# Anwendungen der Thermodynamik und Statistischen Physik

Prof. U. Schollwöck, Lehrstuhl für Theoretische Physik

## Termin/Beginn:

Freitag, 14-16 Uhr, Beginn (erster Vortrag): 3. Mai 2013

## Aufgabe:

45 minütiger Vortrag & Diskussion, Power-point oder ähnliches, Probevortrag mit Betreuer empfohlen

## Themenvergabe:

Heute

**und**

bis Mittwoch, 24.4., first-come-first-serve

per e-mail an heidrich-meisner@lmu.de

# Themen

**1) Spin-wave theory in AFM**

**2) Transfer-matrix**

3) Cluster expansions

**4) High-temperature expansion**

**5) Classical Monte Carlo**

6) Black scholes

**7) Ginzburg-Landau theory**

**8) Real-space RG**

9) Complexity Classes

10) KT transitions

11) Random walk theory

Weitere Themen bei Bedarf möglich, !

Termine: 3.5., 10.5., 17.5., 24.5., 31.5., 7.6., 14.6., 21.6., 28.6., 5.7., 12.7. 19.7.

# Spin-wave theory in AFM

Contact: Carlos Büsser, carlos.busser@gmail.com - Room 402 Theresienstr. 37
Lev Vidmar - same room

Keywords: spin-waves, antiferromagnetism, magnetic phase diagrams, quantum criticality, fluctuations, Ising model, Heisenberg model.

Bibliography:

S. Sachde and B. Keimer, Physics Today, February 2011, pag. 29
E. Manousakis, Rev. Mod. Phys. **63**, 1 (1991).

For basic motivation see “Search & discovery” section in Physics Today Sept. 2011 (pag. 13).

Aslo see:
Equilibrium and Non-equilibrium statistical thermodynamics by M. Le Bellac, F. Mortesagne and G. G. Batrouni, Cambridge University press (2004).

# Transfer matrix

Contact: Carlos A. Büsser, carlos.busser@gmail.com - Room 402 Theresienstr 37
Lev Vidmar - same room

Keywords: transfer-matrix, Ising model, magnetism, spin phases, Heisenberg model.

Bibliography:
L. L. Sanchez-Soto et al, Phys. Rep. **513**, 191 (2011).
J. M. Yeomans, Statistical Mechanics of Phase transitions, Oxford University Press, USA (June 25, 1992)
J. B. Kogut, Rev. Mod. Phys. **51**, 659 (1979).

Aslo see:
Equilibrium and Non-equilibrium statistical thermodynamics by M. Le Bellac, F. Mortesagne and G. G. Batrouni, Cambridge University press (2004).

# Cluster Expansions

- Method to calculate partition function for interacting particles
- High temperature, low density approximation
- Employs graph counting to avoid combinatorial algebra via **Linked cluster expansion**

$$\ln \mathcal{Q} = \sum_{\text{linked clusters}} (\text{counting factor}) \times (\text{cluster integral})$$

**Bonus:** A quantum version is available as well!

**Literature:**

- Edwin E. Salpeter: Annals of Physics 5, 183-223 (1958)
- R. K. Pathria: Statistical Mechanics
- D. L. Goodstein: States of Matter

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# High-temperature expansion of the Ising model

**OVERVIEW**
The two-dimensional Ising model is one of the easiest Hamiltonians admitting a phase transition. For high temperatures, it is possible the expand its partition function in terms of inverse temperature which can be visualized by a cluster-like diagrammatic analysis. The Kramers-Wannier duality shows a surprising connection with low-temperature physics. As an important numerical tool, Monte Carlo simulations have been used to evaluate expansion coefficients.

**LITERATURE**

- David Tong: Lectures on statistical physics (available online: http://www.damtp.cam.ac.uk/user/tong/statphys.html )
- Masuo Suzuki: Quantum Monte Carlo methods in condensed matter physic


**CONTACT**

Peter Kroiß, peter.kroiss@physik.uni-muenchen.de

# Monte Carlo Methods in Statistical Mechanics

Monte Carlo methods are a family of computational techniques based on repeated random sampling which can be used to obtain approximate numerical solutions to problems that are too complicated to solve by more exact methods. These techniques have applications to a wide range of different problems, including topics within physics, biology, mathematics, engineering, and finance.

In this project you will become familiar with the basics of Monte Carlo simulations by researching and implementing the Metropolis-Hasting algorithm for a basic model of magnetism (the 2D Ising model on a square lattice).

# References


W. Krauth: Statistical Mechanics: Algorithms and Computations (2006)

K. Binder: Monte Carlo simulation in statistical physics (2010)

D. Landau: A guide to Monte Carlo simulations in statistical physics (2009)


# Contacts


Simon Thwaite (Simon.Thwaite@physik.uni-muenchen.de)

Alexander Wolf (A.Wolf@lmu.de)

# Black Scholes Model

The Black–Scholes model is a mathematical model of a financial market containing certain derivative investment instruments.

**Talk content**

- Motivation from financial mathematics: What is an option? How to compute a fair price?
- Brownian motion and Ito's lemma
- Derivation of the Black Scholes Equation
- Extensions by Monte Carlo sampling

**Literature**


- Options, futures, and other derivatives; Hull, J. C.; 1997
- An undergraduate introduction to financial mathematics; Buchanan, J. R.; 2012
- The statistical mechanics of financial markets; Voit, J.; 2005
- Statistical mechanics – Computations and Algorithms; Krauth, W; 2006
- Derivation and Interpretation of the Black–Scholes Model; Chance, D; Lecture Notes Louisiana State University; 2011


**Contact**


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# Ginzburg-Landau Theory

In physics, **Ginzburg–Landau theory**, named after Vitaly Lazarevich Ginzburg and Lev Landau, is a mathematical theory used to describe superconductivity. In its initial form, it was postulated as a phenomenological model which could describe type-I superconductors without examining their microscopic properties. Later, a version of Ginzburg-Landau theory was derived from the Bardeen-Cooper-Schrieffer microscopic theory by Lev Gor'kov, thus showing that it also appears in some limit of microscopic theory and giving microscopic interpretation of all its parameters.

**Literature**

## Papers


- V.L. Ginzburg and L.D. Landau, *Zh. Eksp. Teor. Fiz.* **20**, 1064 (1950). English translation in: L. D. Landau, Collected papers (Oxford: Pergamon Press, 1965) p. 546
- A.A. Abrikosov, *Zh. Eksp. Teor. Fiz.* **32**, 1442 (1957) (English translation: *Sov. Phys. JETP* **5** 1174 (1957)].) Abrikosov's original paper on vortex structure of Type-II superconductors derived as a solution of G–L equations for $\kappa > 1/\sqrt{2}$
- L.P. Gor'kov, *Sov. Phys. JETP* **36**, 1364 (1959)


## Books


- D. Saint-James, G. Sarma and E. J. Thomas, *Type II Superconductivity* Pergamon (Oxford 1969)
- M. Tinkham, *Introduction to Superconductivity*, McGraw–Hill (New York 1996)
- de Gennes, P.G., *Superconductivity of Metals and Alloys*, Perseus Books, 2nd Revised Edition (1995)
- Hagen Kleinert, *Gauge Fields in Condensed Matter*, Vol. I World Scientific (Singapore, 1989)


Advisor

Jad C. Halimeh (Jad.Halimeh@physik.lmu.de)

# Real-space renormalization group

- Renormalization group (RG) approach to critical phenomena
- RG transformation of the Hamiltonian:
  Kadanoff block transformation, spin decimation
- RG flow diagrams of the coupling constants:
  recursion relations, fixed points
- Simple applications:
  one- and two-dimensional Ising models
- Literature:
  - W. D. McComb "Renormalization methods: a guide for beginners"
  - R. K. Pathria "Statistical mechanics"
  - J. M. Yeomans "Statistical mechanics of phase transitions"
  - H. J Maris and L. P. Kadanoff "Teaching the renormalization group", Am. J. Phys. **46**, 652 (1978)
  - K. G. Wilson, "The renormalization group: Critical phenomena and the Kondo problem", Rev. Mod. Phys. **47**, 773 (1975)
- Contact: marcin.raczkowski@physik.uni-muenchen.de

# Complexity classes

## Questions

Why are certain problems easy and others hard?

Is there a formal way of defining "hardness"?

## Topics:

Turing machines, Church's thesis, decision problems, Languages, Classes P and NP, NP hard and NP complete

## Ref:

A. K. Hartmann and M. Weight, Phase Transitions in Combinatorial Optimization Problems, Wiley-VCH, ISBN 3-527-40473-2, Ch. 4

Contact: Prof. Lode Pollet, lode.pollet@physik.uni-muenchen.de

# Kosterlitz-Thouless transitions

## Phase transitions

Usually: Ginzburg-Landau, symmetry breaking, finite order parameter

Disordered: Exponential decay

$$\langle S_i^z S_j^z \rangle \propto exp(-x/\zeta)$$

Ordered phase: Long-range order

$$\langle S_i^z S_j^z \rangle \rightarrow const. \text{ for } |i-j| \rightarrow \infty$$

**KT transitions: vanishing order parameter, but:**

$$\langle S_i^z S_j^z \rangle \propto exp(-x/\zeta)$$

$$\langle S_i^z S_j^z \rangle \rightarrow x^{-\alpha}$$

## Topics:

Theory of KT transitions, definition, examples

## Ref:

J.M. Kosterlitz and D.J. Thouless, Metastability and Phase Transitions in Two-Dimensional Systems, J. Phys. C **6**, 1181 (1973).

Contact: Prof.U. Schollwöck, schollwoeck@lmu.de

# Random Matrix Theory

Introduced by Eugene Wigner to explain the spectra of heavy nuclei, Random Matrix Theory developed into an established topic in mathematical physics. The idea is to represent complex systems by an ensemble of random matrices that respect the symmetries of the system under consideration. Random Matrix Theory has proven useful in various research fields including

- nuclear physics
- quantum chaos
- disordered systems
- financial mathematics

**Literature**

Books:

Mehta, M. L. “Random Matrices”
Haake, Fritz “Quantum Signatures of Chaos”

Some related research papers:

Wigner, E. "Characteristic vectors of bordered matrices with infinite dimensions". *Ann. Of Math.* **62** (3): 548–564 (1955).
O. Bohigas, M. J. Giannoni, C. Schmit “Characterization of Chaotic Spectra und Universality of Level Fluctuation Laws” Phys. Rev. Lett 52, 1-4 (1982)
J.-P. Bouchaud, M. Potters “Financial Applications of Random Matrix Theory: a short review” arXiv:0910.1205

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