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Citation Classics

Karle J & Karle I L. The symbolic addition procedure for phase determination for centrosymmetric and noncentrosymmetric crystals. *Acta Crystallographica* **21**:849-59, 1966.

The theoretical background and practical procedures are presented for the determination of the phases of x-rays scattered by a crystal. The phases are determined directly from the measured intensities. Knowledge of the phases permits the immediate calculation of the crystal structure. [The *SCI*® indicates that this paper was cited 945 times in the period 1961-1975.]

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"The development of the symbolic addition procedure for the direct determination of the phases of scattered x-rays provided the opportunity to solve readily the structures of a large class of crystals which had heretofore been inaccessible. This class consists of structures composed of atoms with essentially equal atomic numbers (neglecting hydrogen atoms), particularly those structures which crystallize in space groups which lack a center of symmetry. Earlier methods had already made it possible to address essentially equal atom centrosymmetric crystals, but not many applications were made.

"The alternative approach to solving crystal structures has been to take advantage of a heavy atom already present in the structure or one which is deliberately introduced. This can greatly simplify the analysis and lead to a solution in an entirely routine fashion. It is not, however, always possible or desirable to introduce a heavy atom.

"The analysis of crystal structures, facilitated by the symbolic addition procedure and the development of computers and automatic diffractometers has had a major impact on the progress of many scientific areas. For example, the availability of such capabilities has played a significant role in the practice of organic chemistry by aiding in the identification of reaction intermediates, final products and the clarification of reaction mechanisms...

"The problem of solving crystal structures afforded fascinating challenges from the beginning. As a theoretical problem it has gone through several stages. The problem was regarded as unsolvable because the phases of the scattered x-ray amplitudes are lost in the recording of the intensities. It was possible to show, however, that the values of the phases were still contained subtly in the measured intensities, so that a solution existed in principle. The next stage involved the development of mathematical formulas which had the potential for practical development. Finally, considerable effort was required to bridge the gap between theoretical formulas and practical procedures.

"The key role played in the development of the theory by the physical constraint imposed by the nonnegativity of the electron density is particularly noteworthy. In fact, the role of physical and mathematical constraints in the various fields of structure research and the development of practical procedures are subjects of particular interest and a detailed manuscript concerning these philosophical and mathematical aspects of the subject is being contemplated.

"There is one final word concerning the development of a facility for readily carrying out crystal structure analyses with good single crystals. Such analyses have too often been considered the sole concern of crystallographic research and so, with this development, the field has been considered to be largely without challenges. This is very far from the truth and several examples come immediately to mind. Crystallography is also concerned with structural problems for which good single crystals are often not available. The fields of earth sciences and materials science can attest to this. Actually, this is a familiar occurrence in all areas of application. There are also many types of structural problems for which diffraction data are extremely limited. In addition, there is the broad field of diffraction physics with a great variety of problems other than crystal structure analysis...."