lated structures and quasicrystals. There is also a description of anomalous dispersion and chiral and polar space groups. An excellent example of the structure of a compound with possible inversion twinning is given. Extinction is well described, and the Renninger and λ/2 effects and thermal diffuse scattering are mentioned.

There is also an excellent chapter on *Errors and pitfalls* that all crystallographers should read. The author provides an interesting example from the literature of a structure with some incorrect atom types and shows how this problem was identified and rectified. There is a nice section with a clear example on the various possible types of twinning and how to analyze them. This subject is becoming more important especially for precious proteins where twinned crystals may be all one can obtain. There is also a table (11.1) showing a possible cause of incorrect space-group choices giving the cause of the problem (space groups that differ only in the presence or absence of a center of symmetry so that the condition for reflections is the same). There are also some hints on what may be wrong if anisotropic displacement parameters are poor.

The chapter on *Interpretation and presentation of results* covers the meaning of x, y, z and the use of drawing programs and stereo. Deformation density with X–X and X–N maps is also mentioned. *Crystallographic databases* describes how to use these and, importantly, how to put your structures in them or ensure that they are there. The ICSD (Inorganic Crystal Structure Database), CSD (Cambridge Structural Database), CRYST-MET (Metals Crystallographic Data File) and *Structure Reports* are described. The use of crystallographic information files (CIFs) and how to use the Internet to find crystal structures is also described.

The ending of the book is superb for the crystallographic experimentalist. In the outline of a crystal structure determination, the author tells the reader where to find information on each step within the book. There is also a nice list of questions at the end to ensure that the data collection and analysis were done properly. Finally, there is a worked example of a structure determination. This is a nice example of a small-molecule structure. It goes into experimental details as well as structure determination and refinement. Both Patterson and direct methods are used for structure determination.

My criticisms are minor. The main one is that the author has not paid sufficient attention to the captions for figures. This is something most of us are guilty of. It would be helpful to have a more complete description of what the figure shows and all the symbols used should be described in the caption. There is probably not enough written on structure solution but the example at the end may help clarify that. Also some terms in the text are not adequately described – maybe a glossary would help. For example, in Fig. 3.5, what is 2π?

This book is an excellent blend of theoretical and experimental information and will help students and teachers alike. The student can browse through several such texts and find the one that best satisfies his or her needs with respect to explanation and the use of mathematical and physical concepts. I suspect this book, with its outstanding blend of theory and experiment, will be ideal for many such students.

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Light is a messenger – the life and science of William Lawrence Bragg. By G. K. Hunter. Pp. xxi + 301. Oxford: Oxford University Press, 2004. Price Hardback GBP 35.00. ISBN 0-19-852921-X.

Little did I think when I chose W. L. Bragg's *Electricity* as a school prize 60 years ago that I would have the great privilege of being a member of Bragg's research team during his last appointment, as Resident Professor at the Royal Institution (the RI) and Director of the Davy Faraday Research Laboratory in London. By that time, he was recognized internationally as the Father of X-ray crystallography; what my colleagues and I encountered was a quintessentially courteous English gentleman whose relationship with us was more like a father figure than our 'boss'. Because the Resident Professor has an apartment on the RI premises, we saw a great deal of him and his wife and other family members and felt like members of an extended family, notably being invited to his daughter's wedding. Knowing him towards the end of his professional life, it seemed that he could hardly have had a more successful career – starting with the discovery of 'Bragg's law' and the derivation of the structure of sodium chloride, for which he became (and remains) the youngest person to receive a Nobel Prize, uniquely shared with his father; then to unravel the complexities of mineral structures, and of metals and alloys; and finally to have made crucial contributions in the applications of crystallography to molecular biology. What could have been more satisfying?

But, as Graeme Hunter explains in this excellent and warm-hearted biography, Bragg's life had not been anything like as straightforward as it seemed. Born in Adelaide, one of the two sons of William Henry Bragg, he was a precocious boy whose intellectual brightness led him to be lonely at school, taught in classes with older boys with whom he had little in common. He went on to study physics and mathematics in his father's department at the University of Adelaide, indeed working part of the time in his father's office – a rather odd misjudgement by his father.

When the family came to England on his father's appointment to the University of Leeds, Bragg went to Cambridge, took a second degree, and was in line for a college fellowship when he thought of a simple explanation for the geometrical relationship between a crystal and its X-ray diffraction pattern. I remember Bragg saying that nobody had a bright idea all by himself – he must have come closer than most people to doing so, but he acknowledged the value of Schuster's optics lectures in developing the idea of what became Bragg's law. The law was confirmed and the first crystal structures elucidated in collaboration with his father, who had better apparatus in Leeds. Sadly, the joint work and its recognition created lasting problems between father and son; both rather reserved men, they had difficulty in discussing the matter, and the younger inwardly resented the way in which outsiders tended to give too much credit to his father.

Bragg's career was interrupted by the First World War, in which he served with distinction, developing sound-ranging methods for locating enemy guns. Shortly after returning to Cambridge, he was appointed in 1919 to the Chair of Physics at Manchester in succession to Rutherford, at the age of 29. In Hunter's words, 'his new job quickly degenerated into a fiasco'. He had had no experience of lecturing, he had no administrative experience, and he found himself surrounded by older subordinates and confronted by tough students, many of them ex-servicemen. But he gradually learned the ropes and started a research programme, very largely carried through by his own hands, sometimes on his own and

 Acta Cryst. (2005). A**61**, 262–264

sometimes in collaboration with colleagues. His Manchester work included the development of absolute intensity measurements, determination of atomic radii, methods for the solution of crystal structures with many parameters and analysis of the silicate group of minerals. In the course of work on diopside, he was the first to use two-dimensional Fourier series to derive the electron density of a projection of the structure; he drew contours on the figure field that had been calculated and, over 30 years later, he happily accepted our invitation to draw the contours on one of the 40 sections of the 2 Å map of the enzyme lysozyme, which we had just calculated. Later work in Manchester included structural studies of metals and their alloys, but he also made many contributions to crystallographic methodology. He developed the 'fly's eye' optical analogue for use in the trial-and-error method for structure determination and he arranged financial support for Henry Lipson and Arnold Beevers so that they could print their strips as an aid to calculating Fourier syntheses.

During his Manchester period, he found he had a real talent for giving public lectures, particularly to children, with a great facility for striking analogies and delightfully drawn illustrations (he had inherited artistic talents from his mother). But he made a curious move in 1937 to become Director of the UK National Physical Laboratory, based in the London outskirts. This move, while it provided a splendid 17th century family house in Bushy Park, was unsuccessful professionally as the post was a mainly administrative one – and Bragg had neither the taste nor a gift for administration. He had, however, hardly taken up the post when the sudden death of Rutherford gave the opportunity for Bragg to succeed him as Cavendish Professor in Cambridge. Again, he found that he was not entirely welcome in his new university position; Rutherford's staff had concentrated on nuclear physics, and the Cambridge physicists considered that a crystallographer whose main impact had been in chemistry, metallurgy and mineralogy was hardly a physicist. Ultimately, Bragg's diversification of research at the Cavendish was regarded as successful and he was able to appoint individuals to develop various areas. But, again, a World War delayed progress, although it had an unexpected outcome in the arrival of individuals who wanted to turn from war-time applications of the physical sciences to the study of biological problems. Thus it came about that, with the enlightened support of the Medical Research Council, Bragg was able to establish a 'Research Unit for the Study of the Structure of Biological Systems' with support for Max Perutz, John Kendrew, Francis Crick and others.

Fascinated by the problem of whether X-ray crystallography could be used to determine the structures of biological macromolecules, Bragg himself made a number of innovatory contributions, particularly in exploring the phase relationships between the X-ray reflections from haemoglobin crystals. Again, analogies were employed, for example the use of the timetable of trains between Cambridge and London to provide a sequence of events that occurred at irregular intervals but repeated regularly every 24 h. A model that endeavoured to explain the α-helical structure of protein chains was an unfortunate disaster; not entirely, I think, for the reason that Hunter gives (that Bragg, Kendrew and Perutz were ignorant of the importance of hydrogen bonds), but more because, as a physicist/crystallographer, Bragg expected the helix to have an integral number of amino-acid residues per turn and chose 4 as the optimum. They were 'pipped to the post' by Linus Pauling and Robert Corey, who showed that satisfactory hydrogen bonds forced a non-integral number of 3.6 residues per turn. This was not the first time that Bragg had been out-done by Pauling, but their rivalry was a factor in allowing Crick and Watson to resume their attempts to build a model of DNA, once it became apparent that Pauling as well as the King's College group were hot on the DNA trail.

Bragg's final career move was at the age of 64, when he was appointed Resident Professor at the RI. Yet again, his move was initially inauspicious. For various reasons, the Institution had gone downhill since the death in 1942 of his father, who had held the position for almost 20 years. By 1954, the place was in severe crisis, financially and managerially, but Bragg decided to accept the poisoned chalice, doubtless partly because of the long-standing family connection, partly because he had delivered lectures and courses there on a number of occasions, partly because of his concern that it should continue its work of bringing science to the general population. A very sad consequence of the RI crisis was that it had led to profound disagreements with senior members of the Royal Society, who shunned Bragg when he moved to London. But he succeeded in reviving the RI's rôle and reputation, expanding its activities in popular science lectures, especially to school children, whom he delighted by exploiting his great talent for simple explanations of difficult concepts. The problem of re-establishing effective research at the RI was overcome, again with the aid of the Medical Research Council, by arranging collaborations with Perutz and Kendrew, who had remained in Cambridge. Members of Bragg's RI group participated in determining the structures of myoglobin and haemoglobin, the first two proteins to be solved by X-ray crystallography. And then, the RI group on its own (including David Phillips, Colin Blake, Robert Poljak, Louise Johnson and myself) solved the structure and activity of the enzyme lysozyme, just in time for his 75th birthday. Bragg had given his continual and enthusiastic support to the group, although our increasing use of computer methods and automatic equipment was not sufficiently 'hands-on' to really excite him.

As a Nobel Laureate, Bragg was involved with nominating candidates for Nobel Prizes, and Hunter gives an intriguing account of the behind-the-scenes activities that led to the awards in 1962 of the Nobel Prize in Chemistry to John Kendrew and Max Perutz, and the prize in Physiology or Medicine to Francis Crick, James Watson and Maurice Wilkins. This was a clear triumph for Bragg's Cambridge group. As Hunter says, Bragg seems to have found Crick something of an irritant in Cambridge – Crick had a penetrating voice and Bragg complained that 'he makes my ears buzz'. Perhaps Bragg gave Crick insufficient credit for the crucial realization that the symmetry of the DNA unit cell showed that the molecule had to have two anti-parallel chains; maybe Bragg thought it was obvious, but the significance had escaped other workers.

During his professional lifetime, Bragg had been responsible for the birth of X-ray crystallography and had seen its applications grow from the smallest inorganic compounds through to the structures of biological macromolecules and macromolecular assemblies such as viruses and muscle. Despite his dislike of administration, he had been involved with setting up the X-ray Analysis Group of the UK Institute of Physics, and then in 1948 of the International Union of Crystallography, of which he was the first President.

A couple of years after his arrival in Manchester, Bragg married Alice Hopkinson; the marriage was remarkably successful, her outgoing personality compensating for his reserved character, and her strength supporting him through difficult times. Graeme Hunter's biography skilfully interweaves detailed discussions of the scientific problems that he faced and how he solved them with accounts of the family circle, their travels at home and abroad and their interactions with their very wide circle of friends.

Having known Bragg, I was delighted to read Hunter's account, which succeeds in bringing him to life, contrasting the leaps of imagination with which he solved a succession of scientific problems with his 'ordinariness' and humility, as shown by his readiness to talk to juniors as equals and his clear enjoyment of lecturing to children. This first biography of Bragg is an excellent read.

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books received

The following books have been received by the Editor. Brief and generally uncritical notices are given of works either because of difficulty in finding a suitable reviewer without great delay or in order to inform readers prior to publication of the full review.

X-ray Compton scattering. By Malcolm J. Cooper, Peter E. Mijnarends, Nobuhiro Shiotani, Nobuhiko Sakai and Arun Bansil. Oxford: Oxford University Press, 2004, pp. XVII + 374. Price GPB 95.10. ISBN 0 19 850168 4.

This book provides condensed matter and materials physicists with an authoritative, up-to-date, and very accessible account of the Compton scattering method, leading to a fundamental understanding of the electronic and magnetic properties of solid materials, both elements and compounds. *Contents:* 1. M. J. Cooper: Compton scattering as a probe of electron density distributions; 2. W. Schülke: The theory of Compton scattering; 3. H. Kawata and N. Shiotani: Instrumentation for synchrotron radiation based photon sources; 4. S. Manninen: Instrumentation for laboratory based photon sources; 5. E. Zukowski: Processing of experimental data; 6. N. K. Hansen: The reconstruction of momentum density; 7. L. Dobrzynski: Momentum density studies by the maximum entropy method; 8. P. E. Mijnarends, Y. Kubo, B. Barbiellini, A. Bansil: Momentum density studies in crystalline solids: theory; 9. N. Shiotani: Experimental studies of momentum density in metals and alloys; 10. N. Sakai: Spin-dependent Compton scattering; 11. N. Shiotani, H. Fretwell, M. J. Cooper: Compton scattering and the allied techniques.