Edit

PHYS625 Quantum Many-Body theory I,

An introduction to field theory in condensed matter physics:

Phys 625 introduces field theory techniques for the understanding of many-body condensed matter systems focusing mostly on the many-electron system. 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. Familiarity with graduate level quantum mechanics, statistical mechanics and E&M will be assumed.

Dr. Jay D. Sau

jaydsau@umd.edu (mailto:jaydsau@umd.edu)

Class Meets

Mondays & Wednesdays

2:00 pm – 3:15 pm

ATL 1106

Office Hours

ATL 4441 by appointment

Grader

TBD

TBD

Suggested Prerequisites

Phys 604, 606. 612, 613

Graduate E&M, quantum and math-methods

Some of the topics covered are:

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

Ch. 1 Particles and fields: Field and particle description of phonons(sound), photons(light) etc.
Phonons, photons (weeks 1-3)
Ch. 2 Second quantization (non-relativistic): creation, annihilation operators for fields, Hubbard
model, Spin chains, Jordan-Wigner etc (weeks 4-7)
Ch. 3 Feynman path integral: Describe quantum mechanics without operators (weeks 7-9)
Ch. 4 Functional integral: Extend path integrals to field theories using

coherent states for bosons, the Grassman variables for fermions, the Hubbard-Stratonovich transformation Bosonization (week 10-12)

Ch. 5 Perturbation theory Hubbard-Stratonovich, Feynman diagrams, Connected diagrams, interacting electron gas, Random phase approximation(week 13-15)

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

Course Communication

All updates and information regarding the course will be made using the announcements on ELMS – please make sure your ELMS settings do not delay 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).

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 grades 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/1401842/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/1401842/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 semester 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, January 26	• Particles and fields - introduction (Ch 1) • Classical phonons/Lagrangians (1.1)
Wednesday, January 28	• Classical phonons/Lagrangians (1.1)
Week 2	
Monday, February 2	• Functional calculus (1.2) • Quantum chain (Ch 1.4)
Wednesday, February 4	• Quantum phonon specific heat (Ch 1.4) • Second quantization (Ch 2) • Creation/annihilation operators, commutation relations (2.1)
Week 3	
Monday, February 9	• One body and two body normal ordered operators (2.1) • Applications of second quantization (Bloch's theorem) (2.2)
Wednesday, February 11	• Crystal momentum/Brillouin zone (2.2) • Band structure (2.2) • tight binding model (2.2)
Week 4	
Monday, February 16	• Dirac cones in graphene (2.2)

Wednesday, February 18	• Dirac point from symmetry (not in book)
Week 5	
Monday, February 23	• Chern number of a massive Dirac dispersion (not in book)
Wednesday, February 25	• Quantization of Chern number • Haldane model
Week 6	
Monday, March 2	• Edge state and Hall conductance • interaction second quantization (2.2) • Hubbard model (2.2)
Wednesday, March 4	• Mott-insulators (2.2) • Anti-ferromagnetic superexchange (2.2) • t-J model (2.2)
Week 7	
Monday, March 9	• Bosonization (2.2)
Wednesday, March 11	• Bosonization: Spin-charge separation (2.2) • Quantum spin chains (2.2)
Week 8	
Monday, March 23	• Quantum Anti-ferromagnet (2.2) • Haldane gap

Wednesday, March 25	• Feynman path integral - introduction (3.2) • Multi-variate Gaussian distributions (3.2)
Week 9	
Monday, March 30	• Complex multidimensional Gaussian integrals (3.2) • Wick's theorem (3.2)
Wednesday, April 1	• Quantum partition function/quantum-classical equivalence (3.2.1) • semiclassical (saddle point) limit (3.2.2)
Week 10	
Monday, April 6	• Coherent states for Bosons (3.4.1) • Grassmann integrals and fermion Wick's theorem (3.4.1)
Wednesday, April 8	• Imaginary time boundary conditions for Fermions/bosons (3.5) • Field operator path integrals for fermions/bosons (3.5)
Week 11	
Monday, April 13	• Matsubara frequency identities(3.5)
Wednesday, April 15	• Asymptotic perturbation series (4.1.1) • phi^4 theory (4.1.2) • Hubbard-Stratonovich (4.1.2)
Week 12	

Monday, April 20	• two-point correlation (4.1.2) • non-interacting correlation length (4.1.2)
Wednesday, April 22	• low order perturbation theory (4.1.3) • diagrams (4.1.3) • Green functions to excitations • Linked cluster theorem (4.1.3) • Momentum space feynman diagrams (4.1.3)
Week 13	
Monday, April 27	• Electron gas (4.2) • Wigner crystals (4.2) • Landau-Fermi liquid theory (4.2) • First order feynman diagrams for the electron gas (4.2) • Hartree-Fock terms (4.2)
Wednesday, April 29	• Fermi velocity renormalization in Hartree-Fock (4.3) • Dominance of ring diagrams at nth order (4.3) • Polarizability diagram (4.3) • RPA free-energy (4.3)
Week 14	
Monday, May 4	• Self-energy/Dyson's equation (4.3) • Singularity of Hartree-Fock self-energy (4.3)
Wednesday, May 6	• RPA screened interaction • Thomas Fermi screening/plasmon regime in RPA (4.2) • Friedel oscillations from screening (4.2) • Large N phi4 theory (4.4) • Bethe-Salpeter equation (4.4) • Replica trick for disordered metals (4.4)
Week 15	
Monday, May **	• Summer

Wednesday, May **	• Summer

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