# Physics 9812a: Condensed Matter Physics

Fall 2011

**Lectures:** Monday and Wednesday 10:00 am – 11:30 pm, P&A B 233

**Office hours**: Wednesday 2pm-3pm, P&A B 231

**Web-site**: http://www.physics.uwo.ca/~lgonchar/courses/p9812/index.shtml


**Course Instructors**
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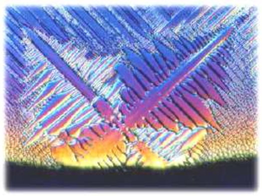


# Prerequisites:

- Quantum Mechanics or Quantum Chemistry
- An undergraduate-level courses in
  - Solid State Physics,
  - Materials Science

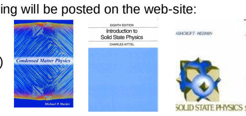
are desirable but not required…



# Textbooks

Several textbooks will be used plus additional reading will be posted on the web-site:

1. M.P. Marder, Condensed Matter Physics (2000)
2. Ch. Kittel, Introduction to Solid State Physics.
3. Ashcroft and Mermin, Solid State Physics (1976)
4. M.A. Omar, Elementary Solid State Physics: Principles and Applications (1993)




**Other Reference Books and Materials** :

O'Reilly, *Quantum Theory of Solids,* (2002) - a nice shorter, lighter, paperback
Kaxiras, *Atomic and Electronic Structure of Solids*, (2003).
Zangwill Andrew, *Physics at Surfaces*, (1996).
Taylor P.L., *A Quantum Approach to the Solids State*, (1970)
Burns G., *Solid State Physics*, (1985). – older book, covers fewer topic, but good pedagogical clarity

**Advance and Specialized Reference Books:**

Taylor and Heinonen, *A Quantum Approach to Condensed Matter Physics* (2002).
Callaway, *Quantum Theory of the Solid State* (2nd Edit., 1974).
Ibach and Lüth, *Solid State Theory* (1991).
Philips, *Advanced Solid State Physics* (2003).
Kohanoff, *Electronic Structure Calculations for Solids and Molecules* (2006).
Cox P.A. *The Electronic Structure and Chemistry of Solids*, (1995).

# Assignments and Grades

- Course requirements will include

**2 homework assignments** (each of them cares 15% of the grade)
**Midterm Exam** (Open book, open notes, ~ October 26, 30 %)
**Final Exam** (December, 40%)

Assignments and their deadlines will be posted on the web site…

- Assignments must be turned in at the requested day before 6pm
- Penalty points may be applied, if you are late more than one time

The Department of Physics and Astronomy may, in rare cases, adjust the final course marks in order to conform to Departmental policy.



# Historical Overview

**1914** – Max Von Laue for X-ray diffraction techniques

**1915** – Bragg (father and son) for X-ray crystal structure determination methods

**1956** – Shockley, Bardeen, Brattain for invention of a transistor

**1970** – Lois Neel (split with Alfven) for study of antiferromagnetic ordering

**1973** – Josephson for prediction of Josephson supercurrent effect

and Esaki and Giaever for semiconductor/superconductor tunneling

**1987** – Bednorz and Muller for high-temperature superconducting ceramics

**2000** – Alferov, Kroemer, and Kilby for developing semiconductor heterostructures used in high-speed- and opto-electronics

**2003** – Abrikosov, Ginzburg, Leggett for the theory of superconductors

**2007** – Fert and Peter Grunberg for the discovery of Giant Magnetoresistance

**2010** - Andre Geim, Konstantin Novoselov two-dimensional material raphene"

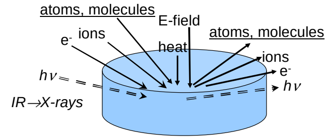


# Aspects of Condensed Matter Physics

***Historical Roots***
- Atomic Structure
- Electronic Structure
- Mechanical Properties
- Electron Transport
- Optical Properties
- Magnetism

***Concepts***
- Self-organization
- Form and function
- Scaling and Symmetry
- Precision Measurement
- Fabrication
- Computation

***Probing Properties***



## Timeline…

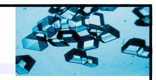
**Part I:**
1. Crystal Lattices; The Reciprocal Space; Experimental Determination
2. Complex Structures
3. Lattice vibrations; Neutron Scattering
4. Electron Theories in Metals; Band Theory
5. Transport Phenomena in Solids (Metals, Semiconductors, Devices)
   – Scanning and Transmission Electron Microscopy
   – Nanofabrication methods: lithography, focused ion beam milling

**Part II:**
6. Optical Properties of Crystals
7. Structural Phase Transitions
8. Magnetism and Superconductivity

**September**
26: No lectures
~28: HWA#1
**October**
~12: HWA#1 is due
~26: Midterm
~31: Nanofab tour
**November**
~14: HWA#2
~23: HWA#2 is due

**December**
12-20 Final Exam




## Lecture 1


### 1.1 Crystal Lattices
### 1.2 The Reciprocal Lattice
### 1.3 Experimental Determination of Crystal Structure

**Crystal:**
a solid composed of atoms, ions, or molecules arranged in a pattern that is repeated in three dimensions
A material in which atoms are situated in a repeating or periodic array over large atomic distances

References:
1. Marder, Chapters 1-3
2. Kittel, Chapter 1 and 2
3. Ashcroft and Mermin, Chapter 4-6
4. Burns, Chapters 1-2
5. Ziman, Chapter 1



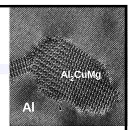
## Lecture 2

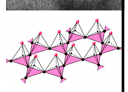
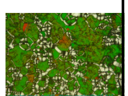
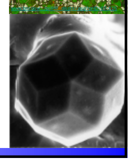
### Complex Structures

2.1 Alloys
- 2.1.1 Phase Diagrams
- 2.1.2 Solid State Solutions and Superlattices
- 2.1.3.Phase Separation and Dynamics of Phase Separation

2.2 Liquids
2.3 Glasses
2.4 Liquid Crystals
2.5 Polymers
2.6 Quasicrystals

References:
1. Marder, Chapter 5
2. Kittel, Chapters 17 and 21, p.48
3. Ashcroft and Mermin, Chapter 19
4. Kaxiras, Chapters 12-13



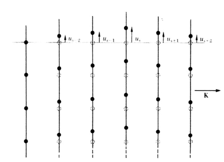
## Lecture 3

### Crystal Vibrations

… and Neutron Scattering

7.1 Vibrations of crystals with monatomic basis
7.2 Two atoms per primitive basis
7.3 Quantization of elastic waves
7.4 Phonon momentum
7.5 Inelastic neutron scattering for phonons

References:
1) Kittel, Chapter 4
2) Marder, Chapter 13
3) Ashcroft, Chapters 22, 24
4) Burns, Chapters 12
5) Ziman, Chapter 2
6) Ibach, Chapter 6



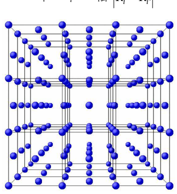
## Lecture 4

### 4. The Single-Electron Model

$$\hat{H} = \sum_l \frac{\hat{\vec{p}}_l^2}{2m_l} + \frac{1}{2}\sum_{l \neq l'} \frac{q_l q_{l'}}{|\hat{\vec{R}}_l - \hat{\vec{R}}_{l'}|}$$

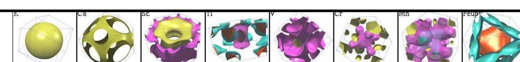
… or Free Electron Fermi Gas

Free electrons subject to the Pauli principle



In 1D: $$H\psi_n = -\frac{\hbar^2}{2m}\frac{d^2\psi_n}{dx^2} = \varepsilon_n \psi_n$$

References:
1. Marder, Chapters 6
2. Kittel, Chapter 6, pp.144-156
3. Ashcroft and Mermin, Chapter 8
4. Ziman, Chapter 3, pp.77-91
5. Kaxiras, Chapter 3
6. Phillips, Chapter 1
7. Ibach, Chapter 6



## Lecture 5

### Nearly Free Electron Model

4.1 Nearly Free Electron Model
- 4.1.1 Brilloiun Zone
- 4.1.2 Energy Gaps

4.2 Translational Symmetry – Bloch's Theorem
4.3 Kronig-Penney Model
4.4 Tight-Binding Approximation
4.5 Examples

References:
1. Marder, Chapters 7-8
2. Kittel, Chapter 7
3. Ashcroft and Mermin, Chapter 9
4. Kaxiras, Chapter 3
5. Ibach, Chapter 7

## Lecture 6

### 6. The Tight-Binding Approximation

… or from Bonds to Bands

Basic concepts in quantum chemistry – LCAO and molecular orbital theory

The tight binding model of solids – bands in 1, 2, and 3 dimensions

References:

1. Marder, Chapters 8, pp. 194-200
2. Kittel, Chapter 9, pp.244-265
3. Ashcroft and Mermin, Chapter 8
4. R. Hoffmann, "Solids and Surfaces: A chemists view of bonding in extended structures" VCH, 1988, pp 1-55, 65-78.
5. P.A. Cox, "The Electronic Structure and Chemistry of Solids", Oxford, 1987, Chpts. 1, 2(skim), 3 (esp. 45-62), and 4 (esp. 79-88).

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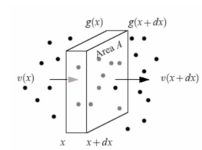
## Lecture 7

### Fermi Liquids and Transport

1. Boltzmann Equation and Relaxation Time Approximation
2. Onsager Relations
3. Thermoelectrical Phenomena
   - Wiedemann–Franz Law
   - Seebeck, Peltier, and Thomson Effects
   - Classical Hall Effect
   - Magnetoresistance
4. Fermi Liquid Theory




References:

1. Marder, Chapters 17, pp. 443-487
2. Kittel, Chapter 9, pp.244-265
3. Ashcroft and Mermin, Chapter 8

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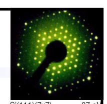
## Lecture X



Si(111)(7x7) 37 eV

### Electron mean free path
### Microscopy principles of SEM and TEM

9.1 Electron Mean Free Path

9.2 Scanning Electron Microscopy (SEM)

-SEM design; Secondary electron imaging; Backscattered electron Imaging

9.3 Transmission Electron Microscopy (TEM)

- TEM/STEM design; spectroscopy (EELS)

References:

1) L. Reimer, "Scanning Electron Microscopy - Physics of Image Formation and Microanalysis", 1985.
2) R.E. Lee, "Scanning electron microscopy and X-Ray microanalysis, 1993.
3) Woodruff & Delchar, Chapter 2 and pp. 449-460.
4) Attard and Barnes, pp,25-28, 47-62.
5) Kolasinski, pp.84-91, 107-108.
6) LEEM: http://www.research.ibm.com/leem/#item2

## Lecture 14

### Nanofabrication and Lithography

Thermodynamics and kinetics of thin film growth
Defects in Films; Amorphous, polycrystalline and epitaxial films
Vacuum film deposition techniques
- Physical Vapour Deposition (PVD)
- Epitaxy and Molecular Beam Epitaxy (MBE)
- Chemical Vapour Deposition (CVD)
- Atomic Layer Deposition (ALD)

Nanomaterials growth approaches: top-down and bottom-up

References:

1. Zangwill, Chapter 16
2. Luth, p.89-114
3. C.T. Campbell, Surf. Sci. Reports 27 (1997) 1-111
4. Kolasinski, Chapter 7