General Information

This proseminar is supervised by Renato Renner and covers topics related to present research questions within the area of Thermodynamics. This includes axiomatic approaches and related mathematical subjects, results from the very recently emerging theory of Quantum Thermodynamics and Black Hole Thermodynamics. Possible topics for student presentations are listed below. Each presentation is based on one or two research publications. For general questions, please contact Volkher Scholz (scholz@phys.ethz.ch).

Format

The student prepares a presentation of around, but not more than, one hour duration, on a specific topic assigned in advance. A tutor from the Institute of Theoretical Physics will provide literature and give a feedback on the student's progress. Students keep the tutor informed about their work in weekly meetings, starting (at least) 6 weeks before the date of the final presentation.

Requirements for passing the module

The student gives a pedagogical talk on the assigned topic, demonstrating a firm understanding of the subject. The presentation is shown to the tutor a week in advance. A written scientific report in English (template available on request) is handed in 4 weeks after the presentation. This report covers the presented material. The presence of the student is required in at least 80% of sessions.

Schedule

Date	Title	Presenter	Tutor
13.10	Axiomatic approach to the concept of entropy	A. Malär	
20.10	The principle of increasing mixing character and some of its consequences	T. Engel	
27.10	Nonequilibrium Equality for Free Energy Differences	B. Mühlmann	
03.11	Landauer's principle	F. Landolt	
10.11	(Im-)Proving Landauer's Principle	C. Glomb	
17.11	Thermodynamics of Quantum Information Systems — Hamiltonian Description	S. Mahanta	
24.11	Entanglement and the foundations of statistical mechanics	M. Zhu	
01.12	Single-shot work extraction	M. Strodtkötter	
08.12	Black Hole Thermodynamics	M. Oreshenko	
15.12	Thermodynamics of Spacetime: The Einstein Equation of State	S. Brun	

1 Axiomatic approaches

AXIOMATIC APPROACH TO THE CONCEPT OF ENTROPY

Student: A. Malär **Date:** 13.10.2014 **Tutor:**

From the abstract: The essence of the second law of classical thermodynamics is the 'entropy principle' which asserts the existence of an additive and extensive entropy function, S, that is defined for all equilibrium states of thermodynamic systems and whose increase characterizes the possible state changes under adiabatic conditions. Lieb and Yngvason presented an elegant axiomatic approach towards this principle, and the talk should be a review about their approach.

Required knowledge: *happy to work with abstract concepts*

Literature: Elliott H. Lieb and Jakob Yngvason. "Axiomatic approach to the concept of entropy". In: *Physics Reports* 310 (1999), pp. 1–96. arXiv: 9708200 [cond-mat]; Elliott H. Lieb and Jakob Yngvason. "The entropy concept for non-equilibrium states". In: *Proc. R. Soc. A* 469 (May 2013), p. 20130408. arXiv: 1305.3912

THE PRINCIPLE OF INCREASING MIXING CHARACTER AND SOME OF ITS CONSEQUENCES

Student: T. Engel **Date:** 20.10.2014 **Tutor:**

From the abstract: The "Principle of Increasing Mixing Character", is a stronger version of the second law of thermodynamics and can be re-derived using von Neumann's density matrix formulation of statistical mechanics. To make the principle more convenient for applications, it is reformulated in terms of "Mixing Homomorphic Functions", a set of state functions all of which must increase in an allowed irreversible process in an-isolated system. The entropy is one such function, but no one function, and no finite set of functions, suffices to determine the increase of mixing character.

Required knowledge: *Mathematical interest*

Literature: Ernst Ruch and Alden Mead. "The principle of increasing mixing character and some of its consequences". English. In: *Theoretica chimica acta* 41.2 (1976), pp. 95–117. DOI: 10.1007/BF01178071

2 Systems out of Equilibrium

NONEQUILIBRIUM EQUALITY FOR FREE ENERGY DIFFERENCES

Student: B. Mühlmann **Date:** 27.10.2014 **Tutor:**

Famous paper pf Jarzynski on systems not in equilibrium: An expression is derived for the equilibrium free energy difference between two configurations of a system, in terms of an ensemble of finite-time measurements of the work performed in parametrically switching from one configuration to the other.

Required knowledge: *Statistical Mechanics*

Literature: Christopher Jarzynski. "Nonequilibrium Equality for Free Energy Differences". In: *Physical Review Letters* 78.14 (Apr. 1997), pp. 2690–2693. DOI: 10.1103/PhysRevLett.78.2690

3 Landauer's principle

LANDAUER'S PRINCIPLE

Student: F. Landolt **Date:** 03.11.2014 **Tutor:**

The orginial paper on the famous principle that the erasure of information increases the entropy.

Required knowledge: *none in particular*

Literature: Rolf Landauer. "Irreversibility and Heat Generation in the Computing Process". In: *IBM Journal of Research and Development* 5.3 (July 1961), pp. 183–191. DOI: 10.1147/rd.53.0183; Charles H. Bennett. "Demons, Engines and the Second Law". In: *Scientific American* 257.5 (Nov. 1987), pp. 108–116. DOI: 10.1038/scientificamerican1187-108

(IM-)PROVING LANDAUER'S PRINCIPLE

Student: C. Glomb **Date:** 10.11.2014 **Tutor:**

Landauer's principle is derived from general properties of the von-Neumann entropy and finite-size corrections are proven.

Required knowledge: *Quantum mechanics, mathematical interest*

Literature: David Reeb and Michael M. Wolf. "(Im-)Proving Landauer's Principle". In: (2013), p. 33. arXiv: 1306.4352

4 Quantum Thermodynamics

THERMODYNAMICS OF QUANTUM INFORMATION SYSTEMS — HAMILTONIAN DESCRIPTION

Student: S. Mahanta **Date:** 17.11.2014 **Tutor:**

How to extract work from one qubit in an optimal way.

Required knowledge: *Quantum mechanics*

Literature: Robert Alicki et al. "Thermodynamics of Quantum Information Systems — Hamiltonian Description". In: *Open Systems & Information Dynamics* 11.3 (2004), pp. 205–217

ENTANGLEMENT AND THE FOUNDATIONS OF STATISTICAL MECHANICS

Student: M. Zhu **Date:** 24.11.2014 **Tutor:**

The autors abandon the main postulate of statistical mechanics, the equal a priori probability postulate in favor of a new postulatio referring to individual states, rather than to ensemble or time averages. The key element in their paper is the quantum entanglement between the system and its environment.

Required knowledge: *Quantum mechanics, the student should be familiar with the concept of entanglement*

Literature: Sandu Popescu, Anthony J. Short, and Andreas Winter. "Entanglement and the foundations of statistical mechanics". In: *Nature Physics* 2.11 (Oct. 2006), pp. 754–758. DOI: 10.1038/nphys444. arXiv: 0511225 [quant-ph]

SINGLE-SHOT WORK EXTRACTION

Student: M. Strodtkötter **Date:** 01.12.2014 **Tutor:**

On the connection between information theory and thermodynamics: formulation of work extraction in terms of information quantities.

Required knowledge: *Quantum mechanics, Quantum information theory helps*

Literature: Johan Aberg. "Truly work-like work extraction via a single-shot analysis". In: *Nature communications* 4 (Jan. 2013), p. 1925. DOI: 10.1038/ncomms2712; Fernando G. S. L. Brandão et al. "Resource Theory of Quantum States Out of Thermal Equilibrium". In: *Physical Review Letters* 111.25 (Dec. 2013), p. 250404. DOI: 10.1103/PhysRevLett.111.250404. arXiv: 1111.3882

5 Thermodynamics and General Relativity

BLACK HOLE THERMODYNAMICS

Student: M. Oreshenko **Date:** 08.12.2014 **Tutor:**

The famous paper on the topic. Black holes behave as thermodynamic objects.

Required knowledge: *General Relativity*

Literature: Jacob D. Bekenstein. "Black Holes and Entropy". In: *Phys. Rev. D* 7 (8 Apr. 1973), pp. 2333–2346. DOI: 10.1103/PhysRevD.7.2333; C.W. Misner, K.S. Thorne, and J.A. Wheeler. *Gravitation*. Gravitation pt. 3. W. H. Freeman, 1973

THERMODYNAMICS OF SPACETIME: THE EINSTEIN EQUATION OF STATE

Student: S. Brun **Date:** 15.12.2014 **Tutor:**

Using assumptions motivated by Black Hole Thermodynamcis, Jacobson derives Einstein's field equations of General Relativity from thermodynamic identities

Required knowledge: *General Relativity*

Literature: Ted Jacobson. "Thermodynamics of Spacetime: The Einstein Equation of State". In: *Physical Review Letters* 75.7 (Aug. 1995), pp. 1260–1263; Ted Jacobson and Renaud Parentani. "Horizon entropy". In: *Found. Phys.* 33.2 (2003), pp. 323–348