Editorial: Altermagnetism—A New Punch Line of Fundamental Magnetism

Non sunt multiplicanda entia sine necessitate, entities should not be multiplied without necessity. This observation made by the Franciscan monk John Punch in 1639 [1] still resonates with one of PRX's editorial philosophies: new terminology should only be introduced into papers when it advances understanding. Yet, the second Perspective article we have invited and are now publishing [2] seems to have done just the opposite. It introduces a new term into the century-old field of magnetism: "altermagnetism." PRX's authors and readers could rightly ask: Why make an exception here?

Let us now take a step back. Interesting magnetic patterns have long been a core topic in condensed matter physics. This interest has intensified during the recent decades, not least because of a growing interest in spintronics. New terms, such as skyrmion orders, have been introduced that justifiably deserve their separate drawers in the nomenclature chest, as they do label and signify new physics. What has been lacking, in our opinion, is a comprehensive classification of different magnetic orders, preferably based on symmetry criteria and observable manifestations. In complement to the Perspective, we present such a classification scheme in Fig. 1. We believe that altermagnetism, describing an array of qualitatively novel phenomenology that has emerged during the past few years, now merits its own drawer.

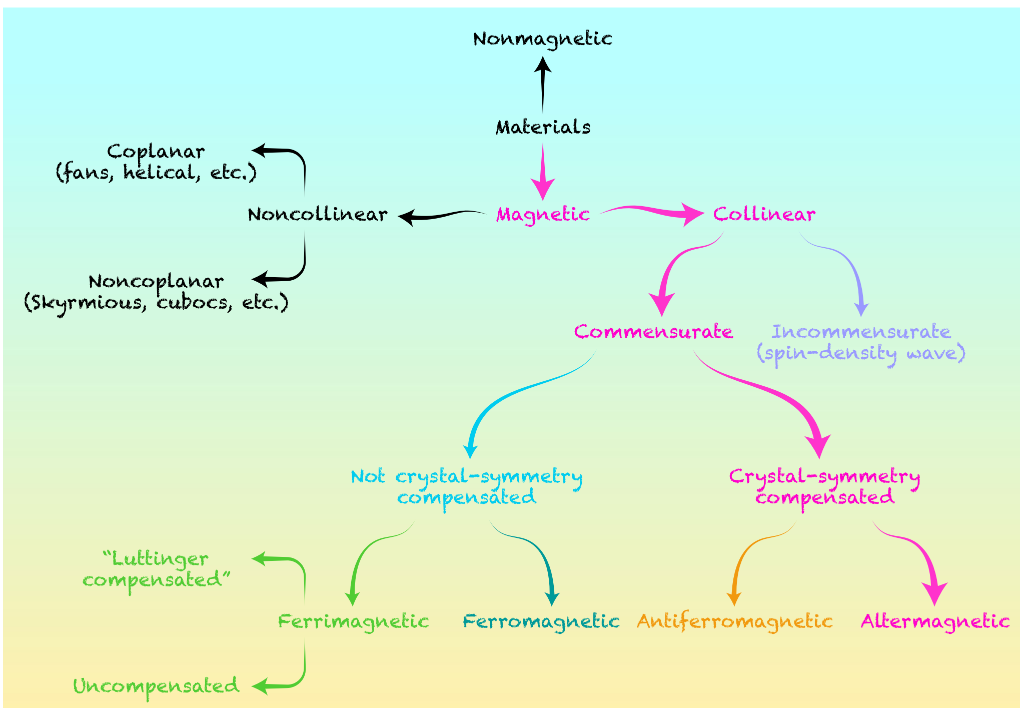

FIG. 1. A comprehensive classification scheme of different magnetic orders that shows altermagnetism as a fundamentally new class of magnetic order.

Each branching in the scheme corresponds to a classification based on a particular symmetry. The first branching point separates magnetic and nonmagnetic materials. The relevant symmetry here is the time-reversal symmetry. Magnetic materials feature a nonvanishing magnetic moment, at least locally, that breaks this symmetry. The second branching separates magnetic materials into collinear and noncollinear magnets. In the former (such as a ferromagnet) the local magnetization vectors through the entire material are all parallel to each other. The latter can be classified as coplanar—where the magnetization rotates in real space but remains in the same plane—and noncoplanar. Further subdivisions of the noncoplanar branch could be meaningfully pursued (zero vs nonzero vector, or scalar chirality, toroidicity, etc.; see a nice review by Cheong *et al.* [3]).

The collinear branch is the one most relevant to the Perspective. Moving along this branch, consideration of translational symmetry across a crystal lattice leads to the separation of magnetic structures that are either incommensurate or commensurate with the lattice. The former are commonly known as spin-density waves. The latter can be partitioned into a spin-up and, possibly, a spin-down sublattice, and its total magnetization may either be zero (or alternatively speaking, "fully compensated") or nonzero. Importantly, a full compensation may be imposed by symmetry or by some other mechanism. In fact, these two distinct cases are of critical importance for properly delineating the altermagnets as a new symmetry class of magnetic materials, as elaborated in the Perspective.

Before discussing altermagnetism, a closer look at the zero-magnetization magnetic structures where the compensation is not symmetry-driven is actually worthwhile. A good example is a ferrimagnetic semiconductor: By virtue of the Luttinger theorem, it can only have an integer magnetic moment per unit cell: 0, 1, 2 μ_B, etc. Therefore, if the total magnetization is zero, it is strictly zero, and this zero is robust: A small perturbation, such as pressure or stress, is not going to do away with it. Such "Luttinger-compensated" ferrimagnets constitute an interesting and largely overlooked class in its own right, even though it is not the focus of the Perspective article itself.

Turning to the other, symmetry-compensated, subbranch: Here, there is a crystallographic symmetry group operation that maps one spin sublattice onto the other. Classical "Neel" antiferromagnets belong to this class, and until a few years ago, it was believed that all antiferromagnets, while being distinctly different from ferromagnets and ferrimagnets, were of this type. The Perspective article, however, explains that this subbranch can, and must, undergo another split, depending on whether the "mapping" operations preserve the Kramers degeneracy (such operations are translations and inversion), or not (all others). While antiferromagnets have staggered magnetic order in the coordinate space, the magnetic order of altermagnets is staggered both in the coordinate space and in the momentum space. This distinction is as fundamental, and as important, as the familiar antiferromagnetic-ferromagnetic dichotomy.

The symmetry arguments notwithstanding, our readers may justly inquire about the phenomenology of altermagnets—do they stand out apart from either ferromagnets or antiferromagnets? The summary in Table I provides an answer. Not surprisingly, many physical observables of altermagnets share common properties either with ferromagnets or with antiferromagnets, though interestingly, more with ferromagnets. Other properties are, however, unparalleled in either ferromagnets or antiferromagnets, as highlighted in the Perspective article.

TABLE I. A comparative summary of the phenomenological similarities and differences between altermagnets and the familiar ferromagnets as well as antiferromagnets.

	FM	AF	AM
Nonrelativistic net magnetization	nonzero or zero	zero	zero
Nonrelativistic Kramers spin degeneracy	no	yes	no
Anomalous Hall	yes	no	yes
Magnetooptics	yes	no	yes
Nonrelativistic spin-polarized current	yes	no	yes
Suppression of Andreev reflection: diffuse contact	yes	no	no
Suppression of Andreev reflection: ballistic contact	yes	no	yes
Supports singlet superconductivity	no	yes	no
Supports locally (in k-space) unitary triplet superconductivity	no	yes	no
Supports k-averaged unitary triplet superconductivity	no	yes	yes
Giant or tunneling magnetoresistance and spin-transfer torque	yes	no	yes

Introducing the term altermagnetism into the scientific vocabulary is therefore not a whim but a conceptual and practical necessity—consistent with John Punch's philosophy. This new term heralds the emergence of a new and exciting research landscape in the century-old field of magnetism, which the authors of the Perspective have skillfully painted with their unique insights and well-informed imagination. Enjoy your viewing of that landscape!

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[1] Johannes Poncius, *Commentary on John Duns Scotus's Opus Oxoniense*, book III, dist. 34, q. 1, in *John Duns Scotus Opera Omnia*, edited by Luke Wadding (Louvain, 1639), Vol. 15; reprinted by L. Vivès, Paris (1894), p. 483a.

[2] Libor Šmejkal, Jairo Sinova, and Tomas Jungwirth, *Emerging Research Landscape of Altermagnetism*, Phys. Rev. X **12**, 040501 (2022).

[3] S. W. Cheong and X. Xu, *Magnetic chirality*, npj Quantum Mater. **7**, 40 (2022).