Lecture Notes on Solid State Physics

Masatsugu Sei Suzuki
Department of Physics, SUNY at Binghamton

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Here are lecture notes on Solid State Physics (Phys.472/572), which I prepared while I taught this course in the Spring 2012 Semester, Spring 2013 Semester, Spring 2018 Semester for both the undergraduate and graduate students. I used the textbook of Introduction to Solid State Physics (Charles Kittel, eight edition). Because of the limited times, I only taught the selected chapters including 1 - 13. Here I also put my lecture notes on many topics which were not taught in the class, including charge density waves, Kondo effect, Mossbauer, and so on. Lecture notes on several topics were already put in my web sites. The lecture notes on the same topics were greatly revised in the present version.

I spent a lot of time on making better figures by using Mathematica. I believe that these figures are helpful to students for understanding the essence of the physics more easily. My lecture notes are far from completeness. While I continue to teach the solid state physics (Phys.472/572) as well as the statistical thermodynamics (Phys.411-511), quantum mechanics (Phys.421, 422, undergraduate courses), I will revise the notes and put notes on new topics.

Now I teach this course in Spring 2019 semester again. I put the syllabus of this course below.

Syllabus:

STATE UNIVERSITY OF NEW YORK AT BINGHAMTON
Department of Physics

Syllabus

PHYS. 472/572 (Solid State Physics)

Spring 2019 (1/22/19 – 5/10/19)
(Revised January 15, 2019)

The Frontiers of knowledge are always on the move. Today's discovery will tomorrow be part of the mental furniture of every research worker. By the end of next week it will be in every course of graduate lectures. Within the months there will be a clamor to have it in the undergraduate curriculum. Next year, I do believe, it will seem so common place that it may be assumed to be known by every schoolboy (Ziman, Principles of the theory of solids, Cambridge University Press, 1964).

Description:

This course integrates topics of solid state physics with experimental demonstrations in the research laboratories of the condensed matter physics. The course will provide a valuable introduction and an overview of the fundamental applications of the physics of solids. This course includes the description of crystal and electronic structure, lattice dynamics, and optical properties of different materials (metals, semiconductors, magnetic materials, superconductors, and dielectrics), based on the classical and quantum physics principles. We need fundamental knowledges on statistical thermodynamics and quantum mechanics to understand the physics of solid state physics is application.

Course Objectives:

To understand the basic concepts underlying Solid State Physics and to be able to independently solve corresponding problems.

Instructor:

Masatsugu Sei Suzuki

Full Professor of the Physics Department

Office:	SN2408, Smart Energy
TEL	607-777-4320
E-mail	suzuki@binghamton.edu
Web site	http://bingweb.binghamton.edu/~suzuki/research.html
ResearchGate:	https://www.researchgate.net/profile/Masatsugu_Suzuki

Curriculum Vita of the Instructor

Education: Ph.D. (March 1977) Physics, University of Tokyo, Japan

Positions held

Professor, Department of Physics, State University of New York at Binghamton, Binghamton, New York 13902-6000 (9/86 – present)

Visiting Professor, Institute for Molecular Science, Myodaiji, Okazaki 444, Japan (8/92 - 12/92)

Visiting Scientist, Schlumberger-Doll Research, Ridgefield, Connecticut 06877 (11/85 - 8/86)

Visiting Research Assistant Professor, Department of Physics, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801 (7/84 - 8/86)

Research Associate, Department of Physics, Ochanomizu University, Tokyo, Japan (4/77 - 8/86)

Class hours (lectures):

T, R: 8:30 - 9:55 AM CW307

Office Hours:

Monday	9:00 AM - 11:00 AM	SN room 2048 (my office)
Wednesday	9:00 AM – 11:30 AM	SN room 2048 (my office)

Home page of Phys 472/572

You can find all the lecture notes in Phys. 472/572, which I prepare, in the Blackboard.

Textbook:

C. Kittel, Introduction to Solid State Physics, 8-th edition (Wiley, 2004).

Text book of Kittel has been the standard solid state physics text for physics students. The author's goal from the beginning has been to write a book that is accessible to undergraduates and consistently teachable. The emphasis in the book has always been on physics rather than formal mathematics. With each new edition, the authors have attempted to add important new developments in the field without sacrificing the book's accessibility and teachability. A very important chapter on nanophysics has been written by an active worker in the field. This field is the liveliest addition to solid state science during the past ten year. The text uses the simplifications made possible by the wide availability of computer technology. Searches using keywords on a search engine (such as Google) easily generate many fresh and useful references.

Supplementary book:

S.H. Simon, The Oxford Solid State Basics (Oxford, 2013)

I like this book very much. The author explains physics very clearly. There are many good problems to be solved.

M.L. Cohen and S. Louie, Fundamentals of Condensed Matter Physics

This book is appropriate for graduate students who want to do he theoretical works. Some topics will be picked up from this book and will be discussed in the class.

Course Outlines

Chapter 1	Structure of Solid Matter. Crystal structures.
Chapter 2	Diffraction from Periodic Structures: Reciprocal lattice. Brillouin zone. Ewald sphere. Ewald construction. x-ray and neutron scattering. Electron diffraction. Scanning tunneling microscopy (STM). Atomic force microscopy (AFM), X-ray diffraction of DNA.
Chapter 17	Surface and Interface Physics (surface crystallography): Ewald sphere
Chapter 4	Dynamics of Atoms in Crystals: Phonons I: crystal vibrations

	Lattice waves, inelastic neutron scattering, Bose-Einstein distribution function, density of states
Chapter 5	Thermal Properties: Phonons II Debye and Einstein models. Phonon heat capacity. Thermal conductivity.
Chapter 6	Free electron Fermi gas Model Fermi-Dirac distribution function, density of states. Specific heat capacity. Pauli paramagnetism.
Chapter 7	Elecronic Band Structure of Solids Bloch theorem and energy band. Kronig-Penney model. Schrödinger equation. Charge density waves (CDW). Peierls instability. Mott insulator and Hubbard model. Fermi surfaces and metals. Harrison construction of Fermi surfaces. de Haas-van Alphen effect, Shubnikov-de Haas oscillation in magnetoresistance
Chapter 9	Motion of Electrons and Transport Phenomena; Boltzmann transport equation. Thermal conductivity. Electrical conductivity. Thermoelectric power.
Chapter 10	Superconductivity BCS theory. Ginzburg-Landau theory. Josephson junction, DC SQUID. rf SQUID. Type-I and II superconductivity. Magnetic flux quantization. Josephson effect.
Chapter 11, 12	
	Magnetism: Diamagnetism and paramagnetism. Hund's law. Crystal field effect. Spin-orbit interactions. Ferromagnetism and antiferromagnetism. Mean field theory. Magnetic order. Magnetic neutron scattering. Magnons, critical behaviors. Magnetic resonance. Bloch equation, nuclear magnetic resonance (NMR), electron spin resonance (ESR). Stoner model. Kondo effect. Magnetic phase transition.
Chapter 13	Magnetic Resonance (NMR)
Chapter 14	Fermi liquid theory.
Chapter 17	Quantum Hall effect
Chapter 18	Landauer formula. Nanostructure (Quantum wire and quantum dot).

Reserved books in the Newcomb Reading room:

1. C. Kittel, Introduction to Solid State Physics, 8-th edition (John Wiley & Sons, 2005). ISBN 0-471-41526-X.
2. S.H. Simon, The Oxford Solid State Basics (Oxford, 2013). ISBN: 978-0-19-968077-1 (Pbk).

3. M.L. Cohen and S.G. Louie, Fundamentals of Condensed Matter Physics (Cambridge, 2016). ISBN: 978-0-521-5133-9 Hard back.

REFERENCES:

Standard textbook

1. J.M. Ziman, Principles of the theory of solids, 2nd edition (Cambridge University Press, 1972).
2. H. Ibach and H. Lűth, Solid-State Physics, An Introduction to Principles of Materials Science, 4-th edition (Springer, 2009).
3. H.P. Myers, Introductory Solid State Physics (Taylor & Francis, London, 1990).
4. S.L. Altman, *Band Theory of Metals* (Pergamon Press, New York, 1970).
5. R.A. Levy, Principles of Solid State Physics (Academic Press, 1968).

Books (topics)

1. R.E. Peierls, Surprises in theoretical physics (Princeton University Press, 1979).
2. R.E. Peierls, More surprises in theoretical physics (Princeton University Press, 1991).
3. L. Hoddeson and V. Daitch, *True Ginus. The life and science of John Bardeen* (Joseph Henry Press, Washington DC, 2001).

4. L. Hoddeson and V. Daitch, *True Ginus. The life and science of John Bardeen* (Joseph Henry Press, Washington DC, 2001).

Advanced textbooks

1. C. Kittel, Quantum Theory of Solids, 2nd edition (John Wiley & Sons, 1987).
2. N.W. Ashcroft and N.D. Mermin, Solid State Physics, Harcourt College Publishers (1976).
3. P.M. Chaikin and T.C. Lubensky, Principles of condensed matter physics (Cambridge University Press, 1995).
4. G. Grosso and G.P. Parravicini, Solid State Physics, 2nd edition (Academic Press, 2003).
5. M.P. Marder, Condensed Matter Physics (John Wiley & Sons, New York, 2010).
6. E. Kaxiras, Atomic and electronic structures of solids (Cambridge University Press, 2003).
7. R.E. Peierls, Quantum theory of solids (Oxford University Press, 1975).
8. J.M. Ziman, Elements of Advanced Quantum Theory (Cambridge University Press, 1969).
9. A. Rigamonti and P. Carretta, Structure of Matter (Springer, 2007).

10. P.L. Taylor and O. Heinonen, A Quantum Approach to Condensed Matter Physics (Cambridge, 2002).

Superconductivity

1. J. Bardeen, L.N. Cooper, and J.R. Schrieffer, Phys. Rev. **108**, 1175 (1957).

2. P.G. de Gennes, *Superconductivity of Metals and Alloys* (W.A. Benjamin, New York, 1966).

3. M. Tinkham, *Introduction to Superconductivity*, Reprint edition (Robert E. Krieger Publishing Company, INC, Malabar, Florida, 1980).

4. J.B. Ketterson and S.N. Song, *Superconductivity* (Cambridge University Press, 1999).

5. T. Tsuneto, *Superconductivity and superfluidity* (Cambridge University Press, 1998).

6. J.R. Schrieffer, *Theory of Superconductivity*, revised edition (Addison-Wesley, Reading, 1983).

7. W. Buckel and R. Leiner, *Superconductivity, Fundamentals and Applications*, Wiley-Vch Verlag GmbH & Co. KGaA, Weinheim, 2004).

8. R.P. Feynman, *Statistical Mechanics* (Benjamin, Reading, MA, 1972).

9. M. Suzuki and I.S. Suzuki, Ginzburg-Landau theory for superconductivity, http://www2.binghamton.edu/physics/docs/ginzburg-landau.pdf

Magnetism

1. K. Yosida, Theory of Magnetism (Springer, 1991).
2. Coey, Magnetism and Magnetic Materials (Cambridge University Press, 2009).
3. R.M. White, *Quantum Theory of magnetism*, 3rd edition (Springer-Verlag, Berlin, 2007).
4. C.P. Slichter, *Principles of Magnetic Resonance* (Harper & Row, New York, 1963).
5. S. Blundell, Magnetism in Condensed Matter (Oxford, 2001).
6. A.H. Morrish, The Physical Principles of Magnetism (John Wiley & Sons, 1965).

Mathematica 11.3: (not required):

The SUNY system gets a license to use the Mathematica 11.3 for all students and faculties in the Binghamton University. I will show how to use the Mathematica 11.3

during the class. As a part of the demonstration, I will also show the programs which I will make.

Examinations:

Calculator: Students are allowed to use a programmable calculator during the examinations. Three one-hour (1 hour) exams will be given during the classes. A required final examination will be given during examination week. Quizzes will be given in class.

Textbook: Students are allowed to see a textbook (Kittel) during the examinations. No index card is available in principle.

Quiz

We will have a quiz every Thursday (15 minutes).

Final Grade Determination:

Your final grade will be based on an absolute scale. Your final grade will be based on the three one-hour examinations, the final exam, the lab grade, the home work grade, and the discussion grade as follows:

200 points	for the best of two picked from three exams
200 points	for the final exam
100 points	for the home work
50 points	for the Quiz
50 points	attendance for lecture classes
600 points	total possible points for the course

There will be no make-up examinations:.

To accommodate a personal "crisis" coinciding with the day of an examination, such that a student misses the examination or performs below his or her normal level, one of the hour exam grades will be dropped. No excuse is necessary for missing or doing poorly on the hour exam which will not be counted - you could break your leg, be "sick" from a party, your alarm clock fails, etc. - regardless of the excuse, your worst 100 examination points will not be counted. THE FINAL EXAM MUST BE TAKEN.

Grade:

Your final grade will be determined by the percentage of 600 total points you manage to attain. These grades may change depending on the graph of the number of people vs total points such as Gaussian distribution with a single peak or double peaks.

85-100	A
80-84	A^-
75-79	B^+

70-74	B
65-69	B^-
60-64	C^+
55-59	C
50-54	C^-
40-49	D
0-39	F

Homework:

Homework assignments will be posted to coincide with material covered in lecture. Over the years, we have noted a strong correlation between students' homework problem solution grades and their final grade in the course. Questions on all exams will resemble homework problems assigned, examples done in class, or examples worked in the textbook.

Exam solutions:

Solutions for examinations will be posted on Blackboard.

Blackboard:

We have established a system where you can access exam solutions and administrative announcements from any on or off campus computer.

Announcements, Lecture note, Solutions of homeworks, Mathematica programs, Web site links, E-mail, and so on

Time Guidelines:

We expect that you will spend a minimum of ten hours each week outside of class working on the course. You should spend twenty minutes before each lecture scanning the textbook to get an idea as to what we will be covering in the lecture and the approach we will be using. This small investment of time will pay dividends in making the time spent in lecture more useful in the learning process. After each lecture, you should spend one hour learning the material covered in the lecture by reviewing your lecture notes and reading the textbook in detail. Each assigned problem set should take about three hours to complete; In this course, you cannot skip a week's worth of work and double up the time spent the following week. Success is produced by not getting behind and doing something every day.

Disclaimer:

We reserve the right to alter conditions and items found in this document at any time in the course of the semester using an announcement made in a scheduled lecture session and a Blackboard.

Students with disabilities:

If you are a student entitled to extra time on examinations or some other accommodation, you must see us before the accommodation can be made for you. You must bring the appropriate letter from the Services for Students with Disabilities Office along with you.

Students in Intercollegiate Sports:

It is the responsibility of students participating in intercollegiate athletics and thereby must be away from campus to make up any assigned work. You must make appropriate arrangements with your instructor (lab, discussion, or lecture) in advance.

Examination re-grading policy:

If after reviewing the posted examination solutions, you believe you deserve more points for a given problem, you must submit a written explanation of why you deserve more credit for the problem. The note must also include a signed statement that you have made no changes on the item in question. We will have copied approximately a quarter of the exams submitted. If a change has been made on an answer resubmitted, you will receive a zero on the exam and be referred to the Arts and Sciences academic honesty committee. The request for a re-grade is to be submitted to either your instructor or your discussion leader. **The request should be made within one week after you receive your exam sheet.**

Important Remarks and Advice:

1. We are aware that this course will cover a lot of ground and will be a lot of work for you.
2. Keep up with your work.

Read the appropriate sections of the text, once, before the lecture. As soon as possible after lecture, go over your notes and the text.

4. Do the problems! It is the only true test of whether you really understand the physics.
5. For each topic, collect a set of typical problems you can solve associated with that topic. Remember how you solve them.
6. Compare and integrate what you see in the text, lecture, discussion, lab, and the assigned problems. It is all part of one course, and the better you see how the pieces fit together, the more sense it will make.
7. The person who has the biggest part in determining what you will get out of this course (abilities, knowledge, and grade) is YOU.

Our Suggestions for Success in the Course:

Come to class. There is little we can do to help you learn the subject if you are not there.

When you are in class, do something productive. Take notes. Writing down the material is the first mechanical link to learning.
Within a day, review your notes, rewrite if necessary, compare your notes with the development in the textbook, and make sure you understand the examples worked.
Start the homework well before it is due. If you are having difficulty; ask your discussion leader, come to an office hour, or access one of the Mastering Physics hints. It is impossible to provide you help if you start an assignment two hours before the time it is due.
Make sure you can eventually do all homework problems and examples worked **WITH YOUR BOOK CLOSED, OR WITH YOUR COMPUTER SCREEN DARK.** You are not doing Physics "Appreciation"; you have to do the physics yourself. This is the place where most students have extreme difficulties.

Schedule of Classes in Phys.472/572 (Spring 2019):

	Date	Topics
Week-1	22, January T	Lecture-1 Chapter 1 Crystal structure
	24, January R	Lecture-2 Chapter 1
Week-2	29, January T	Lecture-3 Chapter 2 Reciprocal lattice and x-ray diffraction
	31, January R	Lecture-4 Chapter 2
Week-3	05, February T	Lecture-5 Chapter 17 Surface and interface physics
	07, February R	Lecture-6 Chapter 4 Phonon-1 Crystal vibration
Week-4	12, February T	Lecture-7 Chapter 4
	14, February R	Lecture-8 Chapter 5 Phonon-2 Thermal properties

Week-5	19, February T	Lecture-9 Chapter 5
	21, February r R	Lecture-10 Chapter 6 Free electron Fermi gas
Week-6	26, February T	Lecture-11 Chapter 6
	28, February R	Exam I
Week-7	05, March T	Lecture-12 Chapter 7 Energy band, Bloch theorem
	07, March R	Lecture-13 Chapter 7
Week-8	12, March T	Lecture-14 Chapter 9 Fermi surface and metals
	14, March R	Lecture-15 Chapter 9
Week-9	19, March T	No class (spring break)
	21 March R	No class (spring break)
Week-10	26, March T	Lecture-16 Chapter 10 Superconductivity, Ginzburg-Landau theory
	28, March R	Lecture-17 Chapter 10
Week-11	02 April T	Lecture-18 Chapter 10

	04, April R	Lecture-19 Chapter 11 Diamagnetism and paramagnetism
Week- 12	09, April T	Lecture-20 Chapter 11
	11, April R	Exam II
Week- 13	16, April T	Lecture-21 Chapter 12 Ferromagnetism and antiferromagnetism
	18, April R	Lecture-22 Chapter 12
Week- 14	23, April T	Lecture-23 Chapter 13 Magnetic resonance
	25, April R	Lecture-24 Chapter 13
Week- 15	30, April T	Lecture-25 Chapter-14 Fermi liquid, charge density wave
	2, May R	Exam III
Week- 16	07 May T	Lecture-26 Chapter-18 Nanostructure
	09 May R	Lecture-27 Chapter-18 Nanostructure, Review
TBA		Final Exam

Homework Assignments (TBA)

Name	Chapter	Problems	Acceptance Period
HW-1	Kittel Chapter 1	1, 2, 3	1/29/18 (T) 8:30 AM
HW-2	Kittel	2-2, 2-3, 2-4, 2-	2/5 (T) 8:30 AM

	Chapter 2	5, 2-6	
HW-3	Kittel Chapter 17 Chapter 4	17-1 4-1, 4-2, 4-3, 4-4	2/12 (T) 8:30 AM
HW-4	Kittel Chapter 4 Chapter 5	4-5, 4-6, 4-7, 4-8 5-1, 5-2	2/19 (T) 8:30 AM
HW-5	Kittel Chapter 5 Chapter 6	5-3, 5-4, 5-5 6-1, 6-3, 6-5	3/05 (R) 8:30 AM
HW-6	Kittel Chapter 6 Chapter 7	6-6, 6-9, 6-10 7-2, 7-4, 7-6	3/12 (T) 8:30 AM
HW-7	Kittel Chapter 9	9-2, 9-4, 9-6, 9-8, 9-10, 9-11	3/26 (T) 8:30 AM
HW-8	Kittel Chapter 10 Chapter	10-1, 10-3, 10-5, 10-7	4/16 (T) 8:30 AM

	11	11-4, 11-5	
HW-9	Kittel Chapter 11 Chapter 12	11-7, 11-8 12-2, 12-3, 12-6	4/23 (T) 8:30 AM
HW-10	Kittel Chapter 12 Chapter 13	12-7, 12-8 13-1, 13-2, 13-5	5/07 (T) 8:30 AM

All homework assignments will be chosen from the textbook (K: Kittel). Note that you may find all the solutions of problems in Kittel from the internet. You can make copies of them as your homeworks. But I suggest you to try to solve them by yourself first.