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Classroom Teaching Reform and Practice of Space Lattice in the Course of Crystallography

Lou Youxin[1,a,*], Zhou Haifeng[1,b], Xie Jixun[1,c], Shao Yongliang[1,d], Yu Yangyang[2,e], Zhao Ping[1,f], Hao Xiaopeng[1,g], Wu Yongzhong[1,h]

[1]*School of Materials Science and Engineering, Qilu University of Technology (Shandong Academy of Sciences), Jinan, China*
[2]*Office of Educational Administration, Qilu University of Technology (Shandong Academy of Sciences), Jinan, China*
[a]*zylyx616866@163.com*, [b]*hfzhou@qlu.edu.cn*, [c]*xiejixun@qlu.edu.cn*, [d]*shaoyongliang@qlu.edu.cn*, [e]*975182505@qq.com*, [f]*zhaoping6101@qlu.edu.cn*, [g]*xphao@qlu.edu.cn*, [h]*wuyz@qlu.edu.cn*
[*]*Corresponding author*

Abstract: *The space lattice in the course of Crystallography exhibits a close relationship with the equivalent points and unit cells within crystals. The foundational aspect of deriving a space lattice lies in the conceptual comprehension and precise assessment of equivalent points within crystal cells. However, conventional classroom teaching has only introduced a limited range of simple two-dimensional structural patterns, thereby neglecting the real-structure problems and impeding students' capacity for high order thinking. This study has presented the utilization of flash demonstration and multi-dimensional real crystals as instructional resources, aimed at fostering high order thinking skills. The process and methodology for deriving space lattice were thoroughly discussed. The derivation of the space lattice's three-step method was proposed. Enhancing the construction of classroom quality is beneficial in attaining the teaching objective of fostering high order thinking skills.*

Keywords: *Equivalent points, Space lattice, Crystal*

1. Introduction

Crystallography is a fundamental course that is crucial for students majoring in some disciplines such as chemistry, materials science, geology, and others. This course centers on the study of crystal macrosymmetry, microsymmetry, crystal growth, and related subjects, necessitating a foundational understanding of chemistry, physics, mathematics, and other relevant disciplines. The abstract content necessitates a profound level of comprehension, rendering it challenging to grasp and apply the knowledge acquired in the course [1]. Undergraduate students possess fundamental knowledge in crystal structure. They have developed a fundamental comprehension that crystals are composed of unit cells. In our crystallography course, students will be exposed to increasingly intricate crystal materials, necessitating a deeper understanding of crystallographic concepts and principles.

The space lattice is a novel concept that represents the distinctive features of a crystal structure. It is also a fundamental concept in various courses such as Test and Analysis Techniques, Material Structure and Properties and Fundamentals of Materials Science. It is extensively utilized in X-ray diffraction, high-resolution electron diffraction analysis, and other associated applications [2,3]. The space lattice holds significant importance in enhancing students' proficiency in applying crystallographic knowledge, and it also plays a crucial role in facilitating deep learning in specialized courses.

2. The Current State of Classroom Instruction on Space Lattice

Based on the secondary education, comprehending the correlation between space lattice and equivalent point is difficult. Therefore, it is essential to define the concept of the equivalence points and to remember the processes for identifying the equivalence points within patterns. The procedure is helpful for undergraduates to understand the derivation of space lattice.

The initial stage helps students have their foundational understanding and grasping the concept that a crystal is comprised of multiple primitive cells, which can be characterized as a primitive lattice

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structure. Crystals can be regarded as being comprised of space lattice, which possesses the geometric structural properties of crystal cells. The space lattice is a geometric configuration formed by interconnected geometric points. To ascertain the space lattice of a crystal, the pivotal step involves identifying the collection of equivalent points that constitute the space lattice. The aforementioned geometric points are commonly referred to as equivalence points.

Equivalent points are defined as points that share the same geometric identity. It depends on whether students should possess comprehension of the two criteria utilized for judgment. Criterion 1 pertains to ions possessing identical properties, while Criterion 2 focuses on ions having an identical surrounding environment. Condition 1 means the identical element, while condition 2 means exactly the same bonds. The real crystals are composed of a large number of ions. Students should accurately ascertain the equivalence of ions in crystals. However, the current state of teaching and learning shows that there are still some problems in classroom teaching.

3. Challenges in Teaching Space Lattice

The recognition of space lattice challenges students' space imagination and logical thinking skills. They encounter some difficulty in the process of acquiring knowledge and comprehending concepts [4]. Traditional classroom teaching in this section primarily utilizes some simple examples. However, it does not encompass complex crystal structures nor visually demonstrate the processes of equivalent point analysis. When students encounter complex crystal structures, they often struggle to manage them.

In order to facilitate the curriculum teaching, students are able to observe the complete process of analyzing equivalence points and gain a comprehensive understanding of the derivation of space lattice through the use of simple patterns. However, there is a lack of methodical summaries. Especially, when encountering some real, complex crystal structures, students still have difficulty in deriving the space lattice. This design of space lattice is implemented with a focus on addressing practical issues encountered in classroom teaching. We present various instances of intricate crystal structures found in contemporary materials, with the aim of fostering innovative and high order thinking. The classroom instruction promotes students effectively acquiring the derivation for space lattice and addressing the challenges associated with deriving space lattice for complex crystal structure.

4. Adopting Animation Demonstration, the Three-step Space Lattice Derivation Method Can Be Effectively Showcased

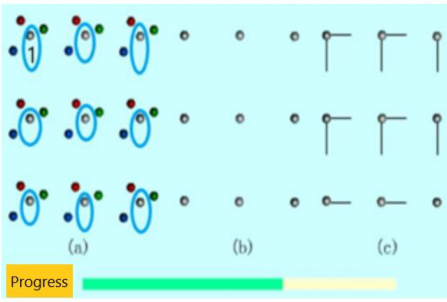

Figure 1: The animation demonstration of space lattice

Flash animation demonstrations provide numerous benefits in terms of interactivity and continuous display, making them suitable for fulfilling the professional development needs in diverse learning environments. The classroom provides an introduction to the two-dimensional structure pattern, which is used to illustrate easily the complete processes of equivalence point analysis and space lattice derivation. The teaching processes can be outlined as follows: Initially, the starting atom can be identified as No. 1 gray atom, using the concept of equivalence points. In this section, we guide students through the processes of analyzing the environment chemical surrounding No. 1 gray atom. Subsequently, we lead them to determine the environment of other gray atoms (circled atoms in the figure1) in relation to No. 1 gray atom. This analysis allows us to determine whether all the gray atoms in the figure belong to the same set of equivalent points. Through the use of simple flash demonstrations and the aforementioned analysis in teaching, students can more easily recognize and comprehend the concept of equivalence points and the processes of space lattice derivation. Additionally, the three-step method of space lattice

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derivation, which involves "1 judgment + 1 shift + 1 connection," can be deduced based on the previous analysis.

5. Based on Three-step Method for Enhancing Students' High Order Thinking Skills

When examining the equivalence points in complex crystal structure, it is common to encounter multiple sets of equivalence points. This poses a challenge for equivalence point analysis, particularly when combined with the difficulty in observing the structure. In classroom teaching instruction, the significance of equivalence point analysis and the three-step derivation method is underscored when addressing the derivation of space lattice for both two-dimensional and three-dimensional crystal structure. Additionally, the specific processes of space lattice derivation will be discussed using some illustrative examples of crystal structures.

Case 1: Analysis of two-dimensional chemical structure using three-step method

Graphene crystal is a two-dimensional material consisting of carbon atoms organized in a single atomic layer. The carbon atoms in the material exhibit sp^2 hybridization, resulting in some strong chemical bonding. This material demonstrates exceptional charge conductivity, high light transmittance, and favorable electrical and thermal conductivity. As a result, it is suitable for applications in solar cell materials and has gained significant popularity [5,6]. This particular case has the potential to expand students' perspective, enhance the integration of theoretical knowledge with practical application, and provide guidance for students in tackling complex real issues. In classroom instruction, the processes of deriving the space lattice of this material are carried out in the following manner: Initially, students are instructed to analyze the characteristics of the cell structure. It is obvious that Graphene crystals consist of some hexagonal atomic rings. To identify all carbon atoms on the hexagonal ring, a specific hexagonal ring containing six carbon atoms can be chosen, starting from the No. 1C atom as shown in Figure.2. Students are then instructed to analyze the direction of the carbon-carbon bonds, using the carbon atoms on the hexagonal ring as a reference point. If the chemical bonding environment of carbon atoms can be classified into six distinct types. A, a, B, b, C, and c letters were assigned to six distinct environments in Figure.2. Subsequently, students can deduce that 1, 3, and 5 C atoms belong to the type of ABc bond environment. All belong to the same equivalent point system. And, in addition, the C atoms at positions 2, 4, and 6 exhibit an abC bonding environment, which is part of a distinct set of equivalent point system. In the two-dimensional space lattice (parallelogram), it is observed that a minimum of four geometric points, specifically 1, 3, 5, and 7 C atoms, belong to a single set of equivalent point system. Subsequently, these equivalent points undergo a shift in a direction, resulting in their connection. The derivation of the space lattice of graphene crystals is accomplished through 1-connection. The atoms chosen for analysis must belong to the same type of atoms. By selecting different systems of equivalent points, it is observed that the deduced space lattice remains the same.

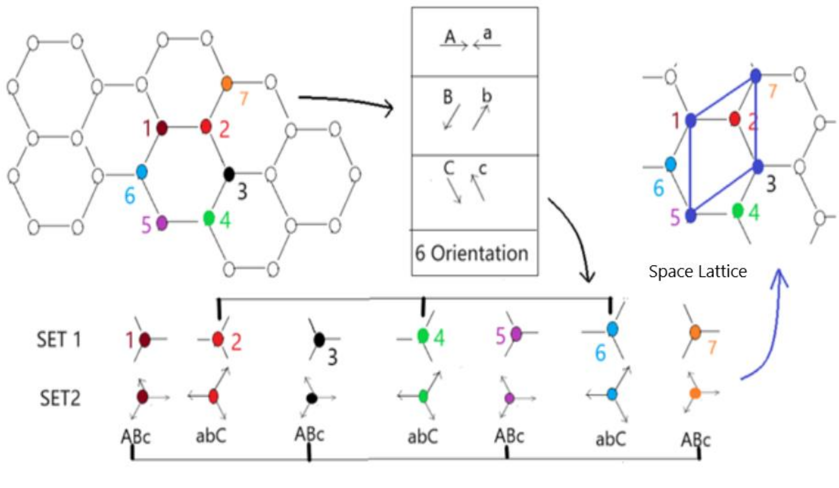

Figure 2: The space lattice derivation of two-dimensional graphene case

Case2: The space lattice derivation of three-dimensional crystal structure using three-step method.

CaF_2 crystals is often used as gemstones, which is known as the "gold industry" in fluorine chemical

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industry. At the same time, fluorite also has excellent mechanical properties, chemical stability and optical properties, commonly used as laser crystals, scintillation crystals, optical devices, etc., in the chemical, which belong to the irreplaceable strategic minerals [7-9]. The CaF_2 cell belongs to the isometric crystal system (shown in Fig.3). The Ca ions are distributed at the corners and face centers, and the fluoride ions are located at the center of the cubes as the cell is composed of eight small cubes [10]. Due to the difficulty of observing the atomic positions in the three-dimensional structure, the analysis of the equivalent points is very difficult. Similarly, we use the three-step method to analyze the derivation of its space lattice (shown in Fig. 3).The whole processes are as follows: Firstly, students are instructed to complete the task of atom symbols of the crystal structure, determine the equivalent point system of calcium ions. First, selecting the starting calcium ion (such as calcium ion No. 1 in Figure3), and in order to facilitate understanding, five calcium ions can be used for analysis (respectively labeled as 1, 2, 3, 4 and 5). We take calcium ion No. 5 as an example to analyze the bond environment and guide the students to discuss the orientations of chemical bonds.The lower part of the bonded with four fluoride ions, and the upper part of the bonded with four fluoride ions, i.e., there are eight kinds of bonding environments (Marked by Arabic numerals). The Ca ions labeled 1, 2, 3 and 4 have the same chemical environment with Ca 5 ion, indicating 1, 2, 3, 4 and 5 Ca ions belong to the same set of equivalent points. In the same way, it is found that all the calcium ions in the cell have the same environment with calcium 5. It can be judged that all calcium ions in the crystal cell belong to the same set of equivalence point system. These equivalence points along a certain direction of translation are carried out, and then connect the equivalence points and obtain the space lattice of CaF_2 crystals, i.e., the face-centered cubic structure of the upper right corner of Fig.3. The above flow also follows the three-step method to derive the space lattice, and the F-ion analysis can also be chosen to obtain the F-equivalent point system with the same derivation method.

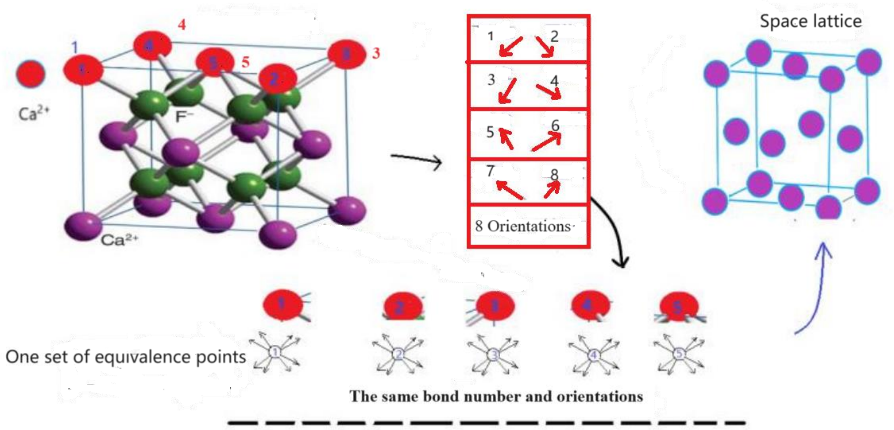

Figure 3: The space lattice plotting process of three-dimensional CaF_2

Through the introduction of complex two-dimensional and three-dimensional crystal structure as classroom teaching content, the equivalence point analysis and space lattice derivation are shown in details. Students actually understand how to apply the equivalent points and space lattice knowledge in practice. After they understand the three-step crystal space lattice derivation method, they can scientifically analyze and solve some comprehensive problems. It is efficient to solve teaching pains in the space lattice and achieve the goal of high order thinking.

6. Conclusions

The derivation of space lattice requires a profound comprehension of the concept of equivalence points, which relies on precise analysis and judgment of equivalence points. In order to promote high order thinking skills among undergraduates, we have implemented some teaching reforms in classroom teaching. In case of space lattice teaching section, we introduce animation demonstrations and present typical crystal structure examples. These demonstrations and examples effectively illustrate the processes and three-step method involved in equivalence point judgment and space lattice derivation. Through this approach, it can be determined that the three-step approach is a valid method. We effectively address the challenges and concerns associated with classroom teaching, thereby achieving the objective of nurturing students with high order thinking skills.

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