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David Sayre (1924–2012)

Sadly we report that David Sayre, the recipient of the Ewald Prize in 2008, died on 23 February 2012. He addressed several important crystallographic problems during his lifetime – initially 'the phase problem' in crystallography so that valid electron-density maps could be obtained from X-ray diffraction data, secondly how to improve and simplify communication between crystallographers and computers so that the calculations necessary to obtain electron-density maps could be made easily, and thirdly the possibility that one could 'see' (that is, image) molecules at atomic resolution in non-crystalline (rather than just crystalline) materials. The results from each of these projects have been useful in the development of X-ray diffraction methods as we use them today, and were recognized when the International Union of Crystallography awarded him their highest honor in 2008.

David was born in New York City on 2 March 1924 to Ralph and Sylvia Sayre. His father was a chemist and David was also interested in science; he graduated from Yale University in 1943 at the age of 19 with a BS degree in physics. At that time World War II was still being fought, so he took a position as a staff member in the Radiation Laboratory at MIT, working on radar. He learned much there about electronics and circuit design, and this was useful in his future studies. After the war David joined Raymond Pepinsky's group at Auburn University, Alabama, in 1946 because he had, he wrote, 'read one of J. M. Robertson's papers showing phthalocyanine, and I could find no one at Harvard who could teach me how to see molecules.' In Alabama he was able to use the 'X-ray Analogue Computer' (X-RAC) that had been built by Ray Pepinsky to calculate Fourier syntheses and display contour maps. It was possible to view maps of molecular electron density on the X-RAC screen and vary the input phases in order to eliminate deep negative troughs and obtain an improved map. For his work there David obtained an MS degree in 1948.

David married Anne Bowns, a writer, in 1947, and in the spring of 1949 they sailed for England where David, in 1951, obtained a DPhil degree in Dorothy Hodgkin's laboratory at Oxford University. In the early 1950s many crystallographers were addressing the phase problem and David was among them. Attempts to relate the electron density in a crystal to the imposition of conditions on possible values for the relative phases of diffracted beams had already been started by Ott in 1928, Banerjee in 1933 and Avrami in 1938. The further requirement of non-negativity in the resulting Fourier summation (that gives electron density) was successfully used by Harker, Lucht and Kasper in 1948 in the determination of the crystal structure of decaborane. Sayre's approach, which he called

'atomicity-based direct phasing,' was to introduce a 'squaring-equation method.' He came across a Fourier integral theorem involving multiplication and convolution and, as he wrote in *ACA RefleXions* (Winter 2010 edition), 'for some reason which is still unknown to me, I simplified it to *self*-multiplication (squaring) and *self*-convolution, and imagined it to myself with equal atoms, and there it was – all in a flash – the phases had to be such as to make the theorem hold.' Essentially when David wrote out the equation for the self-convolution of an array of structure factors he was able to conclude that, for an equal-atom structure, the phase of $F(h)$ is related to that of the product $\sum F(k)F(h-k)$. This triple-product sign relationship is all there in the equation that he included in his article in *Acta Cryst*. (1952), **5**, 60–65; it was known as 'Sayre's equation,' exact for an equal-atom structure, and an important advance in our understanding of direct methods. Many others also working on direct methods have further improved this method of structure determination.

David then applied his newly found method successfully to the determination of the crystal structure of the amino acid hydroxyproline. In his publication of this structure he described the entire method and later wrote that in it 'I gave the basic 3-step process – examination of triplets to find initial phase sets, use of a convolutional relationship to expand the phase sets, and use of a figure of merit to make a selection – which remained in use without essential change until fairly late in the 1980s.' David then worked with Peter Friedlander at the University of Pennsylvania in Philadelphia on the crystal structure of the carcinogen 7,12-dimethylbenz[*a*]anthracene. A three-dimensional crystal structure determination at that time required extensive and expensive computational assistance in view of the complexity of the equations that had to be solved. With a welcome offer of some free time on an IBM 701 computer in New York, David wrote a program that impressed Jim Backus of IBM so much that he 'borrowed' him for the Fortran project in 1955; David stayed on at IBM, mostly at the T. J. Watson Research Center in Yorktown Heights, New York, until he retired in 1990.

David was the assistant project manager of the group at IBM that developed the programming language Fortran. The aim was to produce a way to translate a language that people readily understood into the language of a computer, and *vice versa*. Success meant that scientists and engineers could then do their own programming, relieved of the necessity of assigning experts to do it. Crystallographers used Fortran as soon as it was available. David worked on important portions of this project with Dick Goldberg, and details can be found in an article published in *ACA RefleXions* in the summer of 2007. He also wrote the excellent Fortran program manual that, as Backus wrote, 'stood for some time as a unique example of a manual for a programming language.'

David then returned to the problem of being able to image molecules even if a crystal is not available. Initially he worked on a possible supermicroscope, but the required nature of lens material suitable for X-rays provided a problem. Microscopes based on Fresnel zone plates had produced images, and David worked on these, but then, in 1980, he introduced the concept of 'lensless imaging.' This came from his realization that actual crystallinity is not essential for molecular imaging. If the object is non-crystalline (non-periodic), then the intensity pattern is continuous (unlike the diffraction spots that result from the internal periodicity of a crystal). This continuous diffraction pattern, although weaker in intensity, can be sampled finely enough so that lost phase information can be found by computational methods. The availability of intense synchrotron sources of X-rays has aided this new method of 'X-ray diffraction microscopy.' The result was that it became possible to image structures such as that of a single biological cell, as shown by David and Janos Kirz and co-workers in the 1980s. Later they produced an image of a whole and unstained freeze-dried yeast cell. The final breakthrough came when a three-dimensional structure was reconstructed by Jianwei Miao and colleagues in 2010 from an experimentally recorded diffraction pattern. David described this work to a spellbound audience when he received the Ewald Prize in Japan in 2008, emphasizing the opportunities that arise 'when one can drop the assumption that the specimen in the diffraction experiment must be a crystal.'

David has been an interactive and friendly member of the American Crystallographic Association (ACA), receiving the Fankuchen Award in 1989, and serving several times on the US National Committee for Crystallography. He was President of the ACA in 1983. His scientific studies have improved the quality of work that each crystallographer can achieve. He will be greatly missed.

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