the University of Chicago, had long been concerned with spectroscopy and the ruling of optical diffraction gratings, rather than with his results of 1887, for which he always showed less than marked enthusiasm. Upon the urging and encouragement of many leading physicists and astronomers, "who were reluctant to allow the aether concept to die," especially Morley, and George Ellery Hale, director of the Mount Wilson Observatory, Dayton C. Miller of the Case School of Applied Science (later Case Institute of Technology) undertook to repeat these experiments, which in fact, contrary to the textbooks, had never yielded definitively null results. Miller's primary interest was to repeat the experiment at intervals throughout a year, as originally planned (but never completed) by Michelson and Morley, and also to conduct the trials on a mountain top, where presumably the "ether" would be less "entrained" than in the laboratory rooms with heavy walls where the original trials had been made. To carry out these objectives, Miller rebuilt the Morley-Miller interferometer used in 1902–1904, improved its optics, and had it transported to the Mount Wilson Observatory, where from 1921 to 1926 he carried out extensive trials of the experiment. From the first he found small periodic shifts in the fringe positions as the interferometer rotated. These shifts were both a puzzle and an annoyance to much of the scientific world. In spite of great effort in the analysis of his data, Miller had not found a solution to his results that was generally acceptable at the time of his death in 1941. Had Miller's small positive effect been consistent with the azimuth orientations of his interferometer with respect to the north-south line at Mount Wilson, they would undoubtedly have been taken more seriously. Miller himself always emphasized the discrepancy in azimuth but, unlike certain physicists who repeated the experiment at this time, he was not content to announce a result in agreement with the requirements of relativity theory, even though his fringe displacements were less than 10 percent of those predicted by the ether theory.

This reviewer inherited Miller's extensive data and also his suggestion that I might care to do something to clarify the situation if it was felt desirable. For many years this was not possible; but finally, after serious inquiries about Miller's work had been received from a number of distinguished physicists, four of us at Case decided to reanalyze his data (*2*). This new study showed that Miller's small periodic fringe displacements could not be dismissed as being due to statistical fluctuations in very difficult observations. Unsupported statements that they might be so had annoyed Miller considerably, and those who knew him well were completely confident that as an experimenter he was one of the most skillful and was also highly conscientious in reporting his findings.

Having ruled out statistical fluctuations as the explanation of Miller's results, we then examined the question of magnetostriction in the steel base of the interferometer. This effect, though present, was too small to account for the observations. Next, a detailed analysis was made of possible strains and vibrations that might produce the observed effects, but these also were shown to be negligible owing to the structural properties of the interferometer. Finally, our attention was turned to the temperature conditions existing in Miller's lightweight interferometer house on Mount Wilson. Miller was fully aware that temperature variations and temperature gradients across the interferometer would cause shifts in the fringes like those predicted for an ether drift. However, he had made extensive preliminary tests in the physics building at Case to shield his interferometer from thermal effects, and in the last of these trials he had obtained almost perfect null results (*2*). He was confident that by shielding the interferometer with heavy glass and cork he had reduced the temperature effects to a negligible level. This he almost accomplished. But it gradually became clear to us that under the more severe temperature conditions existing at Mount Wilson the shielding that had proved effective in the Case laboratory was not entirely adequate. Our study showed that Miller's results were closely correlated with the temperature gradients existing across his interferometer. (With his thoroughness in experimental detail Miller had recorded the temperatures with a group of thermometers throughout the course of his observations.) The progress of our analysis was discussed several times with Einstein in Princeton (*1*), who showed genuine interest and emphasized that no uncertainty should be allowed to exist in any experiment touching relativity theory. It is unlikely that the considerable effort that went into the reanalysis would have been made except for his interest and encouragement.

The most relevant experimental phenomena in electronics and nuclear physics that today require special relativity for their analysis were not known to the generation of Michelson, Morley, and Miller, and present-day physicists may be puzzled at the great interest the experiments of these men maintained for so long a period. But the central purpose of Swenson's book is to explain their work against the background of their own times, and it is an account that should be of interest to all those concerned with the history and development of physics. Physicists who remember the excitement (and passion!) of the years when this work was in progress will have great interest in Swenson's book, and younger physicists should find it instructive to see how long and complex are the routes that have led us to our present position.

The original papers of Michelson (1881) and of Michelson and Morley (1886; 1887) are reprinted as appendices, and a photograph (reproduced here) of the original apparatus used in Cleveland in 1886–1887 is printed in the book for the first time.

ROBERT S. SHANKLAND
Department of Physics, Case Western Reserve University, Cleveland, Ohio

References

1. R. S. Shankland, "Conversations with Albert Einstein," *Amer. J. Phys.* **31**, 47 (1963).
2. R. S. Shankland, S. W. McCuskey, F. C. Leone, G. Kuerti, "A new analysis of the interferometer observations of Dayton C. Miller," *Rev. Mod. Phys.* **27**, 167 (1955).

Planes, Solids, and Nolids

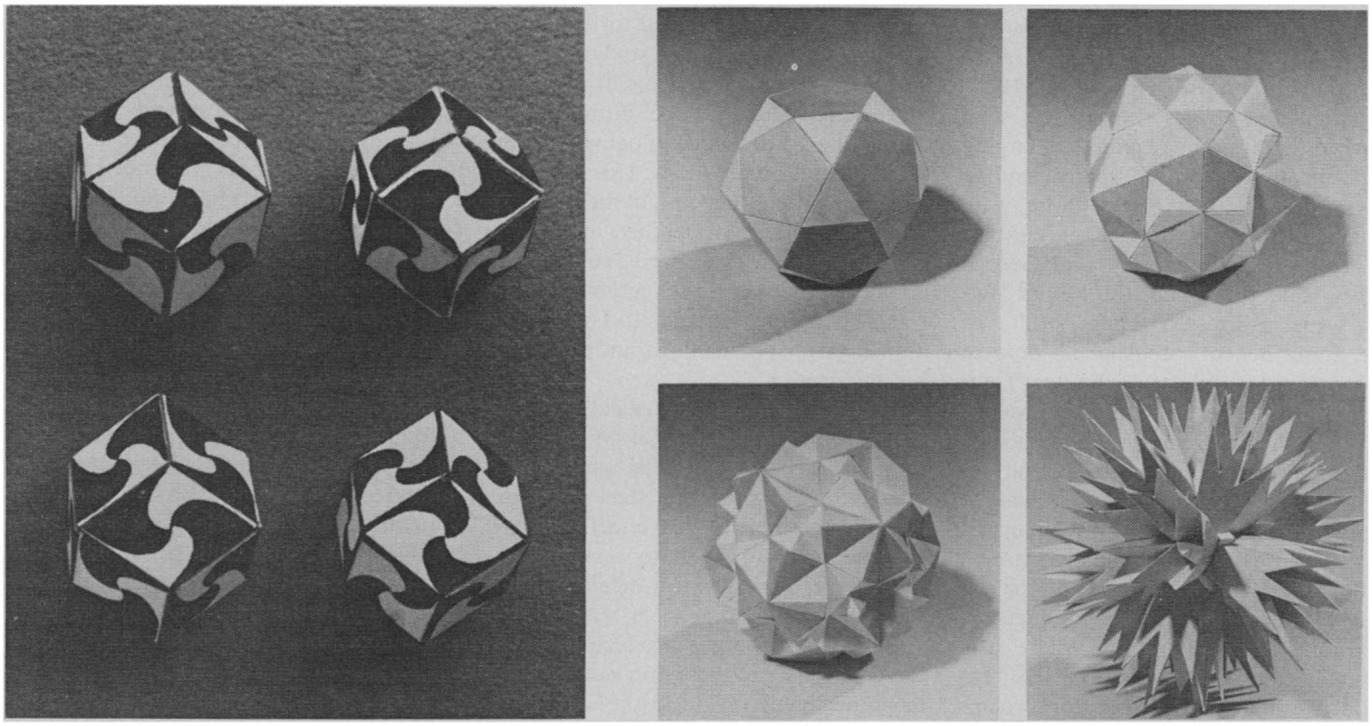
Color and Symmetry. ARTHUR L. LOEB. Wiley-Interscience, New York, 1971. xvi, 180 pp. + plates. $14.95. Wiley Monographs in Crystallography.

Shapes, Space, and Symmetry. ALAN HOLDEN. Photographs by Doug Kendall. Columbia University Press, New York, 1971. viii, 200 pp. $11.

Polyhedron Models. MAGNUS J. WENNINGER. Cambridge University Press, New York, 1971. xii, 208 pp., illus. $14.50.

These three books deal with various aspects of symmetry, in descending order of abstraction:

Color and Symmetry, by A. L. Loeb, presents a beautiful mathematical development of the symmetries possible in a plane. The symmetry operations



Paper constructions. (Left) Rhombic dodecahedra decorated with colored designs to illustrate symmetry operations. [From *Shapes, Space, and Symmetry*] (Right) Icosidodecahedron, its first two stellations, and its final stellation. [From *Polyhedron Models*]

are taken to be rotations about "rotocenters" and reflections and glide reflections across lines. The assemblages of rotocenters that can exist in a plane follow from a diophantine equation and a set of 12 theorems derived by the author. Mirror and glide lines are then introduced and 11 more theorems are proved. The logical sequence is fascinating and beautiful. The list of planar, geometrical symmetries found in this way is complete and includes the 4 planar point groups, the 7 "ribbon" groups, and the 17 doubly periodic plane groups. The derivation of all these groups is accomplished from a single, unified point of view, which carries with it a new notation, rather different from those used by other authors. This new notation indicates explicitly all the symmetry elements present in each group and is an improvement on the traditional symbols in this respect.

Color symmetry is then introduced by connecting each previously mentioned symmetry operation with a set of color changes. Rotations are made to produce sequences of colors, and the number of different colors in each sequence is related to the order of the rotocenter involved. Mirror and glide lines either interchange pairs of colors or leave colors unchanged. The number of colors involved with each type of rotocenter in a system is limited by a second diophantine equation and six additional theorems. By applying these concepts to the purely geometrical planar symmetries already derived, all possible color symmetries in a plane are derived. Distributions of colors that can be produced from one another by permutations are considered by the author to be equivalent; this limitation rules out any consideration of the phenomena of diamorphism and color enantiomorphy, so dear to the heart of the reviewer; however, the effects of removing this limitation can be studied in the future.

It is noteworthy that no explicit use is made of group theory anywhere in this book.

It may well be that this work will become a classic essay on planar color symmetry. The extension of this type of treatment to three-dimensional space would be very valuable; it is to be hoped that someone will soon take up this project.

Shapes, Space, and Symmetry, by Alan Holden, describes very clearly and simply, and illustrates with beautiful photographs of models, a tremendous number of three-dimensional figures, all but a few consisting of plane faces bounded by straight lines. The regular polyhedra are presented, together with their stellations, the relationships among them, and what happens when they are truncated in various ways. Semiregular solids are also illustrated and described, as are various concave solids. "Nolids" composed of symmetrically related polygons intersecting at a point also appear; as their name indicates, they enclose no volume. Interpenetrating polyhedra are mentioned and cleverly depicted. Toward the end, the stacking together of similar and dissimilar solids so as to fill space is discussed and illustrated, the concept of a lattice thus coming into the treatment. Mention is also made of growth forms and other cases in which similar figures of steadily increasing size are joined to one another, and good pictures are appended.

Along with the pictures of the geometrical figures is a running commentary which gradually acquaints the reader with a great deal about their geometries and symmetries; many other interesting facts about the figures, such as their histories and uses, are also mentioned. At the end of the book is a five-page section containing directions on how to construct the illustrated models of the figures out of cardboard. Altogether a most instructive, entertaining, and esthetically pleasing book.

Polyhedron Models, by Magnus J. Wenninger, is a set of 119 excellent photographs of paper models of increasingly complicated polyhedra, starting with the five Platonic solids and then modifying them, by truncation, stellation, faceting, and compounding. Each photograph is accompanied by a set of instructions and diagrams for constructing the model and suggestions for decorating it with colors. The coloring schemes are mostly consistent with the rules of color symmetry, although the color symmetries are often much lower than the purely geometrical symmetries of the figures.

Commentaries on the histories and interesting mathematical properties of the solid figures occur here and there in the text, and add greatly to its educational value. There are also occasional inspirational remarks to encourage model builders. These last are especially appropriate in connection with the extremely complicated figures toward the end of the book; for instance, the "small inverted retrosnub icosicosidodecahedron," a beautifully spiny, partially concave, and very intricate symmetrical figure, of which the author says, "You will need unusual patience and perseverance to complete a model."

The general effect of this book is to create a desire in the reader to become involved with these gracefully symmetrical figures; it is very pleasant reading indeed.

DAVID HARKER
*Biophysics Department,
Roswell Park Memorial Institute,
Buffalo, New York*

For Morphologists

Microreconstruction. W. A. GAUNT. Pitman Medical, London, 1971. xii, 108 pp., illus. £2.25.

A few months ago (3 Dec. 1971, p. 993) I explained in *Science* how three-dimensional structure often can be identified from single sections if only a few simple rules on dimensional reduction are kept in mind. For many people this commonsense approach would appear too primitive. They need to be convinced by the more sophisticated approach of stereology. Like all stereology (of which it is only a very small part), stereological shape determination is a matter of geometrical probability. Simple shapes can be identified stereologically by measuring the length and width of each profile of a feature in section, classifying the quotients length/width of many profiles, and applying mathematical rules elaborated by the reviewer, to a large extent in association with August Hennig.

These two methods are applicable only when the particles are numerous enough so that axial ratios of sections through them can be classified in a statistically significant manner, when the particles are randomly distributed in space or their distribution can be randomized by proper sampling procedures, and when the particles are of a fairly simple shape. When we are dealing with a single object of complicated shape, the shape can be determined only by reconstruction from serial sections. That is, the solid in which the object is contained must be disassembled into a succession of thin slices images of which, traced on plates of appropriate thickness, can be stacked. The result is a magnified replica of the object. Gaunt's posthumous little book *Microreconstruction* gives an excellent account of the history of such reconstruction and thorough instructions on how to do it.

The technique of serial reconstruction was invented in 1883 by Born and subsequently perfected by him and many others. Born devised a method by which plates of wax are produced whose thickness is controlled so that the magnification in height equals the magnification in width. The contour of the feature is traced from successive sections on the wax plates and cut out. The plates are stacked and welded together, and the layered edge can be smoothed out with a hot spatula. Accurate reconstructions can be produced only if the "sections" cut with the microtome are perfectly smooth and uniform.

Gaunt gives instructions on how to produce optimal serial sections. He also describes various techniques of graphical reconstruction, including perspective reconstruction and photographic reconstruction.

As a descriptive embryologist Gaunt confines himself almost exclusively to the use of reconstruction in that field and does not report on the advances or numerous new uses of reconstruction from serial sections in such fields as adult anatomy, pathology, and metallurgy. Even in his own field he overlooks a great step forward that was achieved by Hegre and Brashear in 1947 and was soon extended to use in botany by Postlethwait. This is the technique of block-surface cinematography, where a motion picture camera is mounted over the paraffin-embedded specimen and a frame is exposed after the removal, by the microtome knife, of the previous section. Thus there is no distortion or displacement of the successive images, and from them one can produce plastic or graphical reconstructions of greater perfection than was possible before this technique was introduced.

In other fields, serial sectioning serves less for the faithful representation of an individual structure than for the elucidation of such matters as the spatial interrelations of various components of a tissue or a material. Immediate tracing on glass plates for future stacking has been extensively used to follow the progress of a disease process. This technique and its advantages are not discussed sufficiently in the book.

The use of serial sections to investigate problems of continuity or discreteness in metallurgy is not mentioned. One important method in metallurgy is serial section photography, in essence similar to the Hegre method. As successive layers are removed with a diamond knife or by grinding, the block surface is photographed after polishing and etching. The elucidation of topological parameters is especially facilitated by serial section photography, particularly on motion picture film, which not only permits the production of well-superimposed models but makes it possible visually to "travel" through a specimen, directly observing continuities and discontinuities.

Also not mentioned in Gaunt's book is the extensive use of reconstructed models for volumetry. This method, of course, has now been superseded by the point counting and intercept methods of mathematical stereology.

An important innovation in the field was presented only recently by M. Yamada and S. Yoshida. This is stereoscopic reconstruction. The images of successive serial sections are traced directly with a ball-point pen on transparent paper. With the use of carbon paper two identical sets of contour maps are produced. The sets are then separated, and in one of them the successive tracings are displaced laterally by a specified distance. Thus two contour maps, one as seen by the right eye, the other as seen by the left, are obtained, and each is laid on a light box and photographed. The result is a pair