Altermagnetism and Weak Ferromagnetism

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After brief review of phenomenological theories [1], which have led to the prediction of anomalous Hall effect (AHE) in CrSb [2] and other unconventional antiferromagnets, which are currently called altermagnets [3], and early first-principles calculations predicting unexpectedly large magneto-optical response in weak ferromagnets [4], I will turn to microscopic understanding of these phenomena. I will argue that the key factor why certain classes of antiferromagnets exhibit AHE and other phenomena, which are more common for ferromagnets, is the form of relativistic spin-orbit (SO) interaction in centrosymmetric lattices, which replicates the form of Dzyaloshinskii-Moriya interactions. There are two important aspects. (1) The SO interaction in the bonds surrounding each magnetic site has the same-sign components as well as sign-alternating ones. While the former are responsible for the weak spin ferromagnetism (and can be eliminated in the simplest one-orbital model), the latter give rise to AHE [5]. Therefore, although the weak spin ferromagnetism and AHE are identical from the phenomenological point of view in the sense that both are the consequences of time-reversal symmetry breaking, they are fundamentally different from the microscopic point of view. (2) The SO interaction in the centrosymmetric lattice behaves as an antiferromagnetic object and changes its sign when going from one magnetic sublattice to another. This is a consequence of antiferroelectric lattice distortion, which always accompanies the weak ferromagnetism. That is why the SO interaction collaborates with the Néel field. Both obey the $\{S|\mathbf{t}\}$ symmetry, which combines the 180° rotation of spins about y with the lattice shift $\mathbf{t}$ connecting antiferromagnetic sublattices. This $\{S|\mathbf{t}\}$ symmetry has dramatic consequences on the properties of centrosymmetric antiferromagnets [5,6]: (i) It preserves the spin degeneracy of the bands; (ii) Nevertheless, the time-reversal symmetry is broken, resulting in finite AHE; and (iii) $\{S|\mathbf{t}\}$ is the basic symmetry of spin-spiral magnets, which allows us to apply the generalized Bloch theorem and describe, in some local coordinate frame, the unconventional antiferromagnet as a ferromagnet with only one magnetic site per cell [6]. This naturally explains the emergence of AHE and net orbital magnetization. Another key ingredient responsible for finite AHE is orthorhombic strain, in an analogy with piezomagnetism [5].

[1] E. A. Turov, *Kinetic, optical, and acoustic properties of antiferromagnets* (Ural Division of Academy of Sciences of the USSR, Sverdlovsk, 1990).
[2] E. A. Turov and V. G. Shavrov, JETP (USSR) **16**, 1606 (1963).
[3] L. Šmejkal, J. Sinova, and T. Jungwirth, Phys. Rev. X **12**, 031042 (2022).
[4] I. V. Solovyev, Phys. Rev. B **55**, 8060 (1997).
[5] I. V. Solovyev, S. A. Nikolaev, and A. Tanaka, arXiv:2503.23735 (2025).
[6] I. V. Solovyev, arXiv:2509.00369 (2025).