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Thermodynamic theory for thermally driven domain wall motion in magnetic nanostructures[1]

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It is well-established now that a thermal gradient can be used to manipulate spins in a magnetic texture like skyrmions and domain walls (DWs). A thermal gradient can interact with spins through different channels. For example, a thermal gradient can affect spins through the thermoelectric effects by which spin polarized electric current is generated in a ferromagnetic metal. In turn, the thermally generated electric current can interact with magnetic texture via spin-transfer torque (STT). A thermal gradient can also generate magnons or spin waves that interact with magnetic textures. This effect should be important in a ferromagnetic insulator. Spin waves (or magnons) interact with magnetic domain walls (DWs) in a complicated way that a DW can propagate either along or against magnon flow, similar to its electron counterpart. Probably differ from its electron counterpart where one may attribute the "wrong" DW propagation direction to the Dzyaloshinskii-Moriya interaction and various types of torques due to spin-orbit interactions, it will be very difficult to understand why a DW can move along the magnon flow if the angular momentum transfer is the only mechanism behind the magnon driven DW motion. It will also be difficulty to explain why "wrong" DW propagation direction has not been observed in thermally driven DW motion in both simulations and experiments. Thus, there must be other interaction(s) between spin waves and magnetic textures. In terms of thermal gradient driven DW propagation along a nanowire, a DW always propagates to the hot region of a magnetic insulator wire. We theoretically illustrate why it is surely so from thermodynamic viewpoint. It is shown that DW entropy is always larger than that of a domain. Equivalently, the free energy difference of a DW and a domain decreases as the temperature increases. The larger DW entropy is related to the increase of magnon density of states at low energy originated from the gapless bound spin waves in DWs. This theory should be applicable to other spin textures like skyrmions as well since bound spin waves generally exist in spin textures. The theory also naturally explains why the magnetic domain widths decrease with the increase of the temperature, a well-known experimental phenomenon. In collaboration with X.S. Wang, Hong Kong University of Science & Technology.

References: [1] "Thermodynamic theory for thermal-gradient-driven domain wall motion," X. S. Wang and X.R. Wang, Phys. Rev. B 90, 014414 (2014).

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