# Introduction to Solid State Physics

# 固体物理学

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Solid State Physics (SSP)
1940s

✓ Solid-state physics studies how the large-scale properties of solid materials result from their atomic-scale properties.

Condensed Matter Physics (CMP)
1980s

✓ The most familiar conden. phases are ***solids*** and ***liquids***

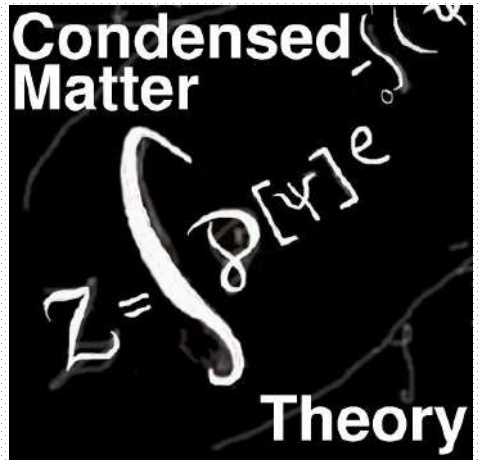
Quantum Matter and Materials
2010s

✓ More ***exotic*** condensed phases:

- superconducting phase at low T
- FM and AFM phases
- Bose-Einstein Condensate

# Condensed Matter Physics

# 凝聚态物理




理论
*Theory*

模拟
Simulation

实验
Experiments

# 凝聚态物理是当代物理学的重要分支

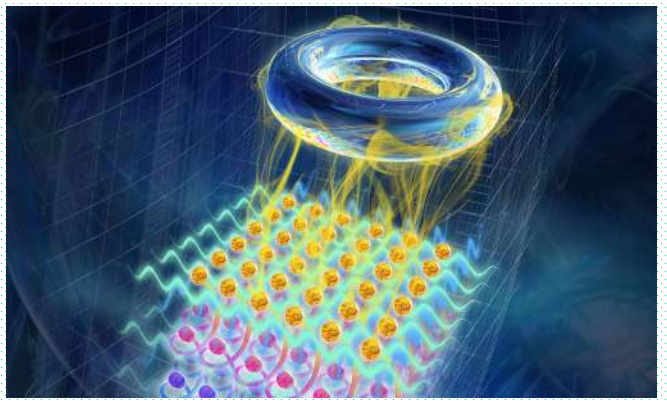
✓ 凝聚态物理学成为了目前物理学**最为活跃的领域之一**。在美国就占到该国物理学者整体的**近三分之一**，凝聚态物理学部也是美国物理学会**最大**的部门。

凝聚态物理 (Condensed Matter)

朗道十诫

**More is Different.**
-- P.W. Anderson

量子物质？
(Quantum Matter)

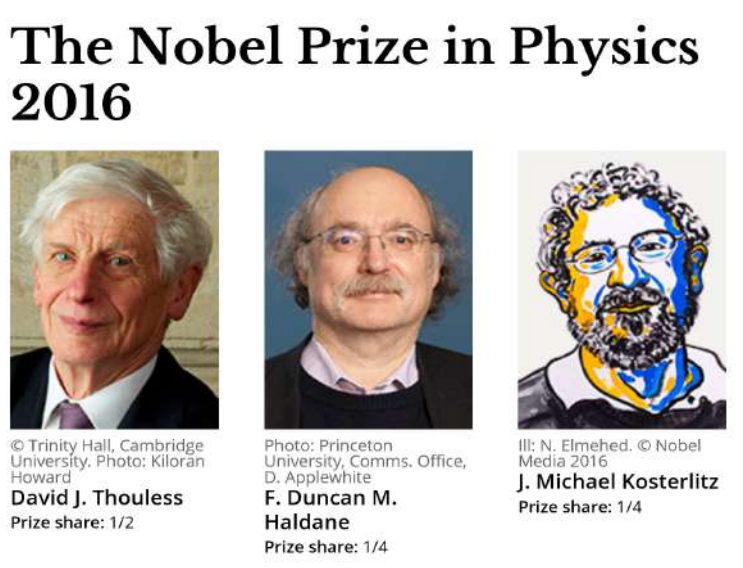


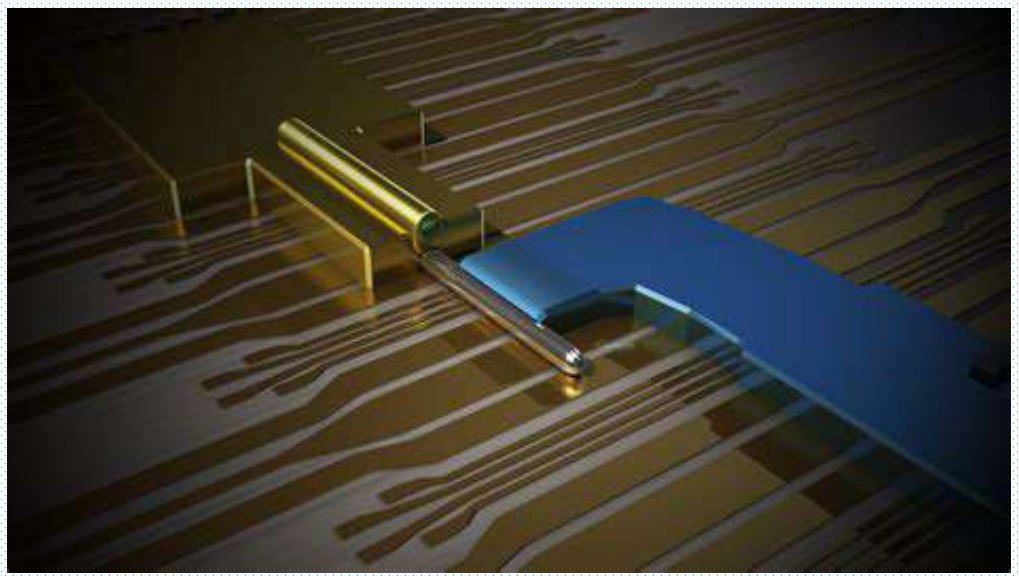
# 具有开拓的思想

- 相互作用量子多体系统是最为复杂的系统之一，相互纠缠的粒子展现出新奇的**量子物态**和**运动规律**。

拓扑序与拓扑相变

“固体宇宙”中的基本粒子

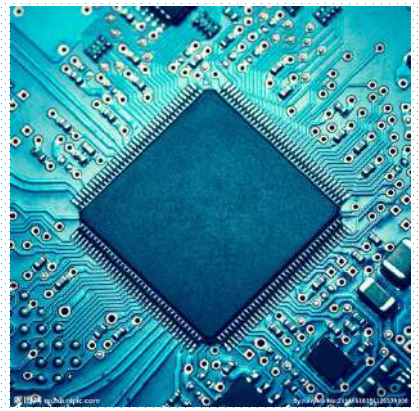


**凝聚态物理关注纷繁复杂现象中的基础和前沿问题**

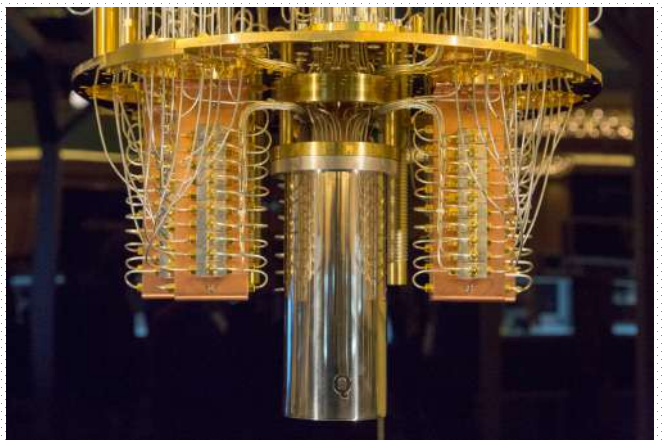
# 强大的实践能力

- 固体物理–凝聚态物理对当代工业，特别是半导体、磁性器件工业起到至关重要的作用。
- 对下一代量子计算器件开发和实用华也举足轻重。
- 面向国家重大战略需求和国计民生重大问题上发挥持续的和重要的作用.



晶体管-集成电路

巴丁

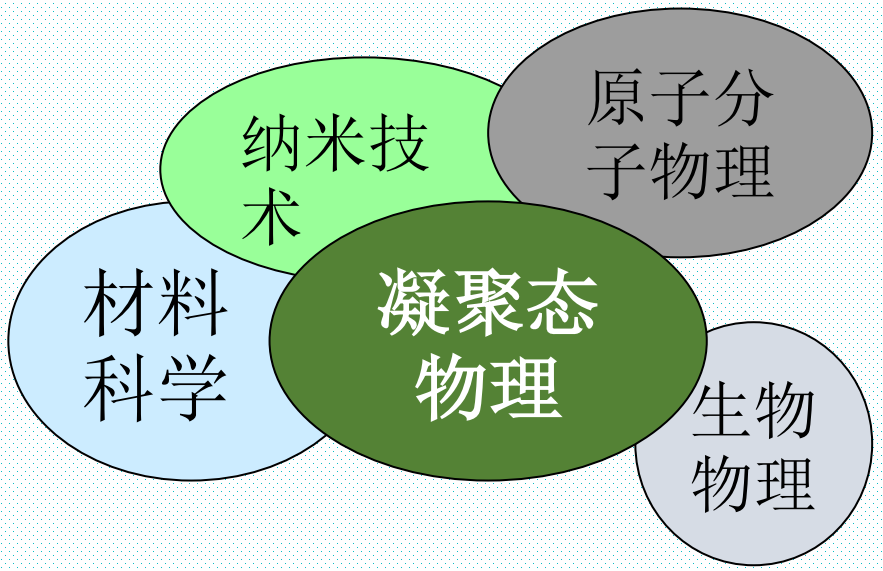


量子计算

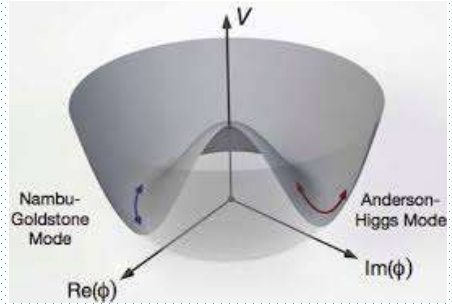
**凝聚态物理是人们认识自然的宝贵知识，同时也是人类深刻改造自然的有力工具。**

# 充满活力的凝聚态物理

✓ 凝聚态物理还与**化学，材料科学**以及**纳米技术**等学科领域交叉，并与**原子物理学**以及**生物物理学**等物理学分支紧密相关。




✓ 凝聚态理论研究中所采用的一些概念与方法也适用于**粒子物理学**及**核物理学**等领域。




Anderson-Higgs 机制

**凝聚态物理是诸多学科融合与交叉的核心地带**

QUANTUM MATTER

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

FACULTY OF PHYSICS

QUANTUM MATTER THEORY



MEMBERS

TEACHING

CONTACT

## Quantum Matter Theory


In the quantum world, systems of many particles can organize themselves into highly entangled states, whose properties transcend those of the individual constituents. Especially fascinating is the emergence of topological order, an unconventional way of quantum organization that contradicts the traditional paradigms of condensed matter physics. Topological states of matter obey emergent global rules, which are dramatically different from the fundamental laws governing the microscopic individuals. For instance, a system of bosonic or fermionic particles forming a topological state can generate excitations that are neither bosons nor fermions, but anyons with novel braiding statistics. Our understanding of how topological order emerges from the microscopic degrees of freedom is far from complete. Especially intriguing is the formation of non-Abelian topological phases, where quasiparticles with non-Abelian braiding statistics arise. Beyond their fundamental importance, non-Abelian anyons hold the promise to revolutionize quantum technology, for their topological properties could be used to encode and process information in a manner resistant to errors. In the Quantum Matter Theory group we work towards the theoretical comprehension of many-body quantum entanglement. We are especially interested in deepening our understanding of topological phases and anyons. To this aim we explore novel physical mechanisms leading to the emergence of topological order from the microscopic quantum individuals.

**Quantum Matter Links**



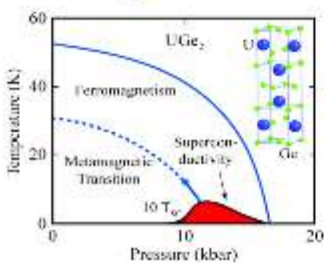
# The Shoenberg Laboratory for Quantum Matter

The Shoenberg Laboratory for Quantum Matter was formed in 2004, combining the Low Temperature Physics group (LTP) and the Interdisciplinary Research Centre in Superconductivity (IRC).

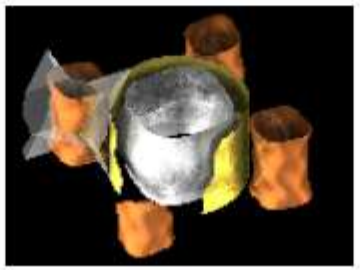
The Quantum Matter Group at the Cavendish Laboratory, University of Cambridge, studies matter under extreme conditions, i.e., at very low temperatures, high magnetic fields and high pressure using advanced experimental techniques. The goal of this research is to understand new forms of magnetism and superconductivity and to find electrically conducting materials with new physical properties not described within the standard models of solid state physics. Some of the recent discoveries of the group are finding applications in the fields of refrigeration and detector technology.

The group is a beneficiary of funding from a wide array of national and international funding bodies. These include EPSRC, the Royal Society, the COST ECOM P16 network, ICAM, KAIST as well as several Cambridge colleges.

**Exotic States of Matter on the Edge of Magnetism**



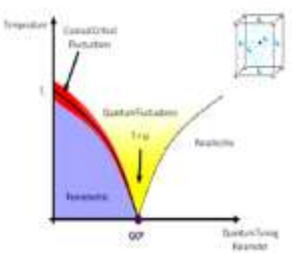

**Electronic Structure of Correlated Materials**



**Novel Superconductors**

**High-$T_c$ Superconductors**

**Quantum Ferroelectrics**



# Classification of States of Matter

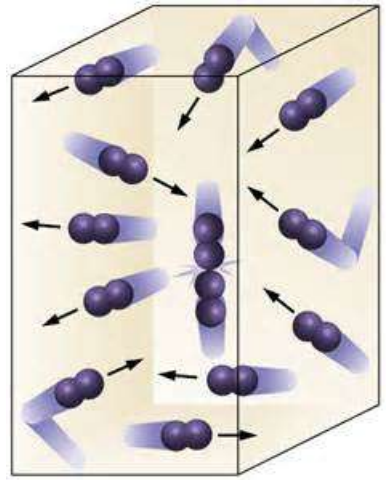
- **Two Answers:**

➢ (1) The materials have 3 (or 4 states): solid, liquid and gases and possibly plasma. But the solid exists in two forms: crystalline (metal, quartz, etc), amorphous (glasses).

quartz

glass

liquid



gas

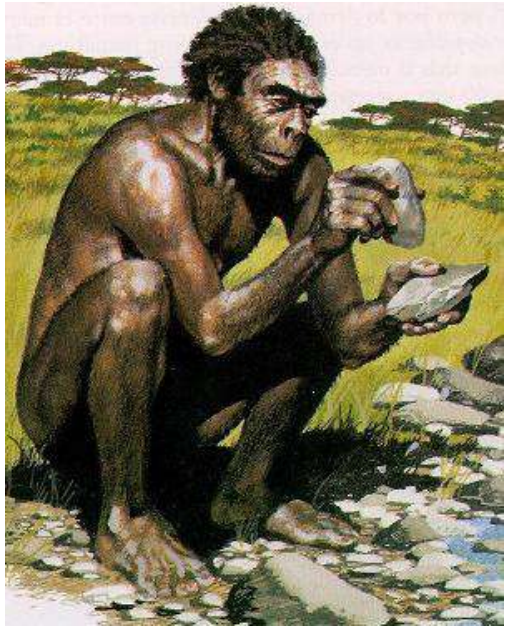
➢ (2) The materials have 2 states: **condensed matter** (liquid and solid), and the **diluted matter**: gases and plasmas.

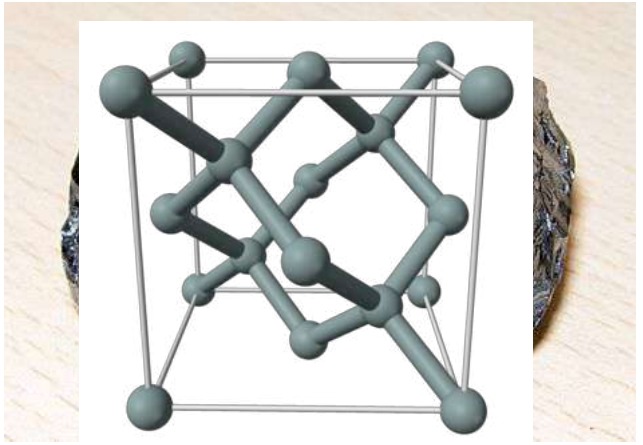
# Why Solid State Physics: The history of materials

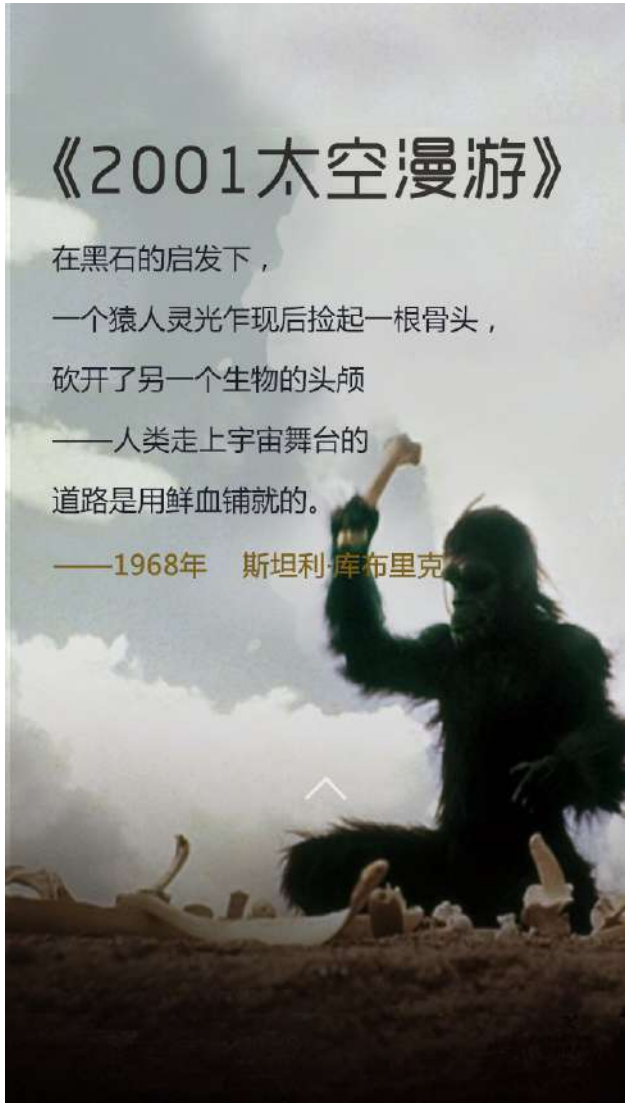
This is the story of humanity

- The Stone Age, 3E6-2000 BC
- The Bronze Age, 2000–300 BC
- The Iron Age, 500 BC–AD 300

- ✓ The age of electronics (silicon)
- ✓ Next: spintronics?...







# Solid state physics or materials physics?

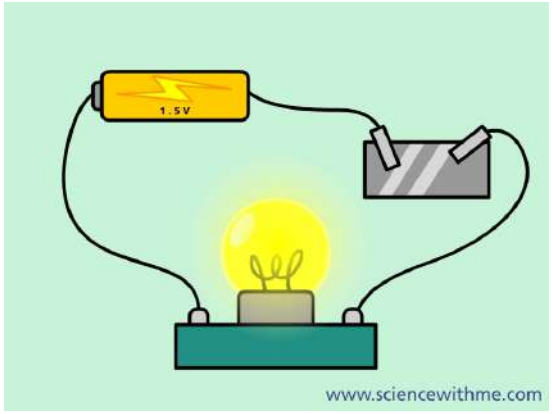
- **Solid State Physics**: the **theoretical framework** for understanding materials, focus on **microstructures** and **properties**. This is the work of «Scientist».

- **Materials Physics**: focus on the **discription** and **performance** of materials for **applications**. Usually associated with the industrial applications of solids, like metals and semiconductors, etc. This is the work of «Engineer».

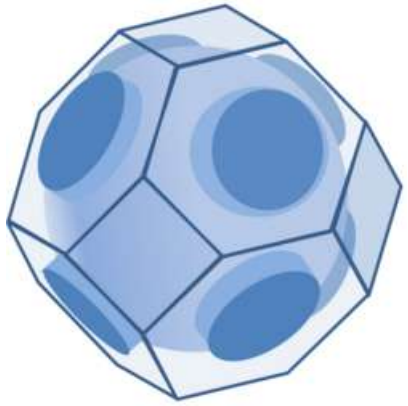
➢ **This course is a solid physics course for Scientists.**

# The objective of the solid state physics

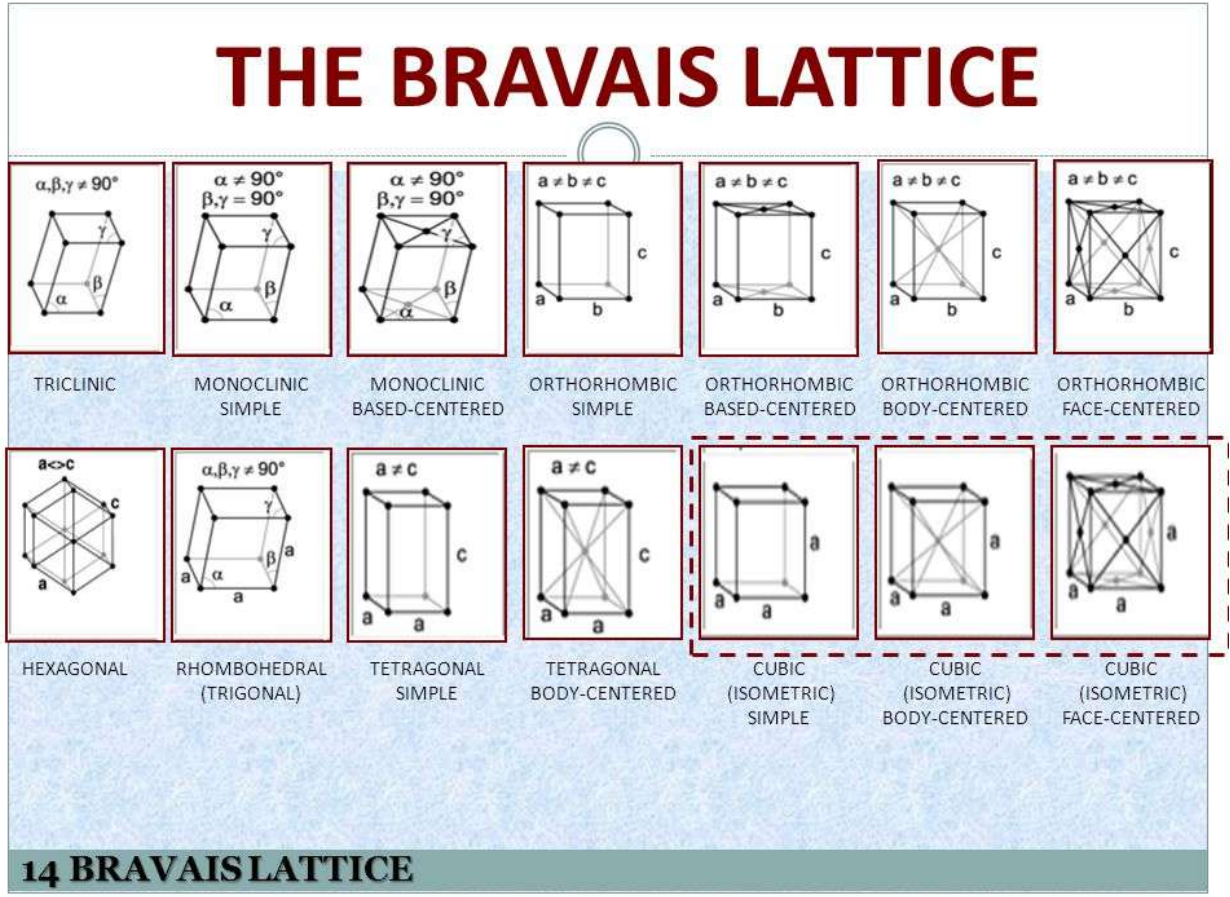
- Explain how atoms group are organized to form solid.
- How to explain the diversity of their physical properties (*mechanical*, *electromagnetic*, *thermal*, etc.) with a unified model .




Why metals conduct electricity



Fermi Surface



# Solid State Physics: Some Preliminaries/Features

- Descriptive & Analytical
  - ✓ *Some descriptions of details in vast range of solids*
  - ✓ *Basic theory of solids*
- Statistical mechanics & Quantum (Field) Theory
  - ✓ *Lie in the heart of solid state physics*
- One picture is worth a thousand words

# Course Overview

- What is solid state/condensed matter physics?

✓ Solid-state physics is the study of **rigid matter**, or **solids**, through methods such as *quantum mechanics*, *crystallography*, *electromagnetism*, and *metallurgy*. It is the **largest** branch of condensed matter physics.

✓ **Theory of Everything:** quantum many-body problem!

✓ Topi n, etc., were ouped toget

✓ Arou sis of **cond**

$$\mathcal{H} = -\sum_{j}^{N_e} \frac{\hbar^2}{2m} \nabla_j^2 - \sum_{\alpha}^{N_i} \frac{\hbar^2}{2M_\alpha} \nabla_\alpha^2 - \sum_{j}^{N_e} \sum_{\alpha}^{N_i} \frac{Z_\alpha e^2}{|\vec{r}_j - \vec{R}_\alpha|} + \sum_{j \ll k}^{N_e} \frac{e^2}{|\vec{r}_j - \vec{r}_k|} + \sum_{\alpha \ll \beta}^{N_j} \frac{Z_\alpha Z_\beta e^2}{|\vec{R}_\alpha - \vec{r}_\beta|}.$$

# The model of solid state physics

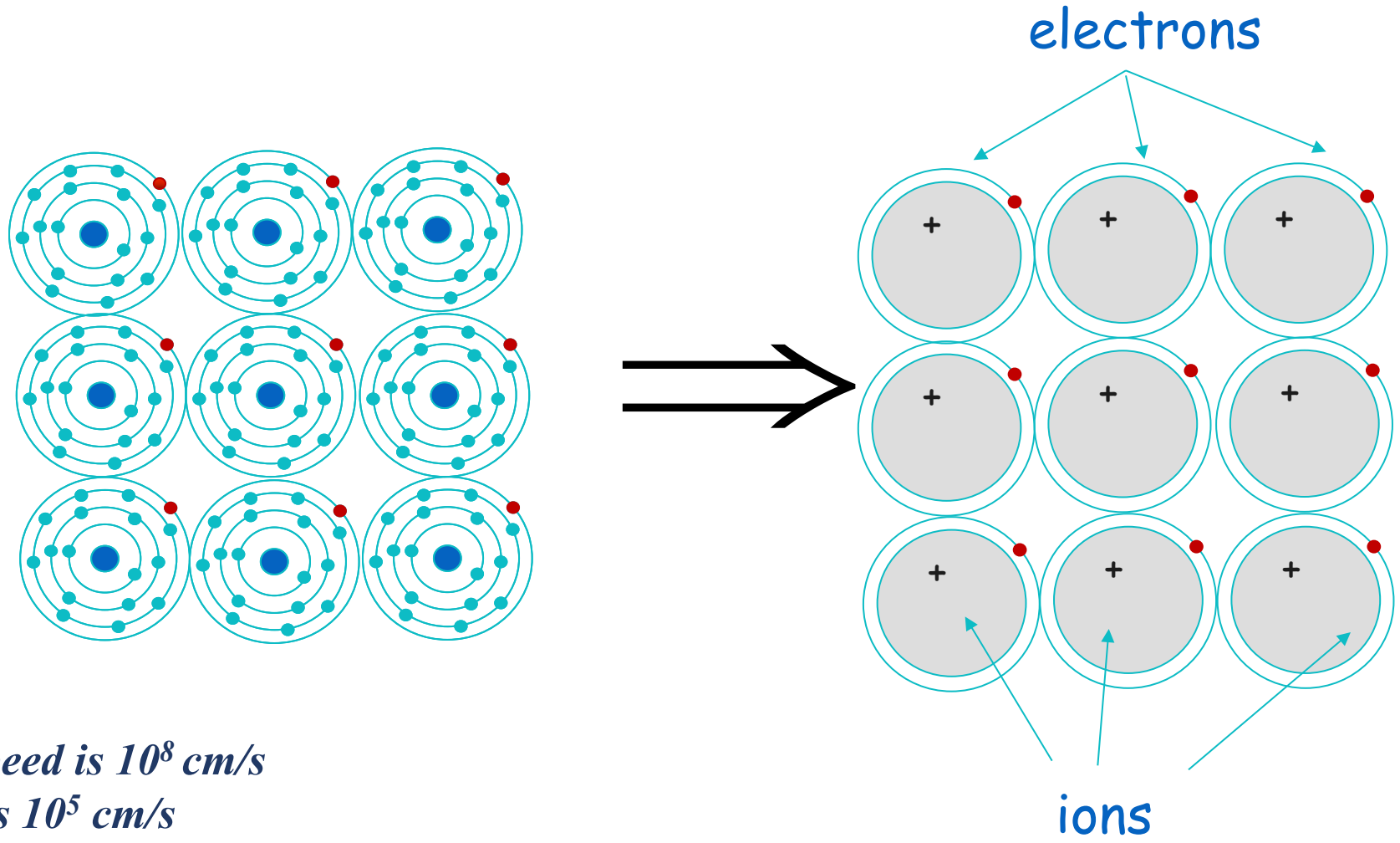
Two founding principles: simplify and decompose into independent sets.

- simplified model: a perfect crystal.

- separate the crystal into two sets

  - ✓ the outer electrons
  - ✓ lattice ions

# Adiabatic approximation (Born-Oppenheimer)




*Electron's speed is $10^8$ cm/s*
*Ion's speed is $10^5$ cm/s*

The solid is a periodic array of ions in a "gas" of electrons.

# Main Contents (6 chapters)

- Crystal lattices, Diffraction
- Cohesion of solids, Mechanical properties
- Crystal dynamics, Thermal properties
- Electron theory of metals
- Electronic band structure

} Electromagnetic properties

- Point defects and dislocation

● 固体物理课:

环节：大课, 讨论课, 小制作, 小论文, 作业, 考试 。

■大课:

学会作笔记（思路、要点、特色）.

主要参考书：*Introduction to Solid State Physics*, 8th edition, C. Kittel, John Wiley & Sons

■问题分析讨论课:

随堂、习题讨论课，主要解决重要概念、解题方法、技巧方面的问题, 问题研究, 作业中出现的问题，章节小结.

■作业:

每周交作业，占总评成绩20% 。

■考试与总评：随堂测验（15%）、大型实验观摩与考察(5%)、小论文等其他环节（10%）、期末统考（50%）.

# 其它参考书


[1] 固体物理导论，(美)基泰尔著

[2] 陆栋 蒋平《固体物理学》，高等教育出版社

[3] 固体物理基础，阎守胜，北大出版社

[4] 固体物理学，胡安，章维益, 高教出版 05.6 版

[5] 固体物理学，黄昆原著，韩汝琦改编，高教版

[6] 固体物理学，方俊鑫，上海科学技术出版社

[7] 固体物理学基础，(美)奥默尔著，北师大

[8] 固体物理简明教程，蒋平，复旦大学出版社

[9] 固体物理学习题指导, 刘友之等, 高教出版社

[10] Solid state physics, Aschcroft & Mermin.