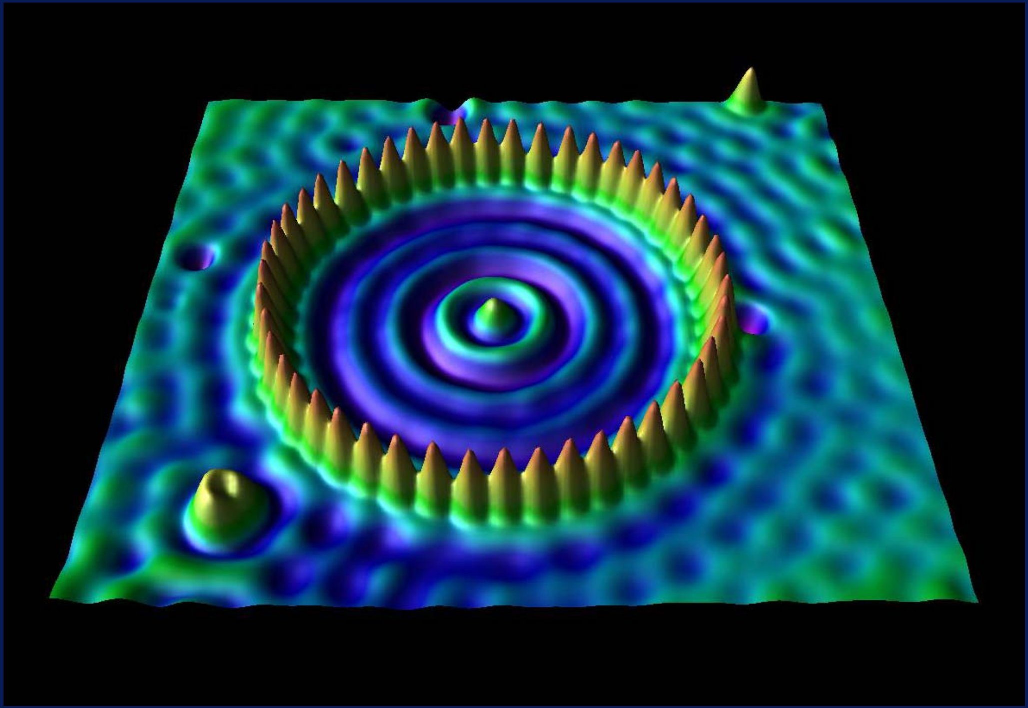
Welcome to Physics 460
Introduction to Solid State Physics



Scanning Tunneling Microscope image of atoms placed on a surface, and confined quantum electron waves
D. Eigler IBM

Teaching Staff

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    - By appointment

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  - Office hours to be announced

- Both of us can be reached most easily by e-mail
  - We will try to always answer promptly and can set up appointments

Course Information

- Course Information on Web site

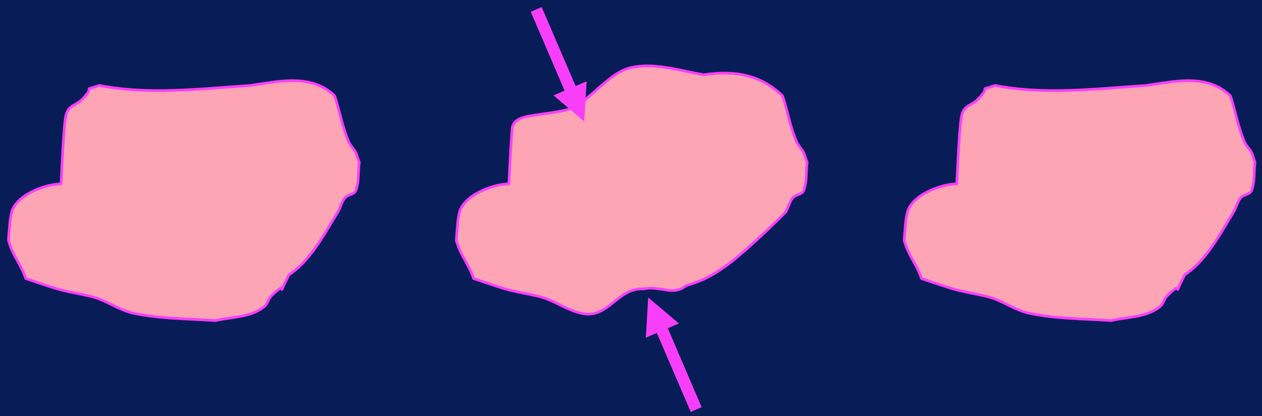
  http://online.physics.uiuc.edu/courses/460/fall06/

- Course Objectives, Information and Policies
- Books on Reserve
- Calendar with links to homework, lecture outlines

- Lecture outlines will also be passed out in class

What is a solid?

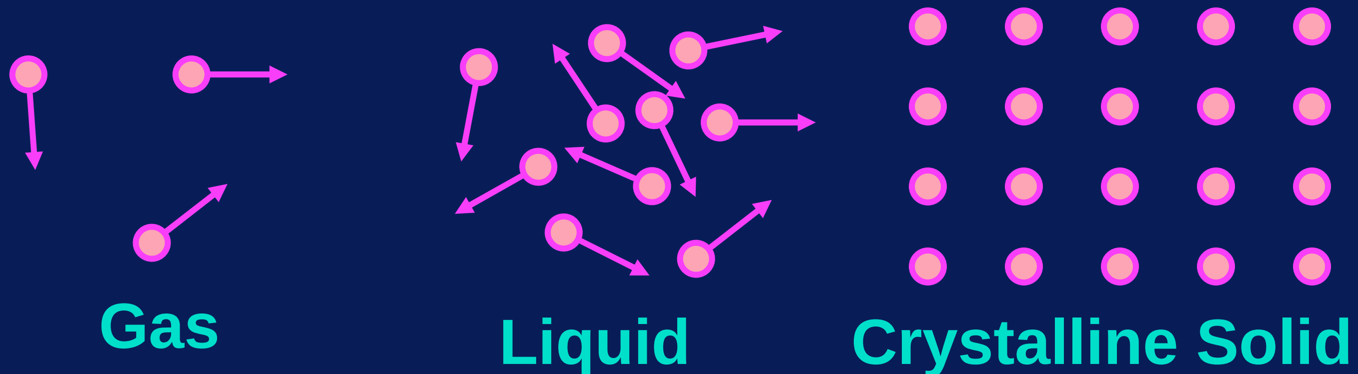
- A material that keeps is shape
  - Can be deformed by stress
  - Returns to original shape
    (If it is not strained too much)



- The mechanical properties of solids - especially strength against large strains - have been part of human advances for thousands of years

What is the structure that makes a solid "solid"?

- Defined by the atoms, i.e., nuclei



- Is a solid really different - or is it just a "slow liquid"
- The atomic scale nature of materials has known for less than 100 years
- Quote from Feynman

What are some properties of solids Useful, Interesting, Surprising,…

- **Metals conduct electricity**
- **Insulators do not**
- **What is a semiconductor?**
  - **Why is your computer made of silicon?**
- **. . . .**

What is Solid State Physics?

Solid State Phenomena

Basic Understanding ⟷ **Practical Use**

Idealized Models **Real Materials**

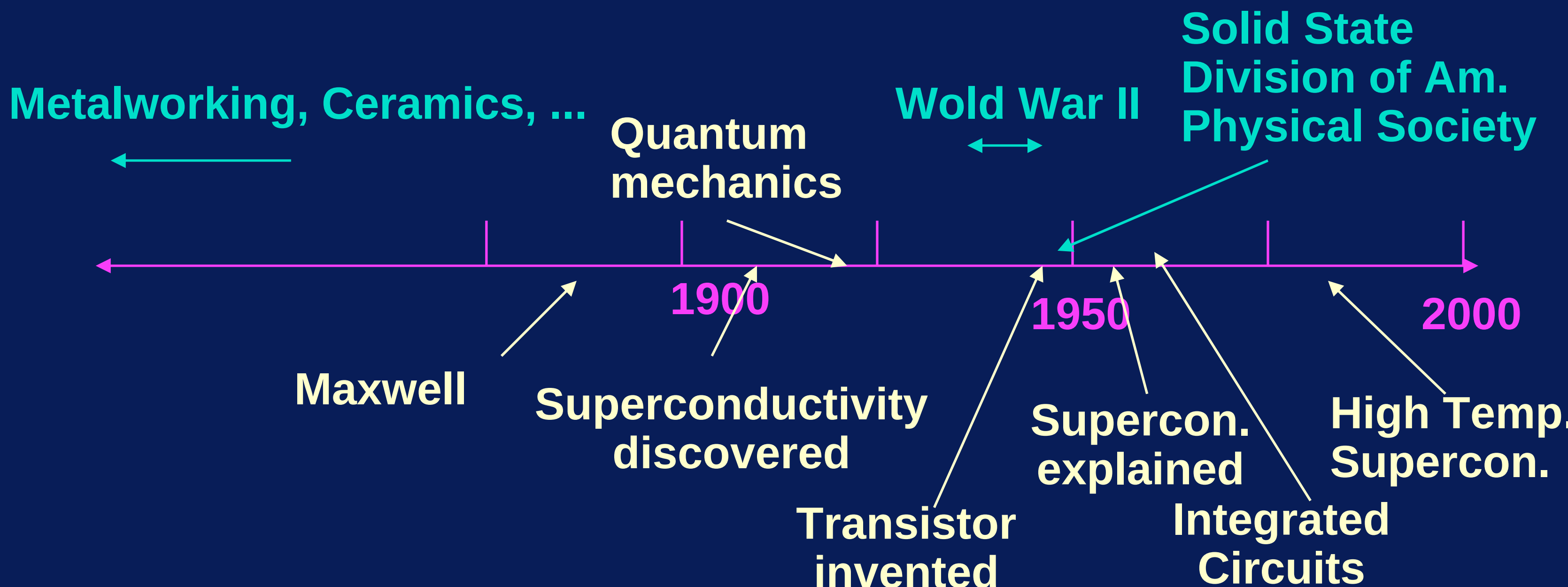
Progress

- **Solid State Physics is important in the real world!**
- **In this Introduction to Solid State Physics, we will emphasize basic principles and idealized models (models that capture the essential features) as the basis for understanding solids**

What is Solid State Physics?

- The body of knowledge about the fundamental phenomena and classifications of solids
- What is a “fundamental phenomenon” ?
  - A characteristic behavior exhibited by classes of solids
- Examples:
  - Ductile vs. brittle materials
  - Metals vs. Insulators
  - Superconductivity - discovered in 1911
  - Ferromagnetic materials
- The basic understanding of such “fundamental phenomena” is provided by quantum mechanics

Solid State Physics becomes a discipline



- **Solid State Phenomena presented conceptual problems resolved by quantum mechanics**
  - **Metallic conduction, magnetism, superconductivity, ……**
- **We will use simple models, and materials to illustrate the phenomena in our course**

Phenomena and Principles

- Mechanical
  - Structures
  - Strength
- Thermal
  - Heat capacity
  - Heat conduction
  - Phase transitions
- Electrical
  - Insulators
  - Metals
  - Semiconductors
  - Superconductors
- Magnetic
  - Ferromagnetism
- Optical
  - Reflection, refraction
  - Colors

- Newton's Laws
- Maxwell's Equations
- Thermodynamics and Statistical Mechanics
- Quantum Mechanics
  - Schrodinger's Equation
  - Pauli exclusion principle
- Order and Symmetry

Course Outline: Two Main Themes

- **Structures of Solids: Kittel 1-5 ≈5 weeks**
  - Crystal structure
  - Diffraction and reciprocal lattice
  - Binding
  - Atomic vibrations and elastic constants
  - Thermal properties
- **Electronic Properties: Kittel 6-10 ≈6 weeks**
  - Free electron gas
  - Energy bands - metals vs insulators
  - Semiconductors
  - Optical properties
  - Superconductivity (Introduction to the phenomena)
- **Other Topics: ≈2 weeks**
  - Magnetism
  - Defects in crystals

Study of solid state physics is different from other courses

- Why?
- Many varied properties
  - Descriptions may sound like a bunch of recipes to memorize
  - The book is like a list

- The derivations do not seem rigorous
  - They seem like they are chosen because we know the answer
  - Just a bunch of recipes for equations to be memorized

- Why?

- Can we make this a real learning experience?
  - Not just memorization?

Study of solid state physics is different from other courses

- The goal is understanding and learning a way to approach problems
- A solid (any piece of matter of macroscopic size) is made of ~ 10^{23} atoms
    - 10^{23} nuclei - 10^{23} electrons that all interact with one another
- In classical physics the three-body problem cannot be solved !
    - The sun-planets problem is "soluble" only because the sun is much more massive than the planets
    - We "solve" by ignoring interactions among the planets and treat only soluble two-body problems
- In solids we must use reasoning to reduce the problem – make approximations - to allow understanding

Study of solid state physics is different from other courses

- The goal is understanding and learning a way to approach problems
- In solids we can use the fact that the nuclei are much more massive than the electrons
  - This is the difference between parts 1 and 2 of the course
  - Goal - to understand why this is appropriate
- Part 1 is about structures and mechanical properties - determined by the massive nuclei
  - We use classical mechanics and waves and we find sensible, soluble equations
  - Quantum mechanics enters at a crucial point
  - Goal - to understand why this is appropriate

Study of solid state physics is different from other courses

- The goal is understanding and learning a way to approach problems
- Part 2 is concerned with the electronic properties
  - For electrons it is essential to use quantum mechanics
  - We can understand many aspects if we ignore interactions between the electrons
  - Goal - to understand why this is appropriate
- Quantum mechanics leads to marvelous properties – the vast array of electronic properties
  - We can understand many aspects from the basic theory
  - For many problems, we can understand the ideas
  - Goal - to understand the ideas independent of the details
    - Superconductivity is a marvelous example

Questions for basic understanding:

- **Why are some materials metals**
  - Easily conduct electricity for 1000's of miles
- **Other materials are insulators**
  - Effectively no conduction across a 1 micron distance
- **Is there a rigorous distinction, or just a great quantitative difference?**

- **What is a semiconductor?**
  - Very important practical issues

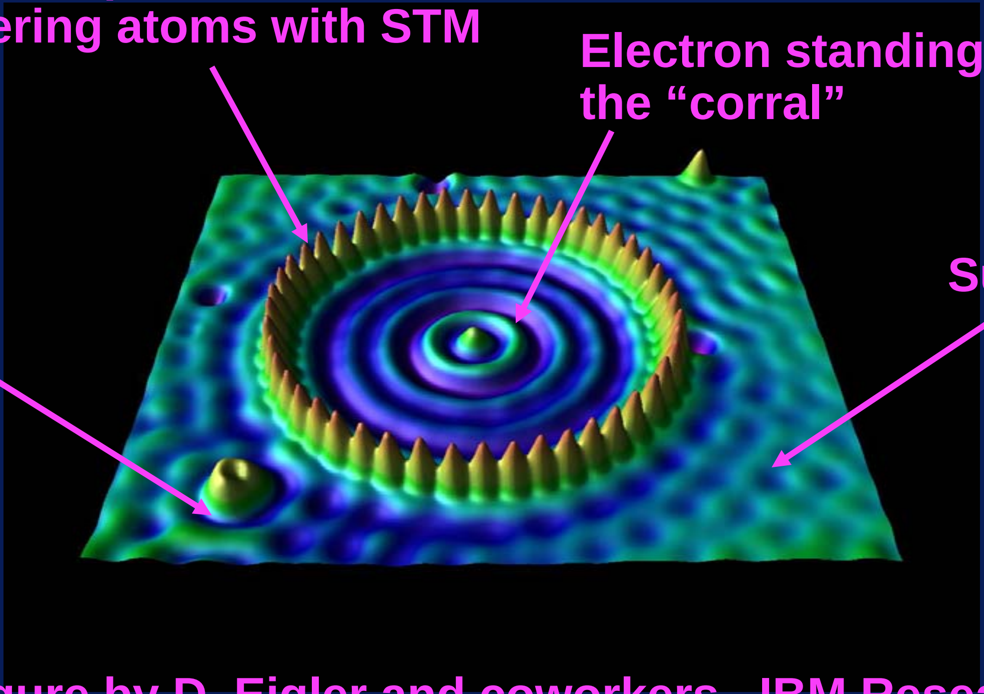
- **What is a superconductor?**
- **Is a superconductor fundamentally from a metal?**
  - A new state of matter?
  - Or only a great quantitative difference?

Example of experimental methods that are the basis of our understanding:

Scanning Tunneling Microscope observation of atoms, electron waves

Corral of atoms placed one at the time by maneuvering atoms with STM

Electron standing waves inside the "corral"



Extra atom

Surface Atoms

Figure by D. Eigler and coworkers, IBM Research

Example of experimental methods that are the basis of our understanding:

What methods can we use to see inside solids?

Maneuvering atoms?
Detect their motion?

"See" Electron waves?

See atomic defects?

Detect the positions of Atoms?

Next Lecture

- Crystal Structures
  - Ideal definitions
- Kittel Ch. 1