out retaining earlier concepts. Furthermore, although the ideas presented are related to a variety of applicable situations, the material is not developed with a view to demonstrating its "usefulness." The discussion, for example, of aperiodic tiles—sets of prototiles that admit tilings of the plane but for which there is no possible periodic tiling—is pursued for its own interest. Yet this beautiful and exciting new field of aperiodic tilings is setting crystallography and physics topsy turvy by providing a framework for the controversial and exciting developments in the area of what have come to be called quasicrystals. These are a form of matter that appears to violate the so-called crystallographic restriction, which states that the only types of rotational symmetry that can be present in physical lattice systems are two-fold, three-fold, four-fold, and six-fold. In particular, the high level of icosahedral symmetry, seemingly confirmable for these new materials from x-ray crystallographic techniques, cannot be explained by classical methods.

Laypeople often think mathematics is a subject with no problems for which answers are not known. It is exciting to see throughout this book a large number of unsolved, easy-to-understand problems. (Sample: Is there a collection of tiles of only one shape that is aperiodic? The so-called Penrose tiles are a set of two shapes that tile the plane aperiodically.) In addition, the format of individual chapters is felicitous. Each chapter begins with an introduction giving a general account of the material to be developed, the technical material follows, and the chapter closes with informative and entertaining remarks and notes. These notes document the historical development of the material, indicate areas where the ideas have hope of application, and suggest connections with other disciplines and other areas within mathematics. The book is stuffed with visually beautiful and mathematically fascinating examples of tilings. One wishes that the economics of publishing had allowed the examples of colored tilings (both of an historical nature from such sources as the Alhambra and in the theoretical discussion of color symmetry) to be shown in color. Persons with a wide range of interests, from chemists and physicists to artists, mathematicians, and crystallographers, will find many things to enjoy in this book. It will serve as a standard reference for this material for many years to come.

As a headline in *Science* indicated (30 May 1986, p. 1087), there is "a math image problem." Mathematics has a reputation for being highly symbolic, highly structured, and impenetrable. Grünbaum and Shephard's superb book shows that it is possible to write a self-contained book using elementary concepts that combine to create a rich fabric of exciting and useful ideas. But without the precision of a technical vocabulary and the compression and increase in clarity allowed by well-chosen notation, mathematics could not do the jobs it sets for itself. If nonmathematicians and laypersons are willing to meet mathematicians halfway by providing the work and staying power to understand and probe the beautiful and useful ideas present in so many portions of mathematics, then with the help of such books as *Tilings and Patterns*, this image problem can be made to disappear.

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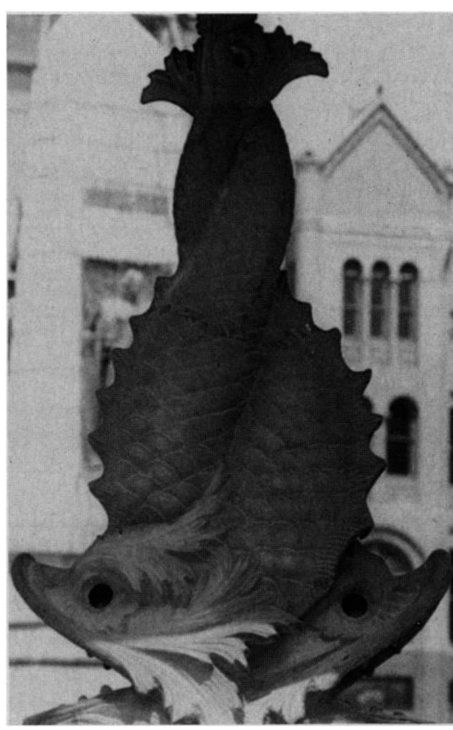
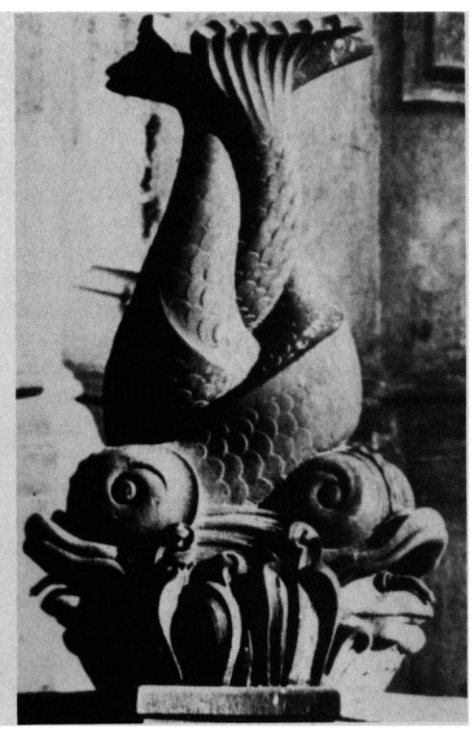
Symmetries

Symmetry through the Eyes of a Chemist. ISTVÁN HARGITTAI and MAGDOLNA HARGITTAI. VCH, New York, 1986. xii, 458 pp., illus. $95.

Hermann Weyl's 1952 monograph, *Symmetry*, is by now a classic. Richly illustrated with examples from art and nature and using little mathematics, it introduced the reader to the concept of symmetry, its foundations in group theory, and its applications in science. *Symmetry through the Eyes of a Chemist* is written in the same spirit. The early chapters are reminiscent of Weyl, with some examples and illustrations in common. István and Magdolna Hargittai are Hungarian, and there is a nice mixture of illustrations of art and architecture from Eastern Europe with more familiar Western European and American themes. After establishing the basis of the study of symmetry in group theory, the authors describe how symmetry concepts are used in a number of areas in chemistry: molecular structure, spectroscopy, chemical reactions, and crystallography. The range is broad, and the applications of symmetry to chemistry are interwoven with an array of examples from art, architecture, music, literature, and nature.

There are today several excellent books that introduce the principles of symmetry and group theory and their applications to chemical problems (for example, Harris and Bertolucci's *Symmetry and Spectroscopy* and Orchin and Jaffe's *Symmetry, Orbitals, and Spectra*). While covering much of the same material, the Hargittais' book has a different flavor. The development is less formal: for example, in the chapter on group theory, results are given without proof. The intention is to convey an appreciation for the ways in which symmetry concepts are incorporated in chemistry rather than to present a comprehensive development. Some topics





Two- and three-fold rotational symmetries, displayed by sculptures of a pair of fish in Washington, D.C. [*left*], and a trio in Prague [*right*]. [Photographs by István and Magdolna Hargittai; from *Symmetry through the Eyes of a Chemist*] that are familiar from the standard texts, such as construction of hybrid orbitals or ligand field theory, are not discussed at length here. Yet several other applications are described quite thoroughly, with detailed examples. This book thus complements the existing literature, with extensive references included for each chapter.

As is perhaps inevitable in a book with such a broad perspective, parts are somewhat uneven. Chemistry is introduced at a very fundamental level (what is a molecule? what is the meaning of an empirical formula?), yet by the end of the same chapter permutational isomerism is discussed. It is hard to imagine a reader who could make such rapid progress. Similar leaps are made in other chapters.

The book begins with an introduction to the idea of symmetry, basic symmetry elements, and properties (polarity, chirality) that depend on the presence or absence of symmetry elements. A 10-page discussion of snowflakes illustrates the authors' approach: first they describe snowflake growth and form in terms of the marginal stability model; they follow with a passage on snow from Thomas Mann's *The Magic Mountain* and a brief history of interest in snowflakes from ancient China through modern Europe; finally, they provide a beautifully illustrated description of the classification of snow crystals.

Chemistry enters in chapter 3, beginning with point groups. The elegant symmetries presented by network molecules like boron hydrides and polycyclic hydrocarbons are described. There is a good discussion of the valence shell electron pair repulsion (VSEPR) model, which in recent years has become an established part of the general chemistry curriculum but is not often discussed in more advanced texts. The elements of group theory are given in chapter 4, with a clear presentation of the concept of a representation. Though informal, the Hargittais' approach establishes basic terminology and builds quickly to the results and tools essential for chemical applications. Chapters 5 and 6 describe the use of group theory in the study of molecular vibrations and molecular electronic structure. The discussion of the construction of symmetry-adapted linear combinations of atomic orbitals is excellent, including for several molecules a comparison of simple cartoon representations generated by symmetry analysis with contour diagrams of molecular orbitals generated by *ab initio* electronic structure calculation. Chapter 6 closes with a curious critique of the current status of electronic structure theory.

The chapter "Chemical reactions" describes the symmetry of the reaction coordinate, frontier orbital concepts, and Woodward-Hoffmann rules. The development is brief, probably inaccessible to someone unfamiliar with these important topics. However, the comparison of the three viewpoints as applied to several systems is valuable. The final chapters deal with translational symmetry: space groups and crystals. This material is richly illustrated, including along with crystals Hungarian needlework patterns and drawings by M. C. Escher.

Chemists, familiar with the use of symmetry in some of these areas, will find this book interesting and enjoyable. Many of the examples and illustrations are beautiful, some are whimsical, a few even a bit forced, but that is a matter of taste. The depth of the treatment varies, but the book gives a fascinating overview of the rich variety of applications of symmetry throughout chemistry, showing both its power and its aesthetic appeal.

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Lectures on Weyl

Hermann Weyl, 1885-1985. K. CHANDRASEKHARAN, Ed. Published for the Eidgenössische Technische Hochschule, Zürich, by Springer-Verlag, New York, 1986. viii, 119 pp., illus. $30. From a celebration, Zürich.

This book contains the three lectures delivered for the celebration of Hermann Weyl's centenary at Zürich. It also contains a complete list of his publications (including mimeographed lecture notes), three pages of Weyl memorabilia, four pages of pictures, and 12 pages entitled "Report on the celebration," half of them devoted to Michael Weyl's speech about his father. The three lectures, given by Chen Ning Yang (15 pages), Roger Penrose (30 pages), and Armand Borel (30 pages), are rather different in style.

In his lecture "Hermann Weyl's contribution to physics," Yang gives many quotations from Weyl. He recalls several pieces of Weyl's work relevant to physics and sketches the current status of these different topics. First, he tells of Weyl's work on the distribution of eigenfrequencies of a vibrating plate; this partly answered a question that had been raised by Lorentz. A more direct involvement of Weyl in physics was his rebuttal of Dirac's proposal in 1929 that protons could be represented by the holes in the sea of negative energy electrons: Weyl, in the second edition (1930) of his book *Gruppentheorie und Quantenmechanik*, showed that the Dirac equation has a built-in symmetry, so the mass of the hole must be that of the electron; "furthermore, no matter how the action is chosen (so long as it is invariant under interchange of right and left), this hypothesis leads to the essential equivalence of positive and negative electricity under all circumstances." In addition, Weyl pointed out the possibility of a relativistic, two-component spinor equation when the particle has zero mass: this is the equation currently used for neutrinos (it violates P and C). Finally, Weyl maintained a continuing interest in gauge theories; Yang distinguishes three periods in this work and relates it to his own interest in these theories, discussing some topological effects (such as the Aharonov Bohm experiment).

Penrose's lecture "Hermann Weyl, space-time and conformal geometry" is inspired by Weyl's work but deals essentially with the lecturer's own research. First, he tells of the interesting history of the nonperiodic pavings of the plane, and of his own contribution and its relevance to the recently discovered quasicrystals. Without transition, he moves to what he calls Weyl's spaces—axisymmetric solutions of Einstein equations with two-point masses—and explains in a rather cryptic manner his recent, unpublished work on their topological properties. In the last part, he recalls Weyl's work (with Brauer) on spinors in n-dimensions and the work in general relativity using conformal geometry. These two topics have been blended by physicists, Penrose among them. He ends his lecture with a description of his recent work in quantum gravity. It is daring: The origin of the second law of thermodynamics might be a speculative "objective state-vector reduction," a purely quantum-gravity effect that does not require the intervention of an observer.

Borel's lecture "Hermann Weyl and Lie groups" is a scholarly study of Weyl's work on this subject (presented against the historical background), his interaction with other mathematicians, his influence, and some glimpses of later progress. The study is precise, even technical, but the reader is greatly helped by long explanatory notes at the end of the paper. Borel quotes not only the original papers but also Weyl's correspondence and writings by historians of science on Lie groups. He explains how Weyl was casually led to this subject, at the age of 37, by his reflections on relativity theory. Weyl had "the extraordinary ability . . . to get into a new subject and bring an important contribution to it within a few months." The field of Lie groups was dominated by Cartan (mainly Lie algebras and local groups) and by Schur and Hurwitz,