

**MSE 410/ECE 340: Electrical Properties of Materials
- Course Syllabus and Objectives -**

- You are responsible for understanding what is expected of you as outlined in this syllabus -

Instructor: Bill Knowlton, ERB 3125, 426-5705, BKnowlton@boisestate.edu

Classroom, Date and Time: MEC 307, Tu-Th 10:30 – 11:45 am

Office Hours: Tues: noon-1pm; Wed: 2-3pm (my office – ERB 3125); will cancel one of them if low attendance; or by appointment – send email (not by phone please)

Discussion Section: Monday: 3-4pm ([Engineering Tutor Center](#) – Grant Street Annex); Wed: 10:15-11:15am ([Engineering Tutor Center](#) – Grant Street Annex)

Teaching Assistant/Grader: Matt Lawson (MSE PhD graduate student)

Prerequisites: MSE 245, MATH 333, ENGR 240 or ECE 210, and PHYS 309 or ECE 212.

Course Website: <http://coen.boisestate.edu/bknowlton/> then, in the left panel, click on "MSE 410/ECE 340"

Text Books: *Principles of Electronic Materials and Devices*, 3rd edition, by S.O. Kasap (McGraw-Hill, 2005). <http://www.kasap.usask.ca/> (required)

Course Handouts/Notes: *Course notes are on the Course Website Notes* – and are referred to in the course content below. It is highly suggested to download and bring to class for all lectures.

Course Videos: *Course videos are on the Course Website. They are for reviewing material presented in freshman/sophomore level physics and chemistry and ENGR 245. Also posted is a tutorial for the BSU Energy Band Diagram Program. You will need headsets to listen.*

Final Exam: Date: *Thursday, December 14*; Time: *10am - noon*; Room: *MEC 307*

Final Exam Schedule: <http://registrar.boisestate.edu/boise-state-academic-calendars/>

Assessment Methods:

- **Problem Sets (30%):** 12-16 problem sets (NOTE: highest percentage of grade comes from the Prob. Sets!!!)
 - There will be considerable computation involved. MSE majors (undergrad and grad) are expected to use the mathematical software package, Mathematica, as this program is the mathematical software package of choice by the Dept. of MS&E. Any program submitted to me must be neat, decipherable, and fully documented. Mathematica is available for students via: (1) [Office of Information Technology \(OIT\)](#), (2) [COEN Virtual Lab](#), and (3) COEN Computer Labs available to COEN students (e.g., ET212, ET238, ET237, ET312, MEC402 and MEC103 - if not please let me know). In addition, you may use other mathematical software packages such as Maple or MatLab or data analysis software such as Origin or JMP. [COEN Virtual Lab](#) and COEN Computer Labs have Mathematica, Maple, MatLab & other engineering software. You cannot use EXCEL unless I specify otherwise. Attend *Office Hours* and *Discussion Sections* for questions on how to use Mathematica, particularly the first few weeks of the semester.
 - To receive full credit, you must:
 - Turn in problem sets prior to class on Thursday. Late problem sets are not accepted.
 - Submitted problem sets must be complete, legible, neat and decipherable. Include your name, problem set number, course name & number, and date. Multiple page problem sets must be stapled except ABET problems (TA/Grader needs to scan them). Problems should be kept in sequential order.
 - When solving each problem, state the question at the beginning of each problem and solve the problem systematically describing the steps taken throughout the problem. The solution must be thorough, complete, neat, and decipherable.
 - You must show all work. That is, your work must be complete.
 - Answers must be circled and, if the answer is not unitless, include units as they are required. All graphs must be thoroughly labeled, have axis titles and units, figure captions, and have detailed explanations. All software programs must be thoroughly documented/commented and follow the above criteria.
 - ABET Problems: over the course of the semester, you will find problems marked "ABET Problem". These problems are to be handed in separately and follow the criteria above. These problems will be assessed more thoroughly than other problems relative to completeness, correctness, legibility, neatness and decipherability, so extra care should be taken when answering these questions.
 - Grading – The TA/grader will provide a cursory review of your solution and provide a grade based on being able to follow and understand your solution. The grade will be based on the final solution and the completeness and validity of the path to the solution as well it's legibility, neatness and decipherability. If the grader cannot decipher your solution, or if your solution is not sequentially organized or not

stapled, you will be graded accordingly. Ultimately, you are responsible for understanding the solution to each problem.

- **Note:** *Keep in mind that problem sets are the major component of your grade.*
- **Lab or Project:** There may be one or two labs &/or projects. Each one will count as one or two problem sets each.
- **Quizzes (25%):** every week on Tuesday covering the problem set of the previous week. If we have over 6 quizzes, then one quiz can be dropped. *Quiz Learning Objectives* are available by email request before 5pm Friday.
- **Midterm (20%):**
- **Final (20%):** Cumulative.
- **In-class participation/engagement (5%):** *answering questions, asking questions, in-class group projects and participation/engagement, providing feedback, office hours, discussion section, hard work, enthusiasm for subject matter, etc., (yes, being present in class also helps, but participation is key). I've seen students lose or gain a grade because of this assessment method. So please participate and engage!*
- **Grading:** BSU has implemented the +/- grading system. The following grade scale for final grades will be used: A=100-94%; A- = 93-90%; B+ = 89-87; B = 86-84; B- = 83-80; C+ = 79-77%; C = 76-74%; C- = 73-70%; D = 69-60%; F = <60% (Note that decimals will be rounded)
- **Grade Adjustments:** Any requests for grade adjustments should be made within *one week* of the time the grade in question was returned to you. These requests must be submitted in writing to the instructor with an explanation of the situation clearly identified and the graded assignment/exam/quiz/project submitted with the request. Please do not approach me after class to argue about points. You are encouraged to approach me after class to ask questions about the lecture material.
- **Other:** All quizzes/exams will be closed book. Typically, calculators are not needed (I'll let you know if they are). Rulers or a straight edge are useful. Exams will include both problem solving and conceptual or short answers. When problem solving, you must show all work to receive full credit. Working or studying in teams is encouraged. However, homework problems that are to be graded (and of course quizzes and exams) must be individually derived and submitted. Submitted problem sets must be legible, neat and decipherable. All graphs must be thoroughly labeled, have axis titles and units, and detailed explanations.

Course Description: Introduction to the physical principles underlying the electrical properties of modern solids. Crystalline and energy band structure of materials, thermal properties and electrical conduction in semiconductors and metals and how these properties relate to solid state devices.

Course Objectives: *At the end of the course, the student should be able to...*

- Apply the Schrödinger equation and Bloch wave functions to find the mathematical solutions that describe simple band theory of semiconductors and dielectrics (nonconductors).
- Apply quantum mechanics to calculate solutions for quantum wells and quantum tunneling.
- Draw energy band diagrams in both real and reciprocal space and compare and contrast the difference between localized and delocalized states in both spaces.
- Describe the operation and potential issues of a variety of semiconductor devices using energy band diagrams and the Fermi energy level.
- Explain why dislocations are detrimental to device operation using energy band diagrams.
- Discuss absorption and transmission in solids using the concept of energy band diagrams and impurities.
- Use a mathematical program such as Mathematica, Maple, and/or MatLab to solve problems such as calculating the Fermi level in an intrinsic semiconductor given the effective mass of electrons and holes and the band gap of the material.

Course Content:

(K = Kasap, P = Pierret, S&W = Solymar and Walsh, F&B = Ferry and Bird)

Part	Lecture Subject Matter	Week Covered - Date	Reading Assignment: Textbook Author and Chapter
1	Syllabus & Motivation for Electrical Properties	1-8/22	Review notes & Video Lectures & K-Ch.1
"	Review – Syllabus Quiz, Short Review: Thermo/Kinetics	1-8/24	Review notes & Video Lectures & K-Ch.1
"	Empirically Derived Electrical Conduction in Solids	2-8/29	K-Ch.2.1-2.3
2	"	2-8/31	K-Ch.2.4-2.6, 2.8-2.10
"	"	3-9/5	"
"	" & Statistical Thermo & Elem. Quantum Mechanics– Historically Fundamental Experiments	3-9/7	K-Ch.2 & Ch.3.1-3.3, Ch.4.6; P-Ch. 2, Notes
"	Review of Complex Numbers, Some PDEs in Engineering, Elementary Quantum Mechanics – Schrodinger Eqn	4-9/12	Dif. Eq. Textbook, K-Ch.3.4-3.5, P-Ch. 2, & Appendix E, <x> <i>handout</i>
3	Elementary Quantum Mechanics – Free e^- , Heisenberg Uncertain. Principle, Probability, Normalizing Ψ , Expectation Values	4-9/14	K-Ch. 3.4-3.5, P-Ch. 2
"	" : Barrier problems-Potential Well (particle in a box = quantum well)	5-9/19	"
"	" : Other Quan. Mech. Quan.'s & Pot. Step/ ∞ -Barrier	5-9/21	K-Ch.3.6-3.7, 3.8.2, P-Ch. 2
"	" : Potential Step/Finite Barrier	6-9/26	K-Ch.3.6-3.7, 3.8.2
4	Modern Theory of Solids-Bloch Theorem & Kronig Penney Model	6-9/28	K-Ch.4.1-4.5 & 4.7-4.8 & 4.11, P-Ch.3, P-Ch. 3, & <i>Course Lecture WebNotes</i>
"	Density Functional Theory – Professor Lan Li. OR: Kronig Penney Model, E -vs- k Dispersion Relation, Direct vs Indirect energy band gaps, effective mass, group velocity,	7-10/3	K-Ch.4.1-4.5 & 4.7-4.8, 4.11, <i>Course Lecture Notes & Handouts</i> , P-Ch.3, F&B-Ch.4.6, S&W-Ch2.3,
"	Density Functional Theory – Professor Lan Li. OR: E -vs- <i>real space</i> : conductor, semiconductor, nonconductor, Dispersion Relation Linear Combination of Atomic Orbitals (LCAO), DFT.	7-10/5	K-Ch.4.1-4.5 & 4.7-4.8, 4.11, <i>Course Lecture Notes & Handouts</i> , P-Ch.3, F&B-Ch.4.6, S&W-Ch2.3,
"	Midterm Exam	8-10/10	
5	n for a metal, density of states, Fermi-Dirac function, Fermi Energy, conductor, Semiconductor, Non-conductor	8-10/12	K-Ch.4.1-4.5 & 4.7-4.8, 4.11, <i>Course Lecture WebNotes</i>
"	Intrinsic semiconductors, Intrinsic free carrier statistics	9-10/17	K-Ch.4.9 & 5.1, <i>Course LectureWeb Notes</i> $f(E)$, $g(E)$, E_g
5	Intrinsic Semiconductors, Extrinsic semiconductors: Effective mass theory, Free carrier statistics	9-10/19	K-Ch.5.1, <i>Course LectureWebNotes</i>
"	Extrinsic Semiconductors: Free carrier statistics, Freeze-out curves, Phonons	10-10/24	K-Ch.5.2-5.3 & Ch.4.10, <i>Course LectureWebNotes</i>
"	Extrinsic Semiconductors: Freeze-out curves, Phonons; Application of Band diagrams to Devices: Metal work function, Contact potential, Seebeck effect	10-10/26	K-Ch.5.2-5.3 & Ch.4.10, & Ch.4.9, <i>Course LectureWebNotes</i>
6	Application of Band diagrams to Devices: Metal work function, Contact potential, Seebeck effect, Schottky & Ohmic Contacts, Optoelectronics Lab Handouts	11-10/31	K-Ch.4.9 & 5.3 & 5.9-5.10 <i>WebDeviceNotes Part 1</i> – Lab Handout

"	Application of Band diagrams to Devices – pn diode/junction & bipolar transistor	11-11/2	WebDeviceNotes Part 2 K-Ch. 6.1-6.5 & 6.6
"	Application of band diagrams to Devices – Bipolar transistor	12-11/7	WebDeviceNotes Part 2 K-Ch. 6.6
"	Optoelectronics Lab (Labs Thurs. & Fri. & Sat.)	12-11/8 – 11/12	Lab Handout
"	App. of band diagrams to devices – Semiconductor heterojunctions	12-11/9	WebDeviceNotes Part 3 K-Ch. 6.9.2-6.9.3
"	App. of band diagrams to devices – Semiconductor heterojunctions & MOS heterojunctions	13-11/14	WebDeviceNotes Part 3 K-Ch. 6.9.2-6.9.3, Part 4 K-Ch. 6.8
"	App. of band diagrams to devices – MOS heterojunctions: inversion, depletion, accumulation – In-class exercise	13-11/16	WebDeviceNotes Part 4 Ch. 6.8
	Thanksgiving Break	11/21 & 11/23	
"	App. of band diagrams to devices – MOS heterojunctions: inversion, onset of inversion, threshold of inversion, capacitance & Quantum effects in MOS devices: poly dep., wave function effects, tunneling – FNT & DT	14-11/28	WebDeviceNotes Part 4 & Part 5 Ch. 6.8
"	App. of band diagrams to devices – Quantum effects in MOS devices: GIDL, DIBL, band-to-band tunneling – In-class exercise, strain engineering – effective mass	14-11/30	WebDeviceNotes Part 4 & Part 5 Ch. 6.8 & Ch. 6.5.2
"	App. of band diagrams to devices – New materials: High k, metal gate electrode & channel– In-class exercise	15-12/5	WebDeviceNotes Part 6 Ch. 6.8
"	App. of band diagrams to devices – New materials: Motivation; Non-volatile memory	15-12/7	WebDeviceNotes Part 6 Ch. 6.8
"	App. of band diagrams to devices – Molecular electronics at the nanoscale	If we have time	WebDeviceNotes Part 7

Course Content:

1. Review: Thermo, Kinetics, thermally activated processes
2. Elementary Materials Science & Engineering Concepts – Review: out of class (see course website for notes and problem set your ENGR 245 book)
3. Empirically Derived Electrical Conduction in Solids
 - a. Drude model
 - b. Matthiessen's and Nordheim's Rules
4. Elementary Quantum Physics
 - a. Photons
 - b. Wave-particle Duality
 - c. Particle (electron) in a box – Pseudo quantum well
 - d. Tunneling: Quantum leaks (energy barrier problems)
5. Modern Theory of Solids
 - a. Atomic and molecular orbitals, molecular bonding
 - b. Band theory of solids: nonconductors, semiconductors, conductors
 - i) Bloch Theorem and Kronig Penney Model
 - ii) Tight Binding Approximation
 - iii) E - k energy band diagrams (intrinsic solids)
 - iv) Effective mass (m_{eff})
 - v) Density of states (DOS)
 - vi) Fermi-Dirac Statistics (Fermions) and the Fermi Energy Level (E_f)
 - c. Metal-metal junctions
 - i) Metal workfunction, Contact potential, Seebeck effect
 - d. Intrinsic semiconductors, Intrinsic free carrier statistics
 - e. Extrinsic Semiconductors
 - i) Effective Mass Theory (a.k.a.: Hydrogenic Model)
 - ii) Free carrier statistics

- f. Phonons
- g. Optical Properties of Semiconductors
6. Semiconductors Devices: Application of Band Theory – Band Diagrams
 - a. *Metal-semiconductor* contacts
 - i) Schottky
 - ii) Ohmic
 - b. *p-n* junctions (What is the Peltier Effect?)
 - c. Bipolar transistor
 - d. Double Heterostructures & Light Emitting Devices
 - i) LED
 - ii) Laser diodes (multi-quantum wells)
 - iii) Nitride and other materials systems
 - iv) Solar cells (if we have time)
 - v) Polymer and bio-devices (if we have time)
 - e. Metal-Oxide-Semiconductor Field Effect Devices
 - i) MOS Band diagrams, nMOS, pMOS (capacitors)
 - ii) Inversion, depletion, accumulation (MOSFETs)
 - f. Quantum Effects in MOS Devices
 - i) Poly-depletion
 - ii) DIBL
 - iii) GIDL
 - g. New Materials in Metal-Oxide-Semiconductor Field Effect Devices
 - i) High-*k*
 - ii) Metal gates
 - iii) SiGe
 - iv) Multi-layer dielectrics
 - v) Nonvolatile memory (NVM) multilayer devices (if we have time)
 - h. Molecular electronics at the nanoscale (if we have time)
 - i. Other: Phonon detectors, quantum dots, etc. (if we have time)

MSE Program Outcomes for this course (taken from ABET):

(a, e, j, l, n)

- a. Ability to apply knowledge of mathematics, science, and engineering. (P)
- e. Ability to identify, formulate, and solve engineering problems. (P)
- f. An understanding of professional and ethical responsibility. (S)
- j. A knowledge of contemporary issues. (S)

Note: P = primarily supports the outcome (as compared to other courses).

S = secondarily supports the outcome (as compared to other courses).

Recommended Textbooks:

- Robert Pierret, *Advanced Semiconductor Fundamentals*, Modular Series on Solid State Devices, Volume VI (Addison-Wesley, 1989) – Most of the applications to quantum mechanics are from this textbook
- Solymar and Walsh, *Electrical Properties of Materials*, 7th Ed. (Oxford, 2004) – similar to our textbook
- Ferry and Bird, *Electronic Materials and Devices*, (Academic Press, 2001) – similar to our textbook
- D. Jiles, *Introduction to the Electronic Properties of Materials*, 2nd Ed (Nelson Thornes Ltd, 2001) – similar to our textbook
- B. Anderson & R. Anderson, *Fundamentals of Semiconductor Devices*, (McGraw Hill, 2005)
 - Ch.6 provides a nice overview of semiconductor heterostructures
 - Ch. 7-8 & Supplement to Part 3 provides a thorough overview of MOS devices
 - Ch. 10: Optoelectronic devices – good overview
- J.S. Blakemore, *Solid State Physics*, 2nd Ed. (Cambridge Press, 1985)
 - Ch.1: provides a nice overview of interatomic binding, crystal structures, and crystalline defects
 - Ch 2: provides an overview of phonon dynamics
 - Ch. 4: covers semiconductor free carrier statistics and freeze-out curves
- John P. McKelvey, *Solid State Physics for Engineering & Materials Science* (Kreiger Publishing Company, 1993).
 - Ch. 4 provides an overview of quantum mechanics and potential barrier problems.

- Ch. 8 provides an overview of quantum mechanics of electrons in systems including the Kronig-Penney model.
- Ch. 9 provides an overview of semiconductor materials including free carrier statistics.

Academic Professionalism in Class:

Respect goes both ways – Please be respectful to everyone in class (not disruptive to class) and I will be respectful when interacting with you.

Class Disruption:

Class disruption includes, but is not limited to, arriving late to class, attempting to hand in homework late, cell phone use (e.g., cell phones on your desk, ringing in class, talking on, texting), and talking to other classmates during lecture.

Academic and Scientific Misconduct:

Information on: [Academic Honesty and Dismissal](#) & [Student Code of Conduct](#) - In particular, read Section 4 and Section 7

- Scientific and Professional Misconduct:
 - [Troubling News - Rise & Fall of Bell Labs Physicist](#) - 2002
 - [Rise & Fall of Renowned Stem Cell Researcher](#) - 2006

Go to course website: <http://coen.boisestate.edu/bknowlton/course-information/82-2/>

Please read and make sure you understand the *Student Code of Conduct- Section 18 - Academic Misconduct*. Any form of academic misconduct or dishonesty is unacceptable and will be dealt with harshly.

Days I might be Traveling: (make-up lectures to be done outside of class)

- None at this time
- Make up lecture (date to be determined) or video lecture will be given in its place.