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The Penetration of Scientific Frontier in Solid State Physics Teaching

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Abstract
Solid State Physics is a core course in undergraduate physics education and its content is closely linked to the frontiers of research in condensed matter physics. The introduction of appropriate scientific frontier advances in teaching can broaden students' academic horizons and motivate them to study in depth and engage in research. In this study, we combine the teaching content in solid state physics and integrate cutting-edge scientific research into the teaching of solid state physics, to provide a theoretical reference for future physics courses that can be high order, innovative and challenging.

Key words: Solid state physics; Solid state physics teaching; Scientific frontier

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INTRODUCTION

Solid State Physics is the study of the structure of solids and the interactions and patterns between their constituent ions (atoms, ions, electrons, etc.) which can explain their properties and uses. Solid state physics studies the physical characteristics of solids (such as optical, electrical, magnetic, thermal and elastic properties) according to the fundamental laws of physics, and it emphasizes how physical properties are interconnected with electronic structures. Solid state physics is rich in content and has a wide range of applications, it is closely related to the disciplines of general physics, thermodynamics and statistical physics, atomic physics and quantum mechanics, and is the basis for technical disciplines such as microelectronics, optoelectronics, energy and materials science. With the rapid development of solid state physics and the emergence of new phenomena and concepts, in teaching solid state physics students need to grasp not only the basic concepts and fundamental theories of solid state physics, but also the research results that include the frontiers of science and technology relevant to the course.

Solid state physics is closely linked to condensed matter physics and new materials science, which are among the most active today. For that reason, the selective introduction of recent advances and applications in these fields into the classroom will contribute to increase students' motivation and clarify their efforts in the course. At the same time, it also makes classroom teaching more dynamic. To capture the vitality of classroom teaching, it is most important to be able to teach in a way that allows students to feel strongly the pulse and momentum of scientific development.

This study discusses in detail how the content of the frontiers of science permeates the teaching practice of the solid state physics curriculum in the following ways By fusion cutting-edge knowledge and the knowledge base reasonably, make the students to understand scientific research sources and the accumulation of basic knowledge and learning, to let students to the basic concept of solid state physics and the understanding of the basic theory of more specific, so as to stimulate the students' learning enthusiasm and interest, broaden the students' field of vision, improve the students' scientific literacy and research potential.

1. CRYSTAL STRUCTURE

The structure of crystals is the basis of the entire solid state physics course. Periodicity is the most important characteristic of the crystal lattice. Crystal lattices are divided into two categories: simple lattices and complex lattices, with complex lattices being one of the most difficult to teach. In recent years, popular two-dimensional materials corresponding to two-dimensional lattices can be used as examples for teaching complex crystal lattices. The lattice structure of graphene is shown in Figure 1. Two adjacent atoms are represented by A and B. From atom A, the three surrounding adjacent B atoms form an orthotriangle, and from atom B, the three surrounding adjacent A atoms form an inverted triangle. Therefore, the geometrical environment in which two adjacent atoms are located is different. The lattice of graphene belongs to the complex lattice, which is formed by the interpenetration of two sublattices A and B. Its primary cell and basis vectors a1 and a2 are shown in Figure 1, and the lattice constant is"a". The two-dimensional Brava lattice $\boldsymbol{R}=l_1\boldsymbol{a}_1+l_2\boldsymbol{a}_2$ (*l*1, *l*2 are integers) can be obtained from a1, a2. The graphene complex lattice can be viewed as consisting of a two-dimensional Brava lattice + primitives, with the primitives containing one each of unequal A and B atoms and τ being the relative displacement between them. For two-dimensional hexagonal boron nitride (BN) materials, it has the same Brava lattice as graphene, the difference being that the two sub-lattices A and B are composed of B and N atoms respectively, and a set of B and N atoms make up the atoms. For a typical two-dimensional monolayer transition metal sulphide (e.g. MoS2), it still has the same Brava lattice as graphene, with the difference that the primitive element is composed of one Mo atom and two S atoms. A significant proportion of two-dimensional materials are hexagonally dense structures with the same Brava lattice as graphene, differing only in the relative positions of the primitives and the atoms within the primitives. Therefore, teaching crystal structure using two-dimensional materials as examples can provide students with a better understanding of the concept of complex lattices and the crystal structure of some new two-dimensional materials in order to significantly improve teaching effectiveness.

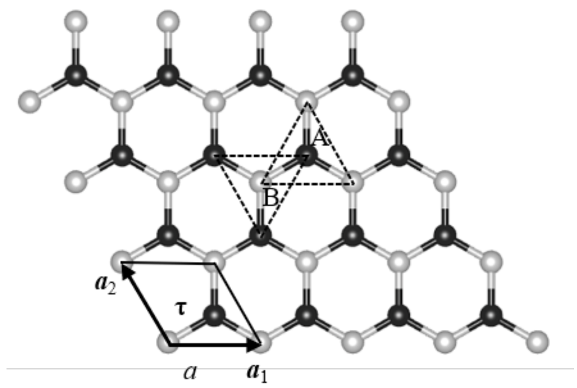

Figure 1
The crystal structure of graphene.

2. SOLID BONDING METHODS

Discrete atoms (ions, molecules) rely on certain interactions between them to bond into a solid, and the different bonding methods affect the physical properties of the solid. As a matter of fact, two or more forms of bonding combined into a solid. As an extension, students were able to deepen their understanding of how solids are bound by analysing the binding modes in the well-known photovoltaic material organic-inorganic hybrid chalcogenide ABX3 (where A is an organic cation, B is a divalent metal and X is a halogen group element). The metal halide framework BX3- contains two types of bonding: covalent and ionic bonding, and the chemical bonding between Pb and I determines the band gap and energy band dispersion in the material. For CH3NH3PbI3 (the structure is shown in Figure 2.) , its electronic energy band structure is composed of the 6s26p0 of Pb and the 5p6 electronic state of I[1]. In this, the upper valence band consists of the p-orbitals of I and the lower conduction band consists of the unoccupied p-orbitals of I. The organic cation $CH_3NH_3^+$ forms hydrogen bonds with the surrounding halogen atoms[2-3], and the enhanced hydrogen bonds freeze the rotation of the $CH_3NH_3^+$ cation and alter the surrounding PbI6 octahedra, which in turn affects the optoelectronic properties of $CH_3NH_3PbI_3$ (e.g. carrier lifetime and diffusion length, etc.)[4].

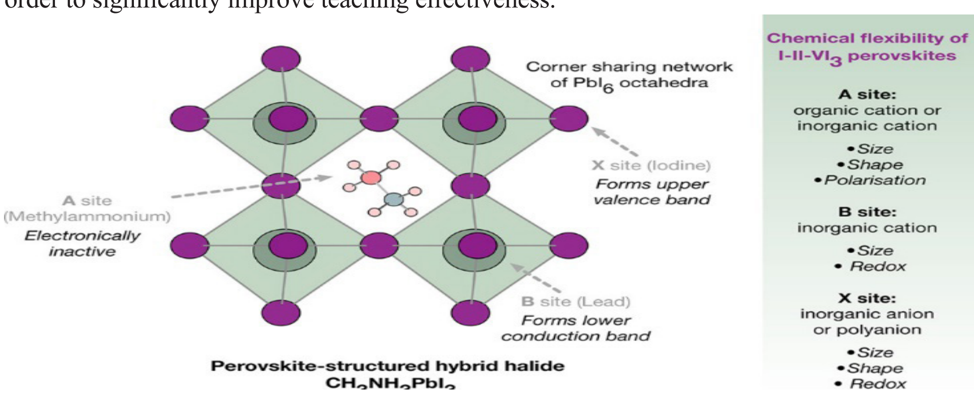

Figure 2
Schematic of the perovskite crystal structure with respect to the A, B, and X lattice sites.[1]

In the organic-inorganic hybrid chalcogenide material ABX3, the greater the difference in the negative charge of the metallic element B and the halogenated element X, the stronger the ionic bonding properties, the less dispersion of the electron cloud along the bond and the closer it can get to the nucleus, resulting in shorter bond lengths and higher band gaps with less dispersion of the electron energy band structure near the band edge. The dependence of the band gap on the negative charge of the cations and anions has been reported in chalcogenide materials5-6. This dependence stems from the ionic and covalent nature of the chemical bond, which in turn affects the bond length and electron localisation of the bond7. Taking CH3NH3PbI3 as an example, the teaching of solid-state combination mode enables students to have a concrete and vivid understanding of the relationship between the combination mode of materials and the performance, and at the same time, it is easy to stimulate students' thinking and exploration of functional materials such as CH3NH3PbI3.

3. ENERGY BAND THEORY

Band theory is one of the important achievements in the development of solid state physics. When we talk about band theory, we stick closely to Bloch's theorem, based on the energy band characteristics of electron motion in the one-dimensional periodic potential field and the essential difference of electron filling in the energy band structures of conductors, insulators and semiconductors, this paper introduces practical cases at the frontier of science to explain in detail that changing the energy band structure can realize the transition between conductors, semiconductors and insulators.

At normal temperature and pressure, CH3NH3PbI3 is a semiconductor material with a band gap of 1.5eV8. Under the action of pressure, with the increase of pressure to 62GPa, the band of CH3NH3PbI3 will overlap and change into metallized properties. However, CH3NH3PbI3 has changed from a semiconductor to a conductor9. At room temperature and pressure, Na is a metallic material. The experimental results show that when the pressure reaches 200GPa, the band of Na expands to 1.3eV. Na changes from a conductor to an insulator10. Under high temperature and pressure conditions, when the pressure is >150GPa and the temperature is >3000K, H2 shows similar characteristics to metal. In the process of heating and pressurizing H2, three states appear: insulator liquid hydrogen, semiconductor liquid hydrogen and metal liquid hydrogen. By heating and pressurizing the method, H2 can realize the transformation from insulator to semiconductor and then to conductor.

Through the above scientific frontier actual cases to prove: change the band structure can achieve transformation between insulators and conductors, semiconductors, and at the same time also can cause the student to the band structure transformation to acquire the method of new type functional materials, in addition to have a more thorough understanding of the content of the course.

Solid state physics is one of the most important links between theory and the frontiers of science. This study has made some discussions on how to integrate the teaching content of solid state physics into the frontier of science. The integration points meet the teaching requirements of solid state physics and can provide theoretical reference for teachers engaged in solid state physics teaching. After the course of solid state physics is integrated into the advance of science, the teaching content is more characteristic of The Times and more conducive to the cultivation of research-oriented talents. For one thing, it is helpful for students to deeply understand and master the basic concepts and theories of solid state physics, and for another, it makes students realize that scientific research comes from the basic knowledge of the discipline, and scientific research is not inscrutable, so as to stimulate students' interest in scientific research and enhance their scientific research potential.

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