# PHYS 704
# Solid State Physics
Spring 2020


**Instructor:** Can Ataca
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Office: PHYS 704
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Office hours: Monday 13:00-14:00 or by appointment for specific time.


**Prerequisite:** PHYS 604 (Solid State Physics 1)
**Lecture Hours:** Monday, Wednesday, Friday 11:00-11:50 AM
**Classroom:** Interdisciplinary Life Sciences 101
**Textbook:** Charles Kittel, *Introduction to Solid State Physics,* ISBN: 0-471-41526-X
(Recommended) Neil W. Ashcroft, N. David Mermin, *Solid State Physics*, ISBN: 978-0-03-083993-1
(Recommended) M. Ali Omar, *Elementary Solid-State Physics*, ISBN: 978-0-20-160733-8

**Course Objectives:** This course focuses on the electronic, optical, magnetic and dielectric properties of materials. The course starts with a discussion of the free-electron model in metals, whereby the valence electrons are assumed to be free particles. A more realistic treatment of these electrons is provided on energy bands in solids. Next, semiconductors are introduced. The detailed coverage of these substances is warranted not only by their highly interesting and wide-ranging properties, but also by the crucial role played by semiconductor devices in technology. The next discussion will examine what happens to a solid when an electric field, static or alternating, penetrates the solid. The field polarizes the positive and negative charges in the medium; the effects of polarization on the dielectric and optical properties will be discussed. The course will then introduce the magnetic properties of matter and the fascinating phenomenon of superconductivity.

At the end of this course, you should be able to:

1. Define the free electron Fermi gas and derive its properties such as heat capacity, electrical and thermal conductivities of metals.
2. Have a detailed understanding of the energy band structures, semiconductor statistics, electrical conductivity and mobility, magnetic

field effects, high electric field and hot electrons, photoconductivity, luminescence and acoustoelectric effects.

3. Derive current/voltage relations of p-n junctions, tunnel diodes, field-effect transistors, LEDs and semiconductor lasers.
4. Construct a Fermi surface and calculate its energy bands with different models such as tight binding or the Wigner-Seitz method.
5. Understand the response of solids under an applied electric field, and the effects of polarization on the dielectric and optical properties. Define plasmon, polariton, polaron and exciton.
6. Specify the magnetic ordering of materials and their corresponding properties.
7. Learn the current understandings of superconducting materials.

**Grading:** Your final grade will be determined by:

| | |
|---|---|
| 2 Term Projects: | 25% each |
| Final Exam: | 25% |
| Homework: | 25% |

Your letter grade will depend on the total score. If your total grade is:

| | |
|---|---|
| $\geq 90$ , your letter grade will be | "A" |
| $90 > X \geq 85$, then | "A-" |
| $85 > X \geq 80$, then | "B+" |
| $80 > X \geq 75$, then | "B" |
| $75 > X \geq 70$, then | "B-" |
| $70 > X \geq 65$, then | "C+" |
| $65 > X \geq 60$, then | "C-" |
| $60 > X \geq 55$, then | "D" |
| $55 > X$, then | "F" |

Please focus on learning the material rather than the grades.

Final Exam: The date of the final exam is determined by the university and it will be on May 15$^{th}$, 2020 (10:30 AM-12:30 PM). The exam will include all the course material covered up to the day of the exam, if not informed otherwise. Final exam will be closed book. At least one question of the exam will be similar to the ones assigned in homework. You may bring one page of **YOUR** hand-written notes to the exam (no photocopies or print-outs are allowed).

Homework: Homework assignments will be available on the Blackboard page every Friday and are due at the beginning of the class the following Friday, unless you are told otherwise. No late assignments will be accepted. I plan to assign weekly (~a total of 14) homeworks. The top 10 highest graded homeworks will be counted towards your grading. This is meant to allow for things that come up unexpectedly.

Term Projects: The two term projects will take place during the semester. One will focus on methodology and the other one will be on materials applications. Every student will choose a subject to work on. No two students can choose the same subject, so please discuss your subject with me before starting to work on it. You will write a detailed report on your chosen subject (5-page manuscript in two columns) and present your subject within a 1/2 class-hour. The deadlines for the methodology and materials applications term projects are the week before the spring break and the last week of April, respectively.

Possible methodology term project subjects: k.p method, tight binding, kinetic Monte Carlo, force-field and reactive force field molecular dynamics, Boltzmann transport, wannier functions, pseudo-potentials (atomic interaction-artificial neural networks, norm-conserving, ultrasoft, PAW, HF,…)

Possible materials applications term project subjects: Berry phase and weyl semimetals, Two-Dimensional topological insulators, thermoelectrics, piezelectrics, machine learning in materials science, quantum computing, alloying and cluster expansion.

**Topics to be covered:**

| Weeks | Subject |
|---|---|
| **1-2** | Free Electron Fermi Gas |
| **2** | Energy Bands |
| **3-4** | Semiconductor Theory |
| **4-5** | Semiconductor Devices |
| **6** | Fermi Surface and Metals |
| **7-8** | Plasmon, Polariton and Polarons |
| **8-9** | Dielectrics and Ferroelectrics |
| **10** | Optical Processes and Excitons |
| **11** | Diamagnetism and Paramagnetism |

| | |
|---|---|
| **12** | Ferromagnetism and Antiferromagnetism |
| **13-14** | Superconductivity |

**Student Responsibilities:**

-Students are responsible for checking their academic e-mails and the Blackboard page of the course daily for getting updates about the course, grades, homeworks and class notes.

-If you need to take a make-up exam, please provide a university-approved excuse (such as a nurse/doctor signed document).

-Solid state physics is a very broad area. There is no possibility that one can teach/learn or cover everything about solid state physics in one semester. In order to benefit the most in a very limited time, every student will work on different subjects on their term projects. At the end, each student will present and teach the class their work. Subjects are specifically chosen to suit students' current research area.

-Homeworks play an important role in supplementing the material we are going to cover in class. They will give you a chance to practice and teach new topics as well. As graduate students, you are here because you are passionate about physics. Please invest time and prepare as much as you can for the homeworks.

**Academic Integrity:** By enrolling in this course, each student assumes the responsibilities of an active participant in UMBC's scholarly community in which everyone's academic work and behavior are held to the highest standards of honesty. Cheating, fabrication, plagiarism, and helping others to commit these acts are all forms of academic dishonesty, and they are wrong. Academic misconduct could result in disciplinary action that may include, but is not limited to, suspension or dismissal. To read the full Student Academic Conduct Policy, consult the UMBC Student Handbook, the Faculty Handbook, or the UMBC Policies section of the UMBC Director.