Theoretical Seminar:

Statistical Physics

Wintersemester 2024/25

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Dates and structure

- **Time: Fridays 9.15 - 11.00, Start: Fr 18. October 2024**
  Venue: SR 1st floor, Philosophenweg 12, 69120 Heidelberg; in-person, no online participation.
- **Prerequisites: Lectures on Quantum Mechanics, and**
  Statistical Physics (MKTP1; can be attended in the same semester). Seminar language is English.
- **Distribution of topics: In the 1st seminar on October 18 the talks will be assigned. The first two talks will be distributed in advance.**
- **Tutors: Julian Rössler, roessler.julian@t-online.de (JR)**
- **Prepare test talk ≥ 1 week before the seminar with a colleague (or tutor).**
- **max. 60 min talk (beamer plus blackboard; max 40 slides) + about 15- 30 min discussion.**
- **pdf of slides to be submitted to GW ~1 week after the talk; appears on seminar page.**
- **LaTeX/ pdf extended summary for each talk ≈ 10-20pp, with references to the original papers (and also advanced textbooks). To be submitted ~1 week after the talk to GW; will be published on seminar page.**
- **6 ECTS-Credit points for oral presentation, pdf of slides, written pdf summary, participation in discussions.**
- **Participation is mandatory, please send advance email to GW if not attending.**

Preliminary list of topics

1) 18.10.2024 Phase transitions and critical phenomena: / Tutor JR

   slides:
   summary:

   (please copy the links into your browser)

2) 25.10. Topological phase transitions (BKT): /

   slides:
   summary:

3) 08.11. One- and two-dimensional Ising model: /

   slides:

   summary:

4) 15.11. Boltzmann equation and H-Theorem: /

   slides:
   summary:

5) 22.11. Master equation, Markovian and non-Markovian processes: /

slides:

summary:

6) 29.11. Langevin- and Fokker-Planck equation: /

slides:

summary:

7) 06.12. The nonlinear boson diffusion equation: /

slides:

summary

8) 13.12. Time-dependent Bose-Einstein condensate formation in ultracold bosonic atoms: /

slides:

summary

9) 20.12. Thermalization of gluons in relativistic collisions: /

slides:
summary

10) 10.01.25 Partial thermalization of recombination photons in the early universe: /

slides:
summary

11) 17.01. Physical basis for the direction of time: /

slides:
summary:

12) 24.01. Pattern formation and self-organization in nature: /

slides:
summary:

General literature

Textbooks

Kerson Huang, Statistical Mechanics, 2nd edition Wiley (2008).

Leo P. Kadanoff, Statistical Physics: Statics, Dynamics and Renormalization,
World Scientific, Singapore (2000).

Lev Pitaevskii and Sandro Stringari, Bose-Einstein Condensation and Superfluidity,
International series of monographs on physics, Oxford University Press (2016).

Subir Sachdev, Quantum Phase Transitions, 2nd edition, Cambridge Univ. Press (2011).

John Cardy, Scaling and Renormalization in Statistical Physics, Cambridge Univ. Press (1996).

Nick Proukakis et al.: Quantum gases - finite temperature and non-equilibrium dynamics,
Vol. I, World Scientific, Singapore (2013).

Hannes Risken, The Fokker-Planck equation, methods of solution and applications, 3rd edition Springer (1996).

Nico G. Van Kampen, Stochastic Processes in Physics and Chemistry, 3rd edition, Elsevier (2007).

Steward Harris, An introduction to the theory of the Boltzmann equation, Dover (2004).

Topic-oriented literature: Original articles (selection); specific books

1) Phase transitions and critical phenomena

H.E. Stanley, Introduction to Phase Transitions and Critical Phenomena, Oxford University Press (1971)
M.E. Fisher, The renormalization group in the theory of critical behavior, Rev. Mod. Phys. 46, 597 (1974)
P. Papon et al.,The physics of phase transitions – concepts and applications, Springer, Berlin (2006).

2) BKT

J.M. Kosterlitz and D.J. Thouless, Ordering, metastability and phase transitions in two-dimensional systems, J. Phys. C: Solid State Phys. 6, 1181 (1973).
Z. Hadzibabic et al., Berezinskii-Kosterlitz-Thouless Crossover in a Trapped Atomic Gas. In: Nature 441, 1118 (2006).
J.M. Kosterlitz, Kosterlitz-Thouless physics: a review of key issues. In: Rep. Prog. Phys. 79, 026001 (2016).

3) Ising model

E. Ising, Beitrag zur Theorie des Ferromagnetismus, Z. Physik 31, 253 (1925).
https://link.springer.com/article/10.1007/BF02980577
R. Peierls, Ising’s model of ferromagnetism, Proc. Cambridge Phil. Soc., Band 32, 477 (1936).
T.D. Schultz, E. Lieb, D.C. Mattis, Two dimensional Ising model as a soluble model of many fermions, Rev. Mod. Phys. 36, 856 (1964).
S.G. Brush, History of the Lenz-Ising model, Rev. Mod. Phys. 39, 883 (1967).

4) Boltzmann equation and H-Theorem

L. Boltzmann, Weitere Studien über das Wärmegleichgewicht unter Gasmolekülen, Sitzber. Akademie der Wiss. 66, 275 (1872).
English translation: L. Boltzmann, *Further Studies on the Thermal Equilibrium of Gas Molecules. The Kinetic Theory of Gases. History of Modern Physical Sciences. 1, 262 (203), doi 10.1142/9781848161337_0015. See book by E. Harris for a modern derivation.*
G.B. Lesovik, A.V. Lebedev, I.A. Sadovskyy, M.V. Suslov, and V.M. Vinokur, H-theorem in quantum physics, Sci. Reports. 6, 32815 (2016), doi:10.1038/srep32815.

5) Master equation, Markov processes
W. Pauli, Über das H-Theorem vom Anwachsen der Entropie vom Standpunkt der neuen Quantenmechanik, In: Probleme der modernen Physik, Arnold Sommerfeld zum 60. Geburtstag, Hirzel, Leipzig (1928).
N. G. van Kampen (1981). Stochastic processes in physics and chemistry. North Holland. ISBN 978-0-444-52965-7.
C.W. Gardiner (1985). Handbook of Stochastic Methods. Springer. ISBN 978-3-540-20882-2.
J. Honerkamp (1998). Statistical physics : an advanced approach with applications ; with 7 tables and 57 problems with solutions. Berlin [u.a.]: Springer. p. 173. ISBN 978-3-540-63978-7

6) Langevin eq., Fokker Planck eq.
A. Einstein, Zur Theorie der Brownschen Bewegung, Ann. Physik 19, 371 (1906).
M. von Smoluchowski, Zur kinetischen Theorie der Brownschen Molekularbewegung und der Suspensionen, Ann. Physik 326, 756 (1906).
P. Langevin, Sur la théorie du mouvement brownien, C. R. Acad. Sci. (Paris) 146, 530 (1908).
A.D. Fokker, Die mittlere Energie rotierender elektrischer Dipole im Strahlungsfeld, Ann. Physik 43, 812 (1914).
M. Planck, Über einen Satz der statistischen Dynamik und seine Erweiterung in der Quantentheorie, Sitzber. Preuss. Akad. Wiss., 324 (1917).
A.N. Kolmogorov, Über die analytischen Methoden in der Wahrscheinlichkeitsrechnung, Math. Ann. 104, 415 (1931).

7) Nonlinear boson diffusion equation
G. Wolschin, Equilibration in finite Bose systems, Physica A 499, 1 (2018) ; Nonlinear diffusion of gluons, Physica A 597, 127299 (2022); Nonlinear diffusion of fermions and bosons, EPL 140, 40002 (2022).

8) Time-dependent Bose-Einstein condensate formation in ultracold bosonic atoms

O. J. Luiten, M.W. Reynolds, and J.T.M. Walraven, Kinetic theory of the evaporative cooling of a trapped gas, Phys. Rev. A53, 381 (1996).
K. B. Davis and M.-O. Mewes and W. Ketterle, An analytical model for evaporative cooling of atoms, Appl. Phys. B 60, 155 (1995).
G. Wolschin, Nonlinear diffusion of fermions and bosons, EPL 140, 40002 (2022).
A. Simon, G. Wolschin, Time-dependent condensate fraction in an analytical model, Physica A 573, 125930 (2021) .
A. Kabelac, G. Wolschin, Time-dependent condensation of bosonic potassium, Eur. Phys. J. D 76, 178 (2022).
M. Larsson, G. Wolschin, Time-dependent condensate formation in ultracold atoms with energy-dependent transport coefficients, Phys. Rev. A110, 023305 (2024)

9) Thermalization of gluons in relativistic collisions

J.-P. Blaizot, F. Gelis , J. Liao, L. McLerran, and R. Venugopalan, Bose–Einstein Condensation and Thermalization of the Quark Gluon Plasma, Nucl. Phys. A 873, 68 (2012).
J.-P. Blaizot, J. Liao and Yacine Mehtar-Tani, The subtle interplay of elastic and inelastic collisions in the thermalization of the quark–gluon plasma, Nucl. Phys. 956, 561 (2016).
G. Wolschin, Equilibration in finite Bose systems, Physica A 499, 1 (2018);
G. Wolschin, Nonlinear diffusion of gluons, Physica A 597, 127299 (2022); Aspects of relativistic heavy-ion collisions, Universe 6, 61 (2020); https://www.mdpi.com/2218-1997/6/5/61
L. Möhringer and G. Wolschin, Exact solution of the nonlinear boson diffusion equation for gluon scattering J. Stat. Mech. 073103 (2024)

10) Partial thermalization of recombination photons in the early universe

Penzias, A.A., Wilson, R.W.: A measurement of excess antenna temperature at 4080 Mc/s. Astrophys. J. Lett. 142, 419–421 (1964)

Sunjaev, R.A., Chluba, J.: Signals from the epoch of cosmological recombination. Astron. Nachr. 330, 657–674 (2009).

Chluba, J., Sunjaev, R.A.: Cosmological hydrogen recombination: influence of resonance and electron scattering. Astron. &Astrophys. 503, 345–355 (2009).

G. Wolschin, Partial Lyα thermalization in an analytic nonlinear diffusion model, Scientific Reports 14, 4935 (2024); https://www.nature.com/articles/s41598-024-54833-z

11) Physical basis for the direction of time

H. D. Zeh, The Physical Basis of The Direction of Time, Springer Heidelberg Berlin (2007).

S. Carroll, and J. Chen, Spontaneous Inflation and the Origin of the Arrow of Time. arXiv: 0410270 [hep-th] (2014).

D. Lazarovici and P. Reichert, Arrow(s) of Time without a Past Hypothesis, http://philsci-archive.pitt.edu/17468/ (2020).

12) Pattern formation and self-organization in nature

Prigogine, I.; Nicolis, G. Hazewinkel, M.; Jurkovich, R.; Paelinck, J. H. P. (eds.), Self-Organisation in Nonequilibrium Systems: Towards A Dynamics of Complexity, *Bifurcation Analysis: Principles, Applications and Synthesis*, Springer Netherlands, pp. 3–12, doi:10.1007/978-94-009-6239-2_1, ISBN 9789400962392 (1985).

D. Walgraef, Spatio-temporal pattern formation, Springer, Heidelberg-Berlin-New York (1996).

S. Kondo, T. Miura, Reaction-Diffusion Model as a Framework for Understanding Biological Pattern Formation, Science 329, Issue 5999, pp. 1616-1620 DOI: 10.1126/science.1179047 (2010).

E. Bodenschatz et al., Focus on Pattern Formation, New Journal of Phys. 5, 003 (2003).

More detailed literature via tutor, or GW.