Fall 2010 **Phys 889** Special Topics in Interdisciplinary Physics: Prof. B. L. Hu

Nonequilibrium Quantum Field Theory (July 4 version)

Classes meet Tu Th 11am-12:15pm in Room 4208 Toll (Physics) Bldg

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Preamble: Scope, Goal and Style

Nonequilibrium Quantum Field Theory (NEqQFT) is a shorthand for the study of nonequilibrium processes of quantum matter or fields under conditions where the tools of quantum field theory is required for an adequate description. It also addresses the statistical mechanical properties of interacting quantum fields in nonequilibrium conditions. The **scope** of this emerging interdisciplinary field encompasses almost all subdisciplines of physics, but for the purpose of this course I will divide them into four parts: a) nonequilibrium open (Langevin) and closed (Boltzmann) quantum systems b) atomic-molecular-optical (AMO) / condensed matter physics, c) nuclear / particle physics d) gravitation / cosmology. Roughly 2/3 of the course material will be addressing the foundation of this theory which contains basic concepts and techniques of nonequilibrium statistical mechanics (e.g., coarse-graining and projection, the Feynman-Vernon influence formalism) and causal formulation of quantum field theory (e.g., the Schwinger-Keldysh or 'in-in' or 'closed-time-path' formalism) and foundational issues such as quantum dissipation and fluctuations, quantum decoherence and quantum to classical transition; quantum correlations and entanglement. The remainder contains applications of this material to various areas of current research as in parts b) c) and d).

Our **goal** is to provide students interested this aspect of their own research field some background knowledge of its foundation and expose them to representative topics of current research. Through learning the course material, one-on-one consultation with the professor, the working of a research project and engaging in discussions with fellow students (see below on requirements) the students is expected to gain some first hand experience in beginning research on some specialized area of this interdisciplinary subject.

In view of the fact that the range of current research materials in this interdisciplinary field is broad and the material fast growing we will present the topics combining the traditional lecture **style** of line by line derivation of formulas or detailed description with that of a mini-series of seminars where the key ideas, the methodology and the results are explained, with more emphasis on understanding than derivations. The lecture style is adopted for the core part of the course material and the seminar style for the research topics. In fact your own research presentations will contribute to this latter part. In this way you will benefit from three levels of learning: lecture, seminars and research, progressing from the more passive to the more active modes, gaining working knowledge on a specific theme you wish to focus on. Though not required to do so, if you feel like wanting to gain a better working knowledge on more than one theme, you can choose a topic in-between two themes, or even three. I can help you design a project suitable to your needs.

Requirements: Students taking this course for credit are required to work on a small **research project** leading to the **final presentation** on a topic of current or fundamental interest within the general scope of the course content (see below) and submit a 10-15 page **scholarly paper**. I will assist each one of you on an individual basis in choosing a topic, in the selection of relevant literature to study and in the preparation of your presentation and research paper, not unlike assisting a PhD student making an entry into research on his/her chosen topic. One day at the end of the semester, likely Mon. Dec. 13, will be reserved for these presentations in lieu of the final examination. All registered students are required to attend the full length of the presentation as it forms an integral part of the course content. More details about this will be announced as the course progresses.

Textbooks, References: No required text. These 4 recommended recent monographs cover the general background materials quite sufficiently. Books for a broader range of related topics are listed following. *You may wish to attend the first class before making any purchase*.

E. Calzetta and B. L. Hu, *NonEquilibrium Quantum Field Theory* (Cambridge University Press, 2008) ISBN 978-0-521-64168-5 QC174.86.N65C35 2008 - *framework of theory developed from relativistic quantum field theory, including quantum decoherence, entropy generation issues and derivation of linear response, kinetic theory and hydrodynamics*

Jørgen Rammer, *Quantum Field Theory of Non-equilibrium States* (Cambridge University Press, 2007) - *focus on condensed matter systems*

Heinz-Peter Breuer and Francesco Petruccione, *The Theory of Open Quantum Systems* (Oxford University Press, 2002) ISBN 978-0-19-921390-0 Paperback 2007 - u*ser friendly*

C. Gardiner and P. Zoller, *Quantum Noise, A Handbook of Markovian and Non-Markovian Quantum Stochastic Methods with Applications to Quantum Optics* *3nd ed.* (Springer-Verlag, Berlín, 2007). Paperback. - *systematic development of subject, useful reference.*

General Background Material:

R. Feynman and A. Hibbs, *Quantum Mechanics and Path Integrals* (McGraw-Hill, New York, 1965).
R. Balescu, *Equilibrium and Nonequilibrium Statistical Mechanics*, (John Wiley, New York, 1975).
R. Liboff, *Kinetic Theory*. 2nd ed. (John Wiley, New York, 1998).
R. Zwanzig, *Nonequilibrium Statistical Mechanics* (Oxford University Press, Oxford, 1999)
R. Kubo, M. Toda and N. Hashitune, *Statistical Physics II: Nonequilibrium Statistical Mechanics* (Springer-Verlag, Berlín, 1978).
E. Lifshitz y L. Pitaevskii, *Physical Kinetics* (Pergamon Press, Oxford, 1981).
J. A. McLennan, *Introduction to Non-equilibrium Statistical Mechanics* (Prentice-Hall, 1989)
L. Reichl, A *Modern Course in Statistical Physics* (University of Texas Press, Austin, 1980)
N. G. van Kampen, *Stochastic Processes in Physics and Chemistry*, (North Holland, Amsterdam, 1981) QC20.7.S8K35 1981 ISBN 0444-86650-7
H. J. Carmichael, *Statistical Methods in Quantum Optics I. Master equations and Fokker-Planck equations* (Springer, Berlin, 1999) ISBN 3-540-54882-3 Corrected 2nd printing 2002

Topics on Fundamental Issues:

D. Giulini et al, *Decoherence and the Appearance of a Classical World in Quantum Theory* (Springer Verlag, Berlin, 1996)
L. Accardi, Y. G. Lu and I. Volovich, *Quantum Theory and Its Stochastic Limit* (Springer-Verlag, Berlin 2002) ISBN 3-540-41928-4
R. L. Stratonovich, *Nonlinear Nonequilibrium Thermodynamics* Vols I and II (Springer-Verlag, Berlin 1993) QC318.I7 S7665 1994 ISBN 0-387-57051-9
Shin Takagi, *Macroscopic Quantum Tunneling*, (Cambridge University Press, Cambridge, 2002) ISBN 0-521-80002-1
Michael A. Nielsen and Isaac L. Chuang, *Quantum Computation and Quantum Information* (Cambridge University Press, 2000) QA401.G47 ISBN 0 521 63503 9 paperback

Particle-Nuclear physics:

L. Kadanoff and G. Baym, *Quantum Statistical Mechanics* (Addison - Wesley, New York, 1962).
S. de Groot, W. van Leeuwen and Ch. van Weert, *Relativistic Kinetic Theory* (North-Holland, Amsterdam, 1980). QC174.9.G76 ISBN 0-444-85453-3
G. Parisi, *Statistical Field Theory* (Addison - Wesley, New York, 1988).
J. Kapusta, *Finite - Temperature Field Theory* (Cambridge University Press, Cambridge, 1989).
M. Le Bellac, *Thermal Field Theory* (Cambridge University Press, Cambridge, 1996).

AMO/Condensed Matter:

C. J. Pethick and H. Smith, *Bose-Einstein Condensation in Dilute Gases* (Cambridge University Press, Cambridge, 2002) QC 175.47. B65 P48 2001 ISBN 0 521 66580 9
J. Rammer, *Quantum Transport Theory* (Perseus, Reading, 1998)
H. J. Carmichael, *An Open System Approach to Quantum Optics* (Springer Lecture Notes, Berlin, 1993)
M. O. Scully and M. S. Zubairy, *Quantum Optics* (Cambridge University Press, Cambridge, 1997) QC446.2.S4 1996 ISBN 0 421 43595 1
U. Weiss, *Quantum Dissipative Systems*, 3nd ed. (World Scientific, Singapore, 2007). ISBN 981-02-4092-9 (Paperback)

Gravitation and Cosmology:

N.D. Birrell and P.C.W. Davies, *Quantum Fields in Curved Spaces* (Cambridge University Press, Cambridge, 1982).
Leonard Parker and David Toms, *Quantum Field Theory in Curved Spacetime: Quantized Fields and Gravity* (Cambridge University Press, 2009)
B. L. Hu and E. Verdaguer, *Stochastic gravity: Theory and Applications*, in *Living Reviews in Relativity* **11** (2008) 3 [arXiv:0802.0658]

Course Contents: The approximate distribution of topics in this course is as follows:

1. Nonequilibrium Statistical Mechanics (~8 lectures)
Major paradigms of Langevin, Boltzmann; Open vs effectively open systems; Concepts and methodology: Coarse-graining, projection operator. Stochastic processes. Pauli master equation, Langevin and Fokker Planck Equation. Density matrix theory. Wigner function. Quantum Brownian motion. nonMarkovian processes. Master and Langevin equation.

2. Modern Quantum Field Theory Techniques (~8 lectures)
Quantum Open Systems: Feynman-Vernon influence functional, Schwinger-Keldysh or in-in or closed-time-path (CTP) formalism, nPI effective action, large N expansion

3. Issues: Quantum correlations, dissipation, fluctuations, decoherence and entanglement. (~6 lectures)
Quantum dissipation and fluctuations; Quantum decoherence and quantum to classical transition; Quantum correlations and Quantum entanglement

4. Current Research: (~7 lectures) Quantum information, quantum thermodynamics, Nonequilibrium BEC dynamics, nonMarkovian processes in strongly correlated (condensed matter) systems, strongly coupled fluids (RHIC), reheating after inflation, stochastic gravity.

Logbook of Lectures: (*preliminary, will vary depending on students familiarity of topics*)

Week:Date Topics
1: 8/31 Nonequilibrium statistical mechanics: Basic concepts and major paradigms.
Stochastic processes.
2: 9/7 Density matrix, Wigner function
3: 9/14 Quantum Brownian Motion: master, Langevin and Fokker-Planck equations
4: 9/21 Quantum Open Systems: Feynman-Vernon influence functional,
5: 9/28 Quantum dissipation and fluctuations
6. 10/5 Quantum decoherence and quantum to classical transition
7. 10/12 Quantum correlations
8. 10/19 Quantum entanglement
9. 10/26 Quantum Fluctuation Theorem, Quantum thermodynamics
10. 11/2 Schwinger-Keldysh or in-in or closed-time-path (CTP) formalism
11. 11/9 Boltzmann equation, BBGKY hierarchy; nPI effective action, large N expansion
12. 11/16 Quantum Kinetic Field Theory and Hydrodynamics
13. 11/23 Nonequilibrium BEC dynamics *Nov. 25 Thanksgiving Holiday*
14. 11/30 Quantum Information:
15. 12/7 Quantum Back-action: Reheating after inflation.
Quantum field and metric fluctuations -- Stochastic Gravity
Dec. 13 (tentative)**: Project Presentation** (please allow a full day – make sure you don't have conflict with the final exams of other courses you are taking)
Dec. 20: Term Paper due. 10-15pages paper of professional standard, assimilating comments during and after your talks. Please send pdf file to hubeilok@gmail.com

Term Project Presentations by Participants in:

Physics 889: Nonequilibrium Quantum Field Theory

Monday Dec.13, 2010, 11am – 5:00pm, in a Room to be announced

11-11:45

11:45- 12:30

Break

12:45-1:30

1:30-2:15

Break

2:30-3:15

3:15-4:00

Break

4:15-5:00

All are welcome. Light refreshment at breaks

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