Lecture Notes in Physics

The Lecture Notes in Physics

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Symmetry, Group Theory, and the Physical Properties of Crystals

Springer

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Preface

Why do we look at some things and think they are beautiful while other things do not appear esthetically pleasing to us? This is a question that has always interested mankind. One answer is given by the following quotation from an early president of the College of New Jersey (now Princeton University):

> "Beauty is found in immaterial things like proportion or uniformity. . . .
> called by various names of regularity, order, uniformity, symmetry,
> proportion, harmony, etc.". . . Jonathan Edwards[1]

Symmetry not only provides the natural harmony that makes something appear beautiful to us, but also is of great value to science because it dictates the physical traits of many objects. Nature itself seems to love beauty since atoms tend to self-assemble into shapes with specific symmetry and crystals grow in geometric lattices. In many cases, if we know the symmetry of something we can predict some of its important properties without having to resort to experimentation or complicated calculations.

One area where the concept of symmetry plays an important role is that of crystalline solids. Crystals, by their very nature, exhibit specific symmetries. Crystalline materials have many important applications in devices based on their electronic, optical, thermal, magnetic, and mechanical properties. Solid state physicists and chemists, as well as material scientists and engineers, have developed rigorous quantum theoretical models to describe these properties and sophisticated measurement techniques to verify these models.

Many times, however, in screening materials for a new application it is useful to be able to quickly and easily determine if a specific material will have the appropriate properties without making detailed calculations or experiments. This can be done by analyzing the symmetry properties of the material. The mathematical formalism that has been developed to accomplish this is called group theory. The symmetry properties of a crystal can be described by a group of mathematical

[1] J. Edwards, *Works of Jonathan Edwards* (Banner of Truth Trust, Edinburgh, 1979)

operations. Then using simple group theory procedures, the physical properties of the crystal can be determined.

During the 45 years I have been involved in teaching and research in various areas of solid state physics, I have made extensive use of the concepts of group theory. Yet I have been surprised at how little emphasis this topic receives in any formal educational curriculum. Generally, a student studying solid state physics or chemistry will be exposed to crystal structures early in the semester and then have no further exposure to crystal symmetry until some special topic such as nonlinear optics is discussed. This book focuses on the symmetry of crystals and the description of this symmetry through the use of group theory. Although specific examples are provided of using this formalism to determine both the microscopic and macroscopic properties of materials, the emphasis is on the comprehensive, pervasive nature of symmetry in all areas of solid state science.

The intent of the book is to be a reference source for those doing research or teaching in solid state science and engineering, or a text for a specialty course in group theory applied to the properties of crystals.

Tucson, AZ Richard C. Powell
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