Introduction to Solid State Physics

固体物理学

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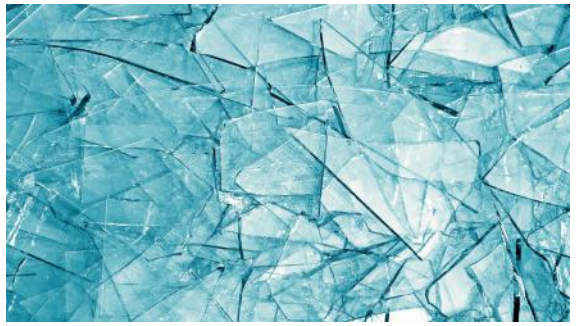
Classification of States of Matter

- **Two Answers:**

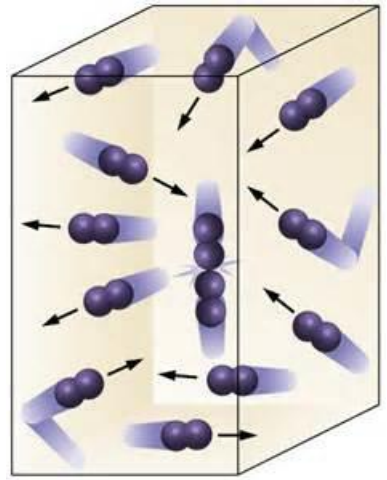
➢ (1) The materials have 3 (or 4 states): solid, liquid and gases and possibly plasma. But the solid exists in two forms: crystalline (metal, quartz, etc), amorphous (glasses).

quartz



glass

liquid



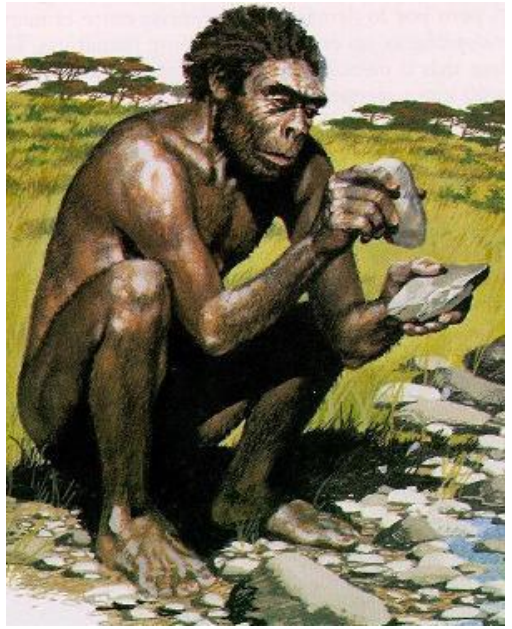
gas

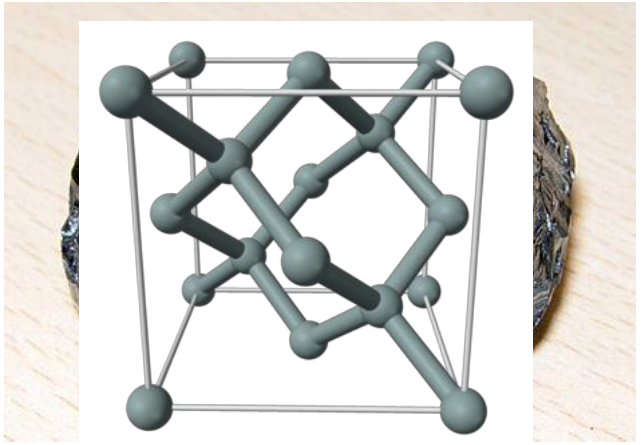
➢ (2) The materials have 2 states: **condensed matter** (liquid and solid), and the **diluted matter**: gases and plasmas.

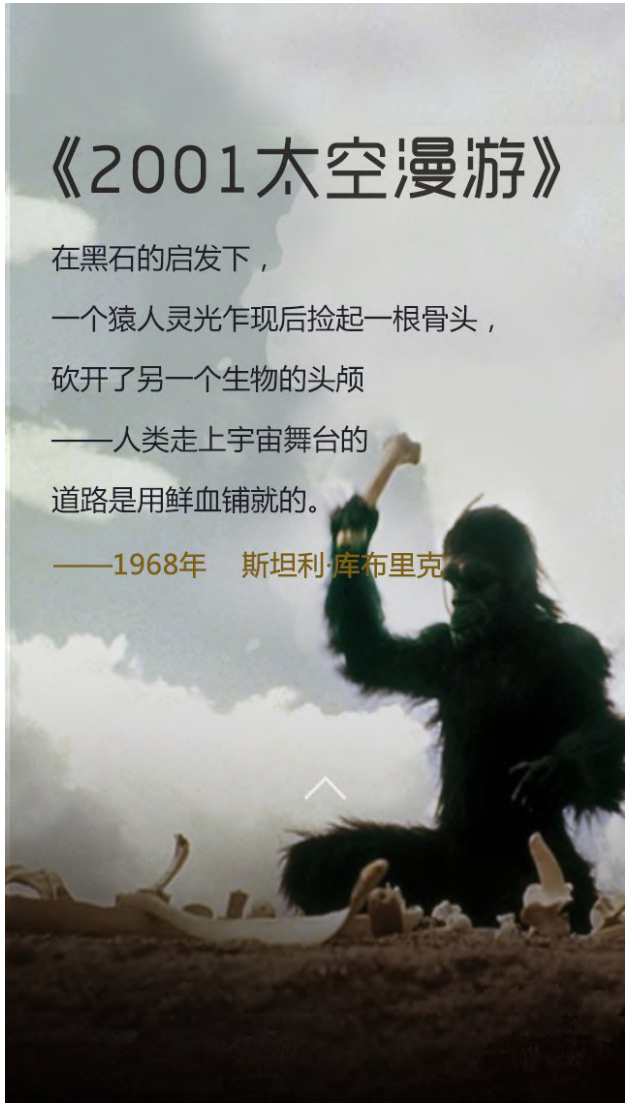
Why Solid State Physics: The history of materials

Story of humanity: *solid state materials*

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





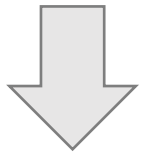


- ✓ The age of electronics (silicon)
- ✓ Next: spintronics?...

Evolution of Solid State Physics: the **past** and **future**

Solid State Physics (SSP)
1940s

Condensed Matter Physics (CMP)
1980s



Quantum Matter and Materials
2010s

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

- ✓ The most familiar conden. phases are ***solids*** and ***liquids***
- ✓ Quantum physics + Statistical mechanics

- ✓ ***Exotic*** quantum effects:
- superconducting phase at low T
- FM and AFM phases
- Bose-Einstein Condensate

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

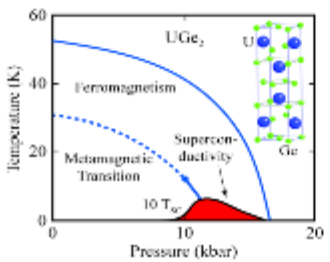
The Shoenberg Laboratory for Quantum Matter

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).

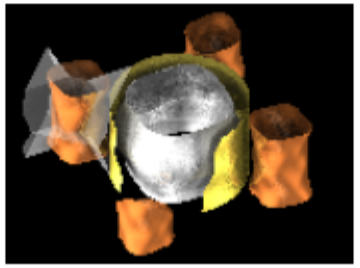
The Quantum Matter Group at the Cavendish Laboratory, University of Cambridge, studies matter under extreme conditions, i.e., at very low temperatures, high magnetic fields and high pressure using advanced experimental techniques. The goal of this research is to understand new forms of magnetism and 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.

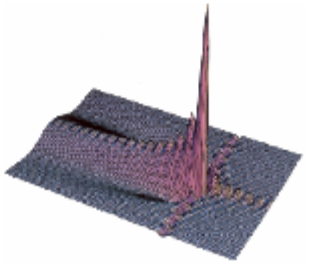
Exotic States of Matter on the Edge of Magnetism



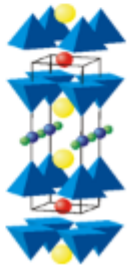
Electronic Structure of Correlated Materials



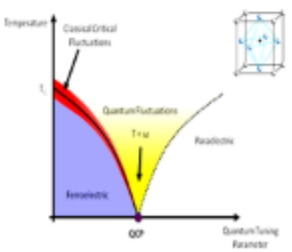
Novel Superconductors



High-T_c Superconductors



Quantum Ferroelectrics



Solid State/Condensed Matter Physics

固体/凝聚态物理

理论

Theory

模拟

Simulation

实验

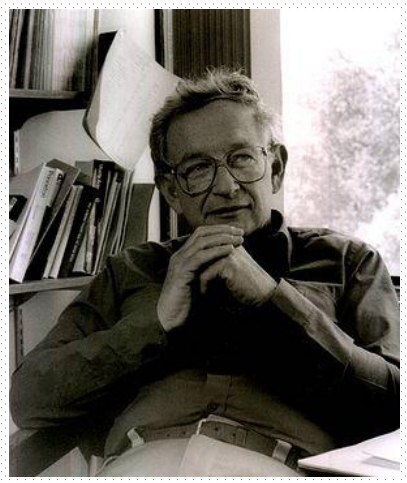
Experiments

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。

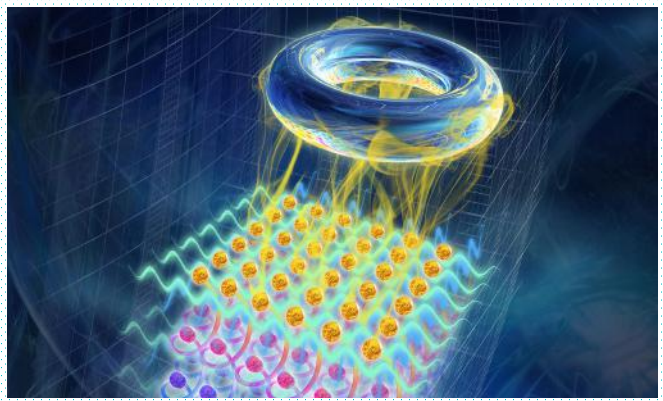
凝聚态物理 (Condensed Matter)

朗道十诫



More is Different.
-- P.W. Anderson

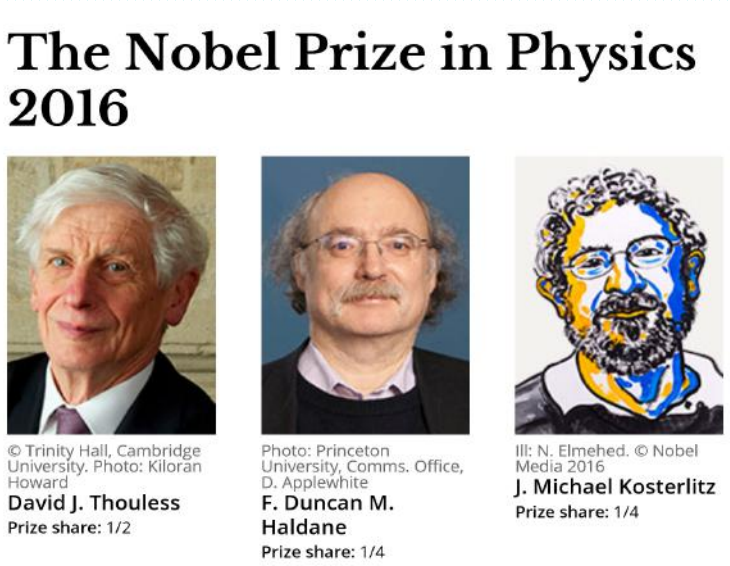
量子物质？
(Quantum Matter)



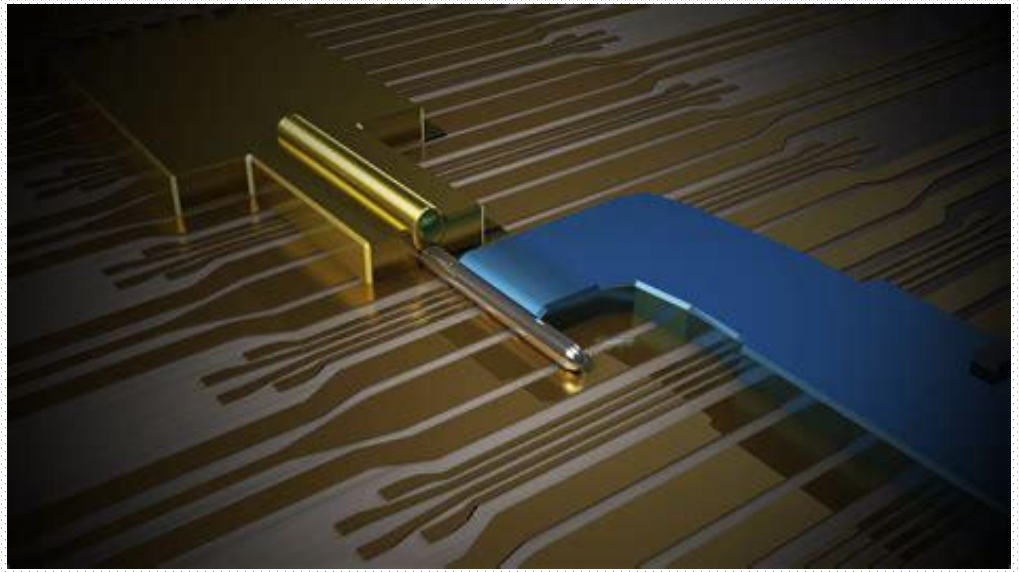
具有开拓的思想

- 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



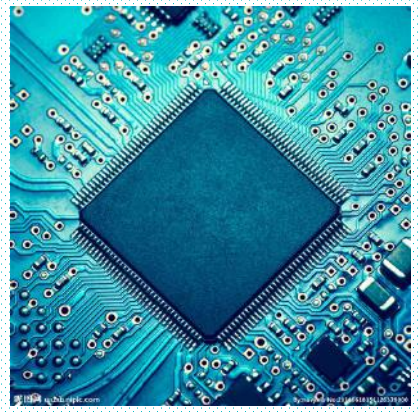
“固体宇宙”中的基本粒子



凝聚态物理关注纷繁复杂的固体世界中涌现出的新奇现象和简洁规律

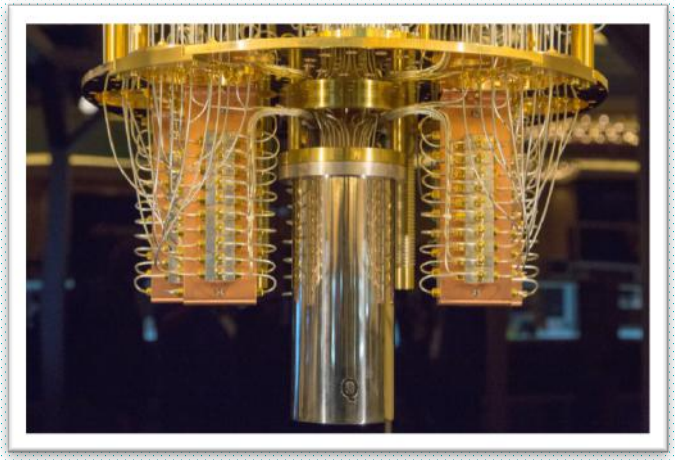
强大的实践能力

- 固体/凝聚态物理对当代工业，特别是半导体、磁性器件工业的诞生、发展，起到至关重要的作用。
- 对下一代量子计算器件开发和实用化也起着关键作用。
- 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

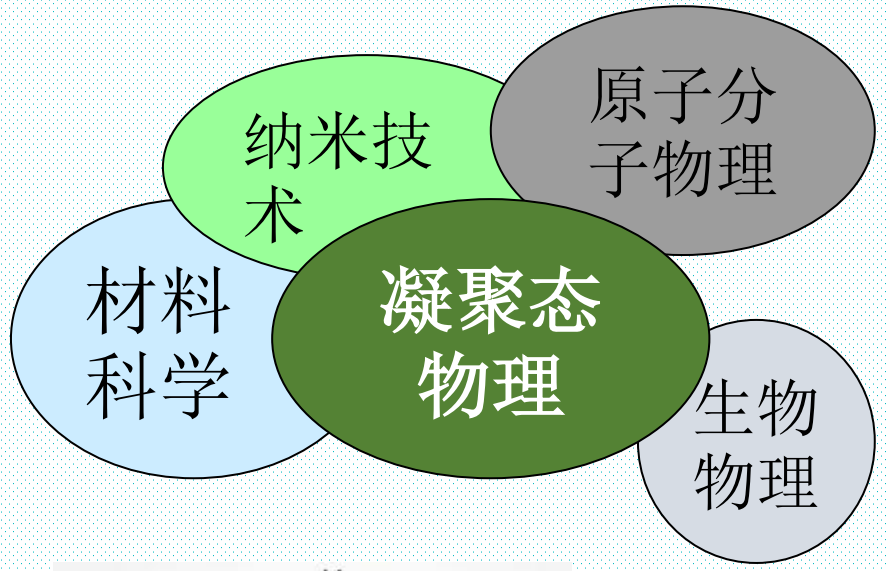


量子计算

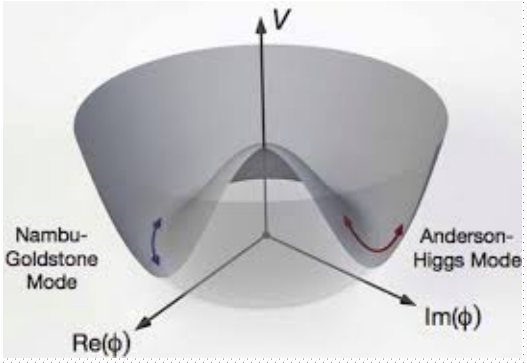
凝聚态物理是认识自然的宝贵知识，也是深刻改造自然的有力工具。

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

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.**

Theory of Everything

- 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

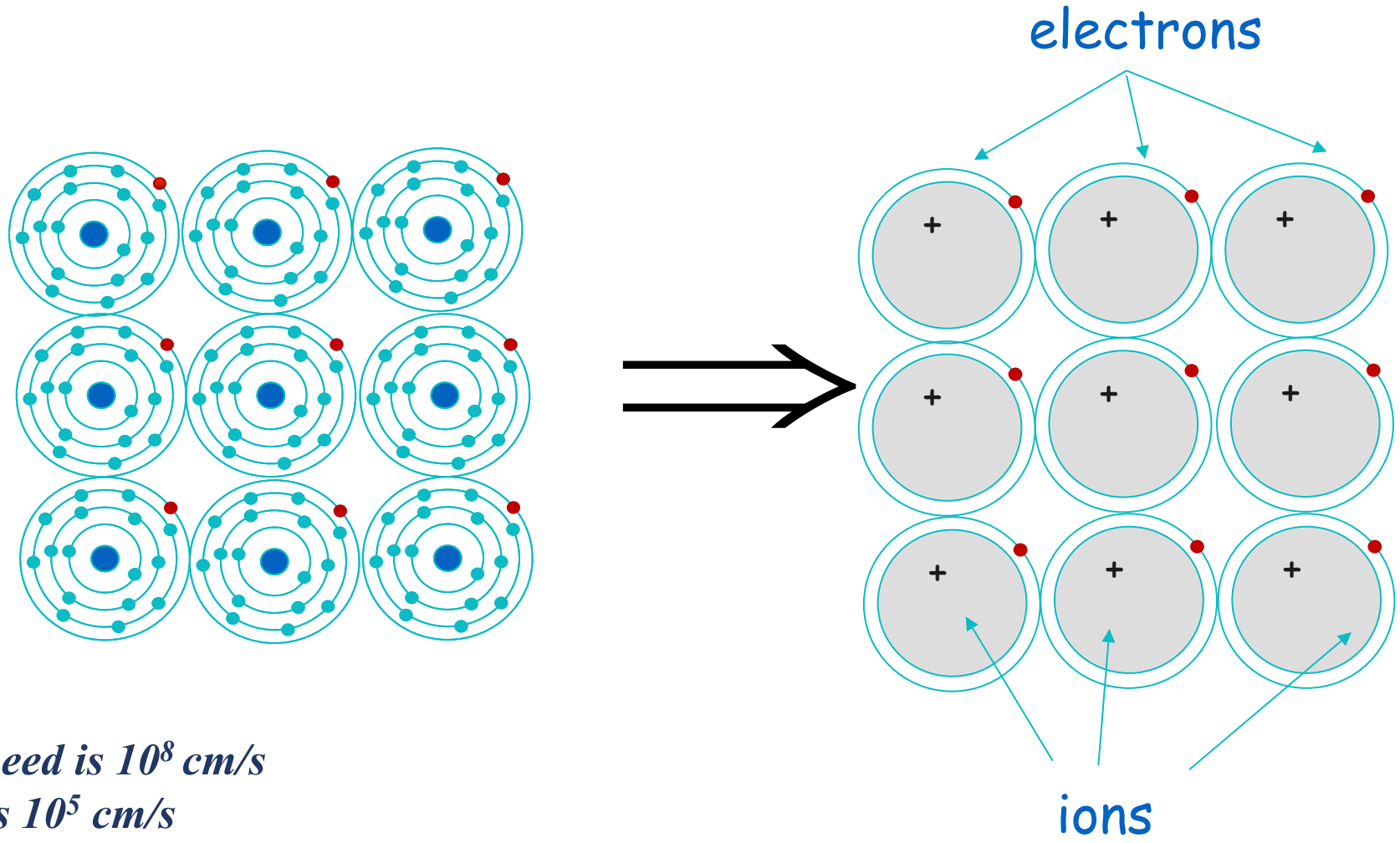
Two founding principles: simplify and decompose into independent sets.

- ❑ simplified model: a perfect crystal.

- ❑ separate the crystal into two sets

  - ✓ Lattice ions
  - ✓ Outer electrons moving in a electric potential due to lattice ions

Adiabatic approximation (Born-Oppenheimer)

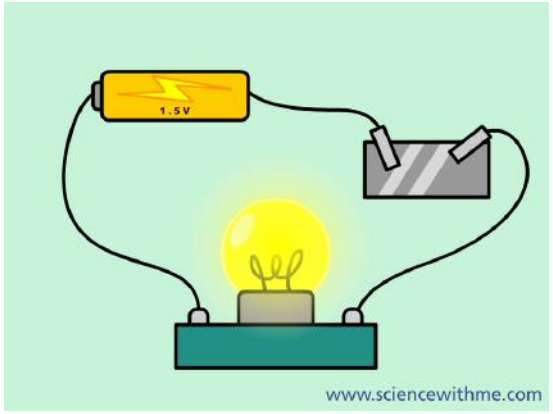


Electron's speed is 10^8 cm/s
Ion's speed is 10^5 cm/s

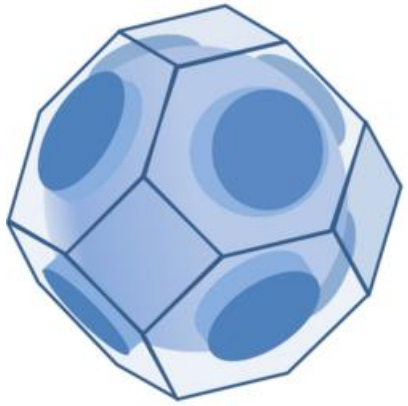
The solid is a periodic array of ions in a "gas" of electrons.

The objective of the solid state physics

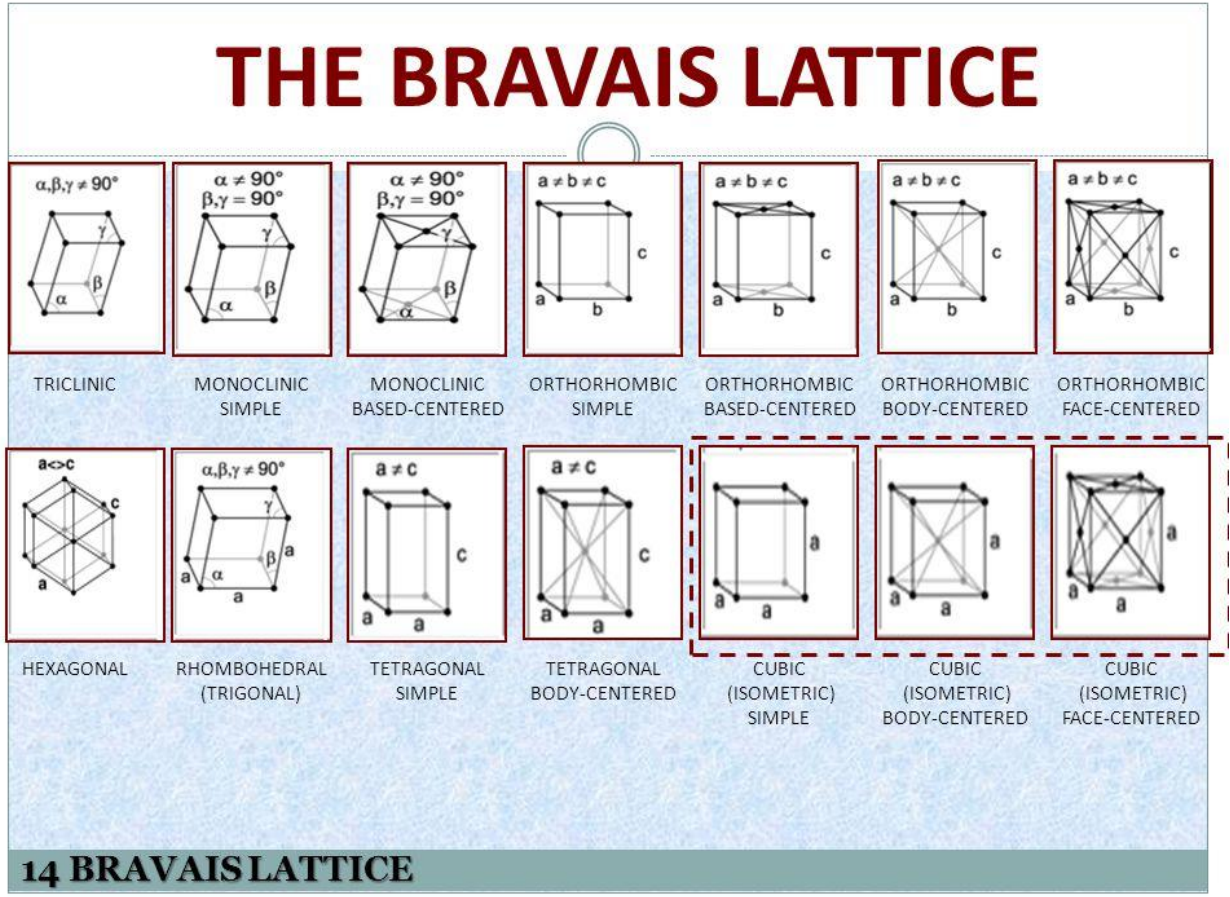
- Explain how atoms group are organized to form solid.
- How to explain the diversity of their physical properties (*mechanical*, *electromagnetic*, *thermal*, etc.) with a unified model .



Why metals conduct electricity



Fermi Surface



Syllabus

Chapter 0: Introduction [2 hours]
Chapter 1: Crystal Structures [6 hours]
Chapter 2: X-Ray Diffraction [4 hours]
Chapter 3: Crystal Binding [6 hours]
Chapter 4 Defects in Crystals [2 hours]
Chapter 5 Harmonic Crystal [14 hours]
Chapter 6 Metals [12 hours]
Chapter 7 Band Theory I [12 hours]
Chapter 8 Band Theory II [4 hours]
Chapter 9 Magnetism and Superconductivity [2 hours]

❖ 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）

■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，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%）.

参考书

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[1] Introduction to Solid State Phyics, Kittel

[2] 陆栋 蒋平《固体物理学》，高等教育出版社

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[9] 固体物理学习题指导, 刘友之等, 高教出版社