textures giving rise to remarkable 3d chirality-selective electron lensing effects. More generally, Weyl metamaterials pave the way for novel 3d electronic devices through curvature engineering.

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