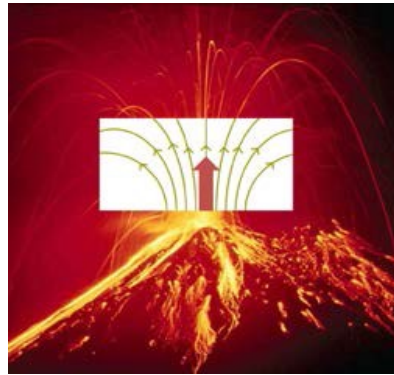


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Onsager Reciprocity in Spin Caloritronics



The spin degree of freedom of the electron affects not only charge, but also heat and thermoelectric transport, leading to new effects in small structures that are studied in the field of *spin caloritronics* (from calor, the Latin word for heat). This lecture addresses the basic physics of spin caloritronics. After an introduction into thermoelectrics and Onsager's reciprocity relations, the generalization to include the spin dependence in the presence of metallic ferromagnets will be addressed. Using this foundation I will describe several recently discovered spin-dependent effects in metallic nanostructures in terms of a two spin-current model of weakly interacting electrons.

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Next, I will argue that a different class of spin caloritronic effects exists that can be explained only by the collective spin dynamics in ferromagnets. The thermal spin transfer torque that allows excitation and switching of the magnetization in spin valves as well as the operation of nanoscale heat engines is complemented by thermal spin pumping. The latter generates the so-called spin Seebeck effect, which is generated by a heat current-induced non-equilibrium of magnons at a contact between an insulating or conducting ferromagnet and a normal metal. Under these conditions a net spin current is injected or extracted from the normal metal that can be detected by the inverse spin Hall or spin valve effects. We'll discuss the Onsager response matrix for magnetic insulators and its experimental ramifications including the recently discovered spin Peltier effect and the figure of merit for spin Seebeck/Peltier heat engines.

More details and a bibliography can be found in Ref. [1].

- [1] G.E.W. Bauer, E. Saitoh, and B.J. van Wees, *Spin Caloritronics*, Nature Materials **11**, 391 (2012); an update will be published as a section of the *Magnetism Roadmap*, J. Phys. D, in press.

**Friday, March 7, 4:00 pm
 Room 136 Jorgensen Hall**

**Host:
 Prof. Alexey Kovalev
 Department of
 Physics & Astronomy**

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