PHYS626-0101: Quantum Many-Body Theory II-Fall 2024 jaydsau

Edit

An introduction to field theory in condensed matter physics:

Phys 626 is a continuation of Phys 625 and applies path-integral-based field theory techniques for the understanding of advanced properties of many-body condensed matter systems focusing mostly on the many-electron system.

The quantum many-body problem still remains one of the most interesting open directions in physics. The basic goal of this problem is to understand and predict collective phenomena that can emerge from the interaction of many quantum degrees of freedom. This problem originated in the early twentieth century through the attempt to understand phases of matter by applying quantum mechanics to the many-electron problem. Despite early successes in the form of an understanding of metals, insulators, semiconductors and superconductors and predictions such as the Josephson effect phases of matter such as strange metals in high-Tc superconductors are left to be understood and topological superconductors remain to be found. New phases in van der Waals heterostructure and UTe2 are also appearing.

In the past few years, the quantum many-body problem has a new incarnation in synthetic quantum systems. Topological phases such as surface codes, quantum error correction, many-body localization, time crystals, quantum scars are examples of quantum many-body phenomena that are being actively studied. The utility of traditional field theory for these newer problems is still unclear.

Quantum field theory is the traditional framework to deal with quantum many-body systems and has had many successes in understanding quite a few of the phenomena listed. While quantum field theory originated in high-energy physics, it also provides the framework to understand many-body quantum systems specifically response as well as perturbation theory. A key complication is that Lorentz invariance typically doesn't apply to condensed matter systems, but simplification is the presence of a natural regularization scale.

Dr. Jay D. Sau

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Class Meets

Mondays & Wednesdays

2:00 pm – 3:15 pm

ATL 1109

Office Hours

ATL 4441 by appointment

Grader

TBD

Suggested Prerequisites

Phys 625, 606. 622, 623

Graduate E&M, quantum and math-methods

Course Communication

All updates and information regarding the course will be made using the announcements on E[...] - please make sure yo[...]MS settings do not delay

Familiarity with graduate level quantum mechanics, statistical mechanics and E&M will be assumed.

While Phys 625 focused on setting up the field theoretic description of the quantum many-body problem by mapping it to a perturbation problem of Gaussian functional integrals, we also discovered that perturbation theory was quite limited. In Phys 626, we will study phenomenologically motivated approximations to such perturbation theory to understand a wide variety of many-body predictions of quantum field theory.

Some of the topics covered are:

Syllabus will closely follow Altland and Simons book (see resources for detail):

Ch 5 Spontaneous symmetry breaking, Stationary field limit of Hubbard-Stratonovich fields, fluctuations, superfluidity, Goldstones theorem, Mermin-Wagner theorem, BCS theory, Meissner-effect/Anderson-Higgs mechanism, non-linear sigma model disordered gas (week 1-4)

Ch. 6 Renormalization group. Scaling of the transverse field Ising model, Kadanoff Block-spin RG, Dissipative quantum tunneling, General theory, Critical exponents, Scaling theory, Wilson Fisher fixed points, RG of the non-linear sigma model, BKT transitions (weeks 5-10)

Ch. 7 Response functions (week 11-12)

Ch. 8 Topological field theory, Theta term, Chern-Simons action (week 13-15)

announcements. I may or may not repeat in class.

Please send any questions or notifications of absences that you need to inform me preferably by email (see above).

Required Resources

Course website: **elms.umd.edu (https://umd.instructure.com/courses/1241725)**

Text book: Condensed Matter Field Theory by Alexander Altland and Ben Simons, Cambridge University Press, 2023, 3rd edition, 770 pages, ISBN 9780511789984

This course will rely on material covered in Physics 625, which I will not review. Please feel free to review them using the link **https://umd.instructure.com/courses/1360817 (https://umd.instructure.com/courses/1360817)**

The material in 625 was based on Chapters 1-4 of the same book.

Campus Policies

It is our shared responsibility to know and abide by the University of Maryland's policies that relate to all courses, which include topics like:

- Academic integrity
- Student and instructor conduct
- Accessibility and accommodations
- Attendance and excused absences
- Grades and appeals
- Copyright and intellectual property

Please visit **www.ugst.umd.edu/courserelatedpolicies.html (http://www.ugst.umd.edu/courserelatedpolicies.html)** for the Office of Undergraduate Studies' full list of campus-wide policies and follow up with me if you have questions.

Activities, Learning Assessments, & Expectations for Students

Lectures: Class time will be occupied by lectures that follow a set of notes that closely follow sections in the textbook. In a few cases I will follow a different textbook, which I will point out. I will post my notes online in this case. In addition to explaining the physical intuition behind concepts I will provide mathematical derivation of some of the more important results where the derivation is instructive. A firm grasp of quantum mechanics at approximately the advanced undergraduate level will be needed to follow parts of the lectures as well do some of the homeworks. The thorough use of quantum mechanics is what distinguishes the graduate solid state course from the undergraduate one.

Participation: The lectures assume that you are keeping track of the material of the previous lecture. This will enhance your learning and participation in the class, which is crucial to the classes success. To ensure a minimal level of participation, I will keep track of your participation through questions you ask or answer. You get full credit for participation if you ask or answer 6 questions in the semester related to the material presented in the lectures. Participation points of 2/lecture will be added to your grade within 24 hours of the lecture you participated in (i.e. asked/answered a relevant question/clarification). I might forget to credit you for this. ***IT IS YOUR RESPONSIBILITY TO EMAIL ME IF I FORGET TO ADD THIS***

WITHIN TWO DAYS. Late (by more than a few days) may or may not be credited depending on whether I remember.

Homework : Problem sets will be posted as assignments on ELMS. The problems can also be downloaded from the **assignments folder (https://umd.instructure.com/courses/1373516/files/folder/Homework)**. Homework submission should be preferably by paper in class or at instructor office. Email submission to TA is allowed but should not be hand written. In case of email submissions, please also hand in a paper submission at a later date to facilitate return at graded homeworks. Homework will be assigned roughly once a week, and is to be turned in at the beginning of class on the due date. Homework will typically be posted on Friday and due the Thursday two weeks later (i.e. about 11 days). 20% will be marked off on homework that is after the deadline. Please contact instructor to discuss in case you will not make the deadline. Homeworks turned in after the solutions are posted may not be graded. If you cannot attend class, please get your homework to me before class starts. New assignments will be posted on the course website, along with the **homework solutions (https://umd.instructure.com/courses/1373516/files/folder/Homework%20solutions)**. Homework problems are carefully chosen to highlight some of the important topics covered in lecture, complete some of the important steps, as well as important applications of the ideas. It is important that you carefully complete and make sure you understand all of the homework. You are encouraged to work with others on homework, however, it is forbidden to blindly copy another person's work. There are 7 homework sets and one will be dropped.

(https://umd.instructure.com/courses/1231767/files/folder/Exams)

Grades

Grades are not given, but earned. Your grade is determined by your performance on exams, homeworks and participation in the course and is assigned based on your score according to a curve. Typically I follow a curve scheme where the median score would be graded at A-. The lowest grade would be B- (very few). The top grades will be A+ and As. The number in each category would be roughly equal depends on appropriate breaks in the score distribution.

Of course, all this being said this rule is subject to change depending on the performance of the class. If some students do extremely poorly (e.g. score well below 40%) I might consider going below B- for the lowest grade. On the other hand, if everyone does well (i.e. above 90%) I have no hesitation giving the entire class an A. Also, if someone scores above 80 that is a B or better independent of whether the average is above 80.

If earning a particular grade is important to you, please speak with me at the beginning of the s ster so that I can offer some helpful suggestions for achieving your goal.

All assessment scores will be posted on the course ELMS page. If you would like to review any of your grades (including the exams), or have questions about how something was scored, please email me to schedule a time for us to meet in my office.

Late work (as explained in the instruction) will not be accepted for course credit so please plan to have it submitted well before the scheduled deadline. I am happy to discuss any of your grades with you, and if I have made a mistake I will immediately correct it. Any formal grade disputes must be submitted in writing and within one week of receiving the grade.

Learning Assessments	#	**Category Weight**
Participation points	6	12%
Homework (out of 9 assignments)	8	88%

Course Schedule

Week 1	
Monday, August 26	• Electron gas revisited: Hubbard Stratonovich (5.1.1)
Wednesday, August 28	• Saddle point analysis (5.2.1) • Fluctuation corrections (5.2.2) • Bose-Einstein condensation (5.2.1)

Week 2	
Monday, September 2	• Labor day
Wednesday, September 4	• Weakly interacting Bose gas (5.2.2) • Spontaneous symmetry breaking/Mermin-Wagner (5.2.3) • Superfluidity (5.2.4) • Superconductivity/BCS Hamiltonian (5.3.1)
Week 3	
Monday, September 9	• Cooper instability (5.3.2) • Mean-field BCS theory (5.3.3)
Wednesday, September 11	• Nambu-Gorkov Green function (5.3.4) • Ginzburg-Landau theory (5.3.5)
Week 4	
Monday, September 16	• Phase-mode action (5.3.6)
Wednesday, September 18	• Meissner effect/Anderson-Higgs mode (5.3.7)
Week 5	
Monday, September 23	• Renormalization group of the 1D Ising model (6.1.1)

Wednesday, September 25	• Renormalization group of dissipative quantum tunneling (6.1.2)
Week 6	
Monday, September 30	• Renormalization group flow (6.2.1) • Analysis of RG flows (6.2.2)
Wednesday, October 2	• Review of critical phenomena (6.2.3) • Scaling from RG (6.2.4)
Week 7	
Monday, October 7	• RG of ferromagnetic transition (Engineering dimensions) (6.3.1) • Landau mean-field theory (6.3.2)
Wednesday, October 9	• Gaussian model (6.3.3) • RG analysis of Ginzburg-Landau-Wilson theory (6.3.4)
Week 8	
Monday, October 14	• Non-linear sigma model (6.4.1) • One loop expansion (6.4.2)
Wednesday, October 16	• BKT transition (6.5.1) • Topological phase transition (6.5.2)
Week 9	
Monday, October 21	• RG of the BKT transition (6.5.3)

Wednesday, October 23	• Experimental probes in condensed matter - concepts (7.1.1) • Summary of experimental methods (7.1.2)
Week 10	
Monday, October 28	• Linear response theory (7.2) • Fluctuation-dissipation theorem
Wednesday, October 30	• Lehmann-representation of correlation function (7.3.1)
Week 11	
Monday, November 4	• Sum rules for correlation function (7.3.2)
Wednesday, November 6	• Electromagnetic linear response a.k.a conductivity (7.4)
Week 12	
Monday, November 11	• Su-Schrieffer-Heeger model (8.1.1) • Non-interacting Symmetry protected topology (8.1.1)
Wednesday, November 13	• Particle on a ring (8.2)
Week 13	

Monday, November 18	• Homotopy (8.3)
Wednesday, November 20	• Topological field theory theta terms (8.4.1) • skyrmions (8.4.2)
Week 14	
Monday, November 25	• Instanton gases (8.4.3) • Path integral over spins (8.4.4)
Wednesday, November 27	• Thanks-giving recess
Week 15	
Monday, December 2	• Wess-Zumino terms (8.4.5) • Haldane conjecture (8.4.6)
Wednesday, December 4	• Quantum Hall effect (8.4.7)

Note: This is a tentative schedule, and subject to change as necessary – monitor the course ELMS page for current deadlines. In the unlikely event of a prolonged university closing, or an extended absence from the university, adjustments to the course schedule, deadlines, and assignments will be made based on the duration of the closing and the specific dates missed.

Course Summary:

Date	Details	Due
	Participation points (https://umd.instructure.com/courses/1373516/assignments/6929423)	