Irreversible thermodynamics and transport of charge, heat, and spin (ME8603)

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Syllabus

Text: Powerpoint lectures and notes from the instructor. Lectures are on Carmen. Download, print, take to class and take notes.

Reference books/articles:

- H. Callen, Thermodynamics, John Wiley & Sons, New York, 1960
- J. M. Ziman, Electrons and Phonons, Clarendon, Oxford (1960), reprint 1972
- Heikes et Ure, Thermoelectricity: Science and Engineering, Interscience, New York 1961
- S.R. Boona and J. P. Heremans: Spin Caloritronics, Energy and Environmental Science (2014)
- Kamran Behnia, Fundamentals of Thermoelectricity, Oxford U.P. , 2015

Evaluation: graded (conventional A-E scale) take-home homework problems, to be solved individually. All external sources of material are allowed. Approximately one homework per section (6 or 7 total).

On Carmen but will be updated as the classes progress. I expect you to solve **all** problems, at your pace. No deadlines, turn them in when you have them ready.

Types of transport: microscopic mechanisms

1. **Diffusive regime**: mean free path of the particles that carry heat, charge of spin is smaller than sample dimensions. Microscopic transport mechanisms governed by the **Boltzmann** equation.
2. **Ballistic regime**: mean free path limited by sample dimensions: Microscopic transport governed by **ray** equations.
3. **Quantum-confined regime**: particle wavefunction limited by sample dimensions: concept of quantum of conductance: **quantum mechanics**.
4. **Quantum corrections to transport**:

   Localization effects

   Landau levels

5. **Advection or Drag regimes** (2-phased flow, phonon-electron, phonon-magnon, magnon-electron drag):

   Similar to ballistic, but particle/particle interactions dominate over particle/sample wall interactions

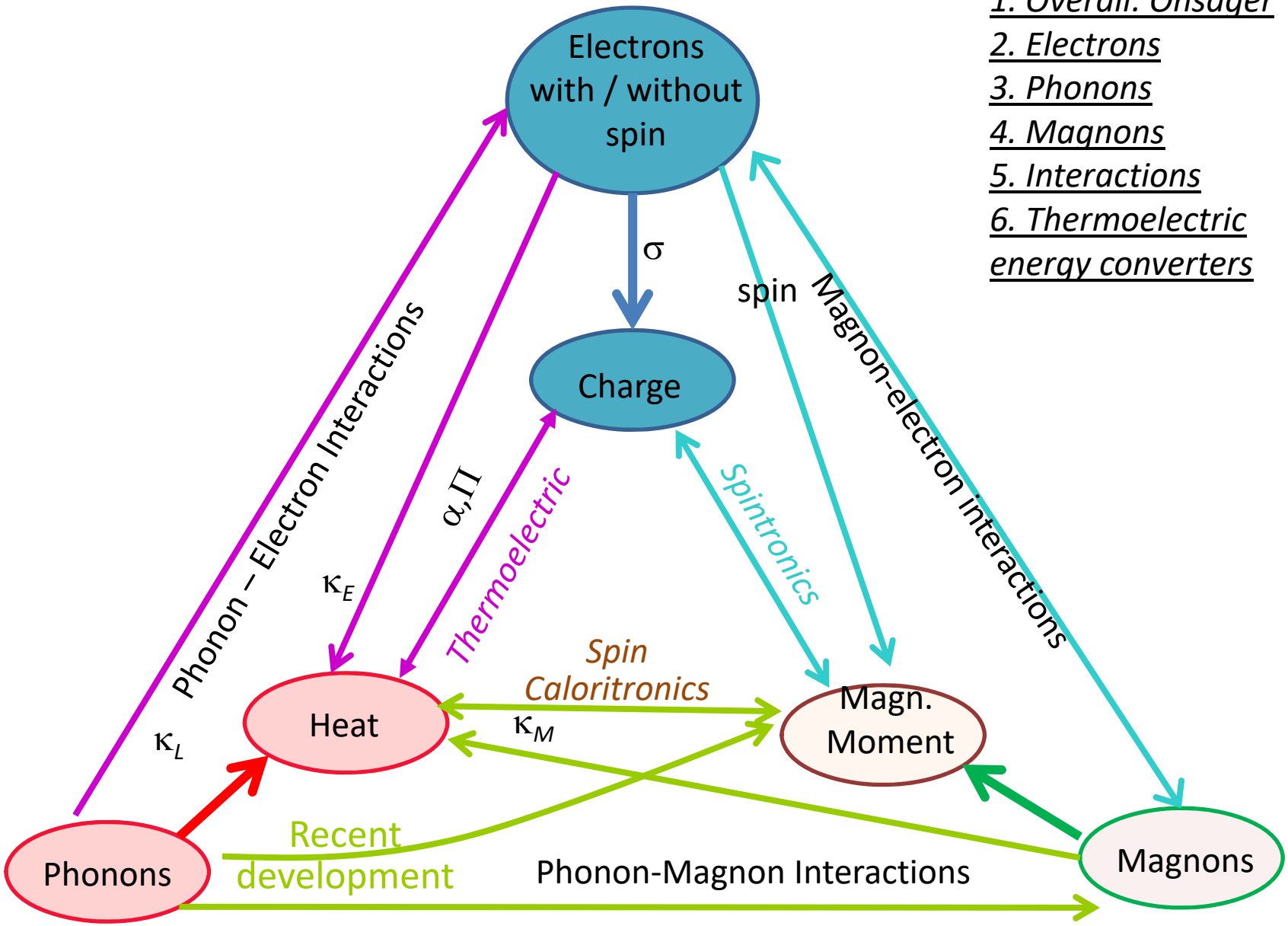
Irreversible thermodynamics = macroscopic theory, covers all cases.

Diffusive transport only used as example. Slides with BLUE heading are only examples

What quasi-particle carries what?

Hence the structure:

1. Overall: Onsager
2. Electrons
3. Phonons
4. Magnons
5. Interactions
6. Thermoelectric energy converters



Boona & Heremans, Energy and Environmental Science, 7 885 (2014)

Planned structure

Section 1: Irreversible Thermodynamics
Chapter 1.1: The Onsager Relation
Chapter 1.2: The Onsager Reciprocity Relation
Chapter 1.3: Single Conductivities: isothermal electrical conductivity;
isopotential thermal conductivity
Chapter 1.4: Mixed conductivities: thermoelectric effects
Chapter 1.5: Thermomagnetic effects and symmetries
Chapter 1.6: Onsager relations in Boltzmann and Landauer-Büttiker formalisms

Section 2: Electrons
Chapter 2.1: Types of transport mechanisms, Mott and Ioffe-Regel criteria
Chapter 2.2: Diffusive electron transport in crystalline solids
Chapter 2.3: Scattering
Chapter 2.4: Non-linear transport: drift/diffusion equations
Chapter 2.5 : Quantum corrections : Landau levels, size quantization, weak localization
Chapter 2.6 : Non-quantum corrections : hopping, advection (drag)

Section 3: Phonons
Chapter 3.1: Types of phonon transport, criteria
Chapter 3.2: Diffusive phonon transport in crystalline solids
Chapter 3.3: Amorphous solids

Section 4: Magnons
Chapter 4.1: Introduction to thermodynamics of magnetism
Chapter 4.2: Magnons and magnon thermal conductivity
Chapter 4.3: Crossing interfaces
Chapter 4.4: Spin-Seebeck, Spin-Peltier, Spin-dependent Seebeck and spin-dependent Peltier effects

Chapter 5: Interactive effects and advection
Chapter 5.1 Phonon-electron interactions and phonon drag
Chapter 5.2 Magnon-electron interactions and magnon drag

Chapter 6: Applications: solid-state thermal energy conversion
Chapter 6.1 Thermoelectric heat engines, the thermoelectric figure of merit zT
Chapter 6.2 Thermoelectric materials optimization

Tentative schedule (indicative only, will almost certainly be disrupted)

Class 1: Onsager relation: chap 1.1
Class 2: Onsager reciprocity relation, 1.2
Class 3: Type of Conductivities 1.3
Class 4: Thermoelectric effects 1.4
Class 5: Thermomagnetic effects 1.5
Class 6: Landauer formalism 1.6

Class 6 (con't): Types of Transport 2.1
Class 7: Boltzmann and diffuse transport 2.2
Class 8: More diffuse transport 2.2
Class 9: Multicarrier transport 2.4
Class 10: Drift/diffusion 2.4; Quantum corrections, Landau 2.5
Class 11: weak localization 2.5
Class 12: Non-quantum corrections

Class 13: Phonons intro 3.1
Class 14: Phonons thermal properties 3.2
Class 15: Phonon thermal conductivity 3.2
Class 16: Phonons in amorphous solids 3.3

Class 17: Magnons, introduction 4.1
Class 18: Magnons, heat conduction 4.2
Class 19: Magnetism across interfaces 4.3
Class 20: spin Seebeck effects 4.4

Class 21: Magnon drag and phonon drag

Class 22: Thermoelectric power gen 6.1
Class 23: Thermoelectric cooling 6.1