

SEOUL NATIONAL UNIVERSITY – SCHOOL OF PHYSICS

<http://phya.snu.ac.kr/ssphy2/>

**SPRING SEMESTER 2004**

# **Solid State Physics II**

## **Chapter 0 Overview**

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# Preface

The purpose of this lecture is to help students to understand various physical phenomena in condensed matter systems based on the fundamental physical principles. As a second part of the two-semester course on the solid state physics, we will focus on the fundamental phenomena and related physical concepts in condensed matter physics. Topics to be covered include superconductivity, magnetism, ferroelectricity, impurities and defects, and surface/interfaces. Based on the basic physics concepts discussed in the previous semester, I will try to introduce basic physical concepts and relevant physical models, which I hope help you to understand the subjects.



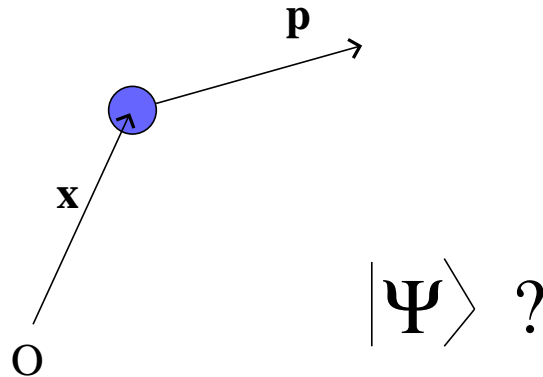
# What is all about condensed matter physics?

... How do we understand the physical properties of single particle systems in a classical or quantum sense? In other words, **what do we measure or observe?**



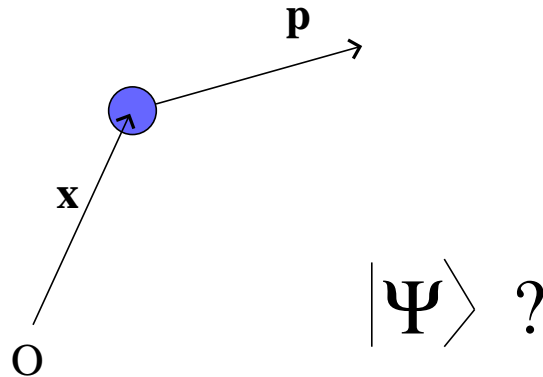
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... In classical dynamics, the state of a single particle is determined by the observables  $\{\mathbf{x}(t), \mathbf{p}(t)\}$ . It can be extended to the system with many particles where the state of the system is described by the set of observables  $\{\mathbf{x}_i(t), \mathbf{p}_i(t) | i = 1, 2, \dots, N\}$ . However, when  $N \sim 10^{25}$ , it is practically impossible to trace the orbits of all, even the part of, the particles. Here it is the point where the statistical physics comes into playing a role. Instead of following each individual particles, we measure a quantity by an (ensemble or time) average of the given quantities adopted in classical dynamics. In addition, now we have to deal with new observables such as entropy, temperature, ....

The same thing applies for the case of quantum systems. The only difference is the dynamics state of the quantum system is determined by a state vector

$|\psi(\mathbf{x}, t)\rangle$  for a single particle and  $|\Psi(\mathbf{x}_1, \mathbf{x}_2, \dots, \mathbf{x}_N, t)\rangle$ .



# Macroscopic vs. microscopic objects

- **Observables** for the macro object consisting of more than  $\sim 10^{20}$  particles:



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- **Observables** for the macro object consisting of more than  $\sim 10^{20}$  particles:
  - specific heat  $c_v$   $\longleftarrow$  entropy, temperature
  - bulk modulus or compressibility  $\kappa$   $\longleftarrow$  pressure  $P$
  - polarization  $\mathbf{P}$ , magnetization  $\mathbf{M}$   $\longleftarrow$  electro-magnetic field  $\mathbf{E}$ ,  $\mathbf{B}$
  - reflectivity, color, conductivity, ... etc.



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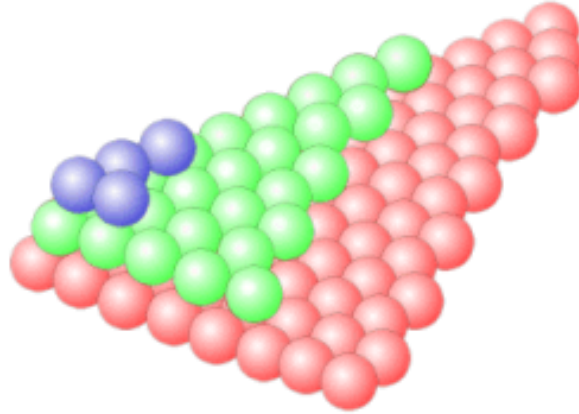
(Hint: This is the phenomenon called magnetic levitation, which is mainly attributed to the “Meisner effect” of superconductors.)



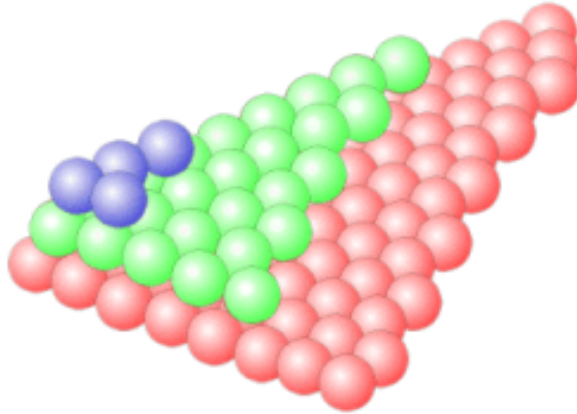
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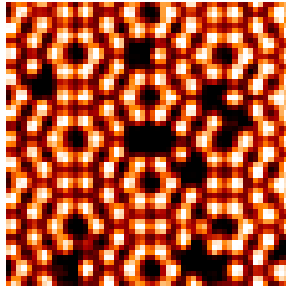
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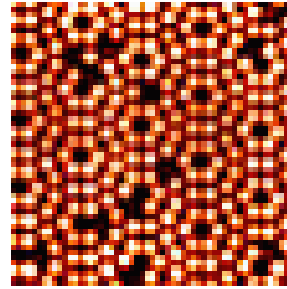
- conductance  $G$  / electron tunneling current  $I$
- force  $F$
- magnetic Flux  $\Phi$
- charge density distribution, electron cloud (bonding), ... etc.



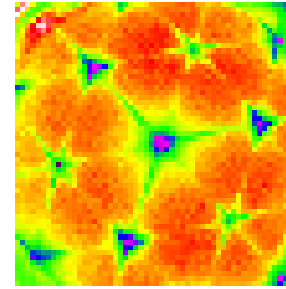
an AFM image



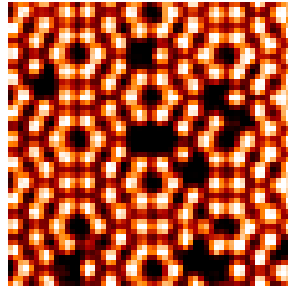
an STM image



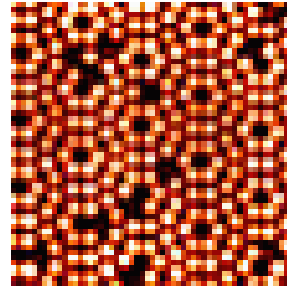
a LEED image



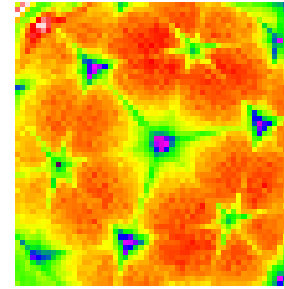
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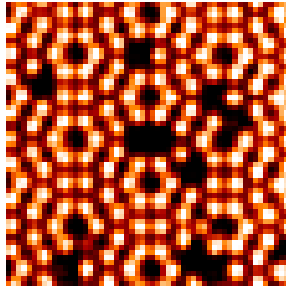


What do we really see in these images?

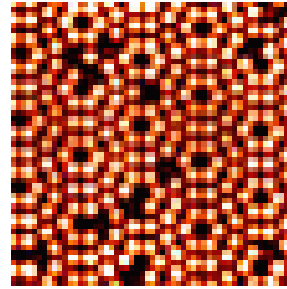
What physical quantities do they represent?



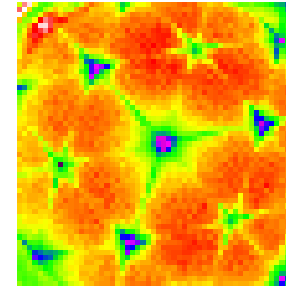
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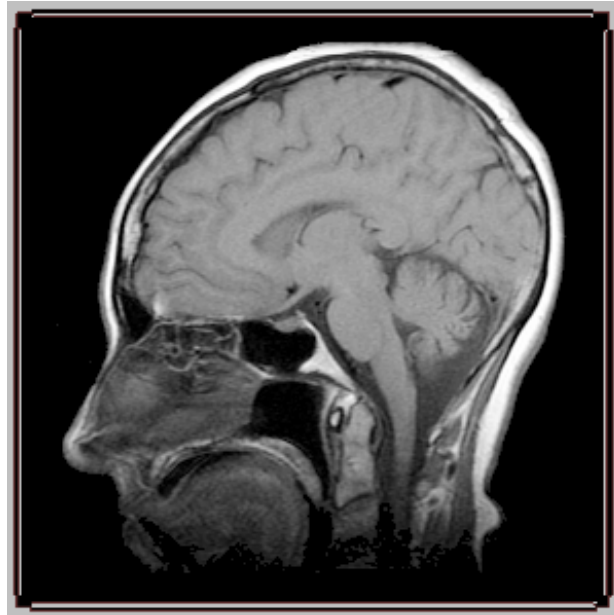


What do we really see in these images?  
What physical quantities do they represent?

An example of the SEM System:

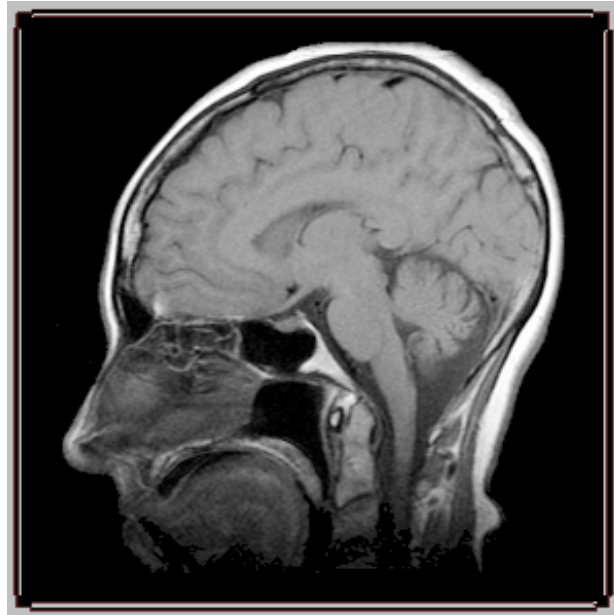


**MRI Image:** What do we really see in this image?  
What physical quantity does it represent?





**MRI Image:** What do we really see in this image?  
What physical quantity does it represent?



(This is an image of our brain probed by using the technique of the nuclear magnetic resonance.)



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$$\lambda \sim \frac{\hbar}{p} \sim d$$



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- An example of exactly solvable models:

$$\mathcal{H} = \hbar\omega\left(a^+a + \frac{1}{2}\right)$$

$$a^+a|n\rangle = n|n\rangle$$

$$a|O\rangle = 0$$



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- **How to disturb the “black box”?**



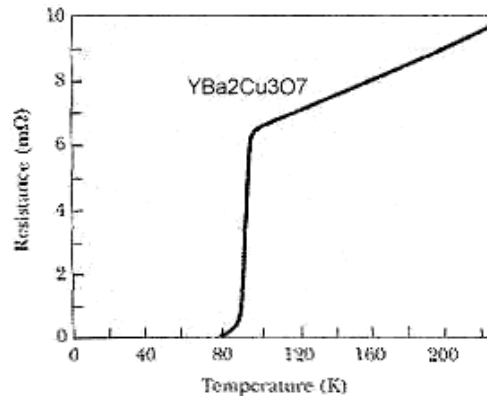


**Question:** Measuring the dc resistance is a way of disturbing the system? What really happens inside the black box when we apply a bias voltage?



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♠ Current-Voltage curve of a YBCO high  $T_c$  superconductor

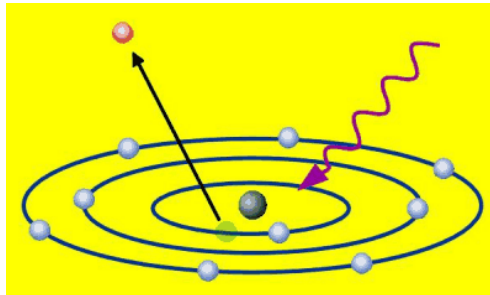


**Question:** What happens when we shine a light on the matter?



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Light scattering experiment: (Photoemission / IR spectroscopy)



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“elementary excitations in solids”



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“elementary excitations in solids”

- quasi-particles: electrons, holes, polarons, excitons, Cooper pairs, ...
- collective excitations: phonons, magnons, zero-sound, plasmons, ...



# Energy scale

The condensed matter system is merely a collection of atoms, where each atom consists of electrons and a nucleus ( $m_e \ll m_N$ ).

From the **uncertainty principle**  $\Delta x \Delta p \sim \hbar$ ,

$$\Delta p = \sqrt{2m_e E} \approx \sqrt{3mk_B T}$$

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- atomic unit:  $\hbar = e^2 = m_e = 1$

$$\Delta x \approx a_B = \frac{\hbar^2}{me^2} = 0.529177\text{\AA} \text{ (Bohr radius)}$$

$$E_B = -\frac{1}{2} \frac{e^2}{a_B} = -\frac{me^4}{2\hbar^2} = -13.6058\text{eV} = -1\text{Ry}$$

In atomic unit,  $a_B = 1$ ,  $E_B = -1/2$ ,  $c = 1/\alpha \approx 137$ ,

$k_B \approx 3 \times 10^{-6}$ , ...

( $\alpha = e^2/\hbar c$ : fine structure constant)



- energy of an electron in a box of size  $L$ :

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- electrons in solid

- Fermions: **Pauli exclusion principle**
- Degenerate Electrons: **lowest possible excitations** near the Fermi energy



# Homework #1

(due: Tuesday, 9 March 2004)

Estimate the scale in *atomic unit*:

- (a) ground state energy of an electron in a cube of length 1 nm.
- (b) energy and momentum of a photon with  $\lambda = 10^4 \text{ \AA}$ .
- (c) energy of an electron in a magnetic field of 1 T.
- (d) thermal wave length of an electron and a neutron in a thermal bath of 300 K.
- (e) Fermi energy of a degenerate electron (neutron) gas with its density  $10^{22} \text{ cm}^{-3}$  respectively.

