C. R. Chimie 19 (2016) 267–273

Contents lists available at ScienceDirect

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William Lawrence Bragg: Forerunner to modern crystallography

William Lawrence Bragg was an Australian–British physicist and crystallographer who was defined by a high code of honor based on sacrifice and work. William Lawrence Bragg, who won the Nobel Prize in Physics in 1915, is most famous for his law on the diffraction of X-rays by crystals, a theory that makes it possible to calculate the positions for all dispositions of a crystal. He presented his theory to the Cambridge Philosophical Society on 11th November 1912. William Lawrence Bragg, with his encyclopedic spirit, discovered that sodium chloride crystals are not made of molecules at all, but are rather patterns of sodium and chloride ions. This early experiment served as the foundation for the science of X-ray crystallography. Because of William Lawrence Bragg, crystallography became an important tool for chemists and mineralogists. Bragg's Law is fundamental to the determination of the molecular structure of materials. Bragg's work has had an enormous impact across modern science and its applications, in medicine, physics, chemistry and the biological sciences, including determining the structures of proteins and the DNA genetic structure. Their techniques are routinely used in many industries, including the development of new drugs and chemicals, and in the mineral industry.

This year, the French Academy of Sciences is celebrating its 350th anniversary, which is the perfect occasion to remember William Lawrence Bragg, as he was also a member of the French Academy of Sciences.

The life of Bragg: *O sancta simplicitas*!

In the year in which Benz invented the accelerator (to allow drivers to control speed), a Benz automobile was started with a spark ignition, Branly launched wireless telegraphy, and the central automatic telephone was invented, William Lawrence Bragg was born. When William Lawrence Bragg was born, a great artist, Vincent Van Gogh, disappeared from the Earth. Life and death, the Sky and the Earth! *Pretium doloris*: the tragedy of Van Gogh's death and the joy of Bragg's birth. William Lawrence Bragg was born five years before Röntgen discovered X-rays (1895).

William Lawrence Bragg, the eldest child of William Henry and Gwendoline, was born in Adelaide, South Australia, on 31 March 1890. He had a brother and a sister. His father was the Professor of Mathematics and Physics at the University of Adelaide. He received his early education at St. Peter's College, located at his birthplace. He was a very able student, and from the age of 11, he studied at this college. He was an impressionable boy and showed an early interest in science. In 1904, at age 15, William Lawrence Bragg entered Adelaide University to study mathematics, chemistry, and physics. He graduated in 1908, at the age of 18. In the same year, his father accepted the Chair of Physics at Leeds University and brought the family back to England. William Lawrence Bragg entered Trinity College, Cambridge, and received a major scholarship in mathematics. After initially excelling in mathematics, he transferred to the physics course in the later years of his studies. In Trinity College, Cambridge, he obtained first class honors in the Natural Science Tripos in 1912. After finishing his studies, he stayed on to work at the Cavendish Laboratory. From 1912 to 1914, he worked with his father, and in 1914, he was appointed as a fellow and lecturer in Natural Sciences at Trinity College and began his research under the supervision of Thomson. The First World War interrupted his work. Bragg was commissioned as a 2nd Lieutenant in the Leicester Royal Horse Artillery, and in August 1915, he began working on sound-ranging methods for locating enemy's guns. In the autumn of 1915, Bragg's brother Robert was killed in the War. He supervised the work on enemy gun location, between 1917 and 1919, rising to the rank of Major. In 1919, William Lawrence Bragg was appointed to succeed Rutherford at Manchester University, where he held the Langworthy Chair, which was, at that time, arguably the second most important position in Britain after the Cambridge Chair, where Rutherford succeeded Thomson. He held this post until 1937. However, he was elected the Fellow of the Royal Society in 1921. In 1937, Bragg moved to the National Physical Laboratory as a director for a year, but after Rutherford's premature death, he was invited to Cambridge as the Cavendish Professor of Experimental Physics. He was

http://dx.doi.org/10.1016/j.crci.2016.02.007
1631-0748

the Cavendish Professor of Experimental Physics, Cambridge, from 1938 to 1953. He moved to the Royal Institution, London, as the Fullerian Professor of Chemistry between 1954 and 1966 and as director of the Davy–Faraday Research Laboratory – a post once held by his father. In 1941, he was knighted as 'Sir Lawrence' and spent 6 months as a Scientific Liaison Officer in Canada. Between 1939 and 1943, he was the President of the Institute of Physics. He was the Emeritus Professor from 1966 to 1971.

William Lawrence Bragg was awarded the Barnard Medal in 1914, the Nobel Prize in Physics for his work on X-ray crystallography in 1915, the Hughes Medal of the Royal Society in 1931, the Royal Medal of the same Society in 1946, and the Roebling Medal of the Mineral Society of America in 1948. He was awarded the Copley Medal by the Royal Society for contributions to the development of structural determination methods by X-ray diffraction in 1966 and was appointed to the Order of the Companion of Honor in 1967.

He was the Chairman of the Frequency Advisory Committee from 1958 to 1960. Knighted in 1941, Sir Lawrence held the degrees of M.A. (Cambridge), Honorary D.Sc. (Dublin, Leeds, Manchester, Lisbon, Paris, Brussels, Liege, and Durham), honorary Ph.D. (Cologne), and honorary LL.D. (St. Andrews). He received many honorary fellowships and was an honorary or foreign member of the French, American, Chinese, Swedish, Dutch, and Belgian Scientific Academies.

In 1921, he married the charming Alice Hopkinson, a historian from Cambridge, with whom he had four children: two sons (Stephen and David) and two daughters (Margaret and Patience). Stephen became the third generation of Bragg's to study mathematics at Cambridge University.

Research activities or *dignitas dignitatum*

William Lawrence Bragg started his first important work as a result of the claim made in 1912 by Friedrich, Knipping, and Laue that they had observed the diffraction of X-rays by a crystal. Over the summer of 1912, William Lawrence Bragg had many conversations about X-rays and crystals with his father and began investigating von Laue X-ray patterns. Laue used a crystal to create a diffraction pattern, proving that X-rays were transverse (crosswise) electromagnetic waves, similar to light. William Lawrence Bragg, believing that Laue's explanation was incorrect in detail, carried out a series of ingenious, original experiments that led to a sudden and brilliant inspiration that ultimately solved the riddle. William Lawrence Bragg suggested that ZnS should be seen as face-centered cubic rather than as simple cubic. He was then able to show that, as a result, the diffraction pattern was entirely explicable as having arisen from the diffraction of white X-radiation through a three-dimensional grating. Laue had calculated the conditions for the diffracted intensity maxima for the simple cubic system, where the incident beam was parallel to one side of the cell. William Lawrence Bragg discovered how to use X-rays to determine the molecular structure of crystals. William Lawrence Bragg also posited Bragg's law, $n \cdot \lambda = 2\, d \sin\theta$, the equation that links the wavelength of X-rays to the distance between two crystal planes and the angle of incidence. William Lawrence Bragg identified that X-rays were explained, in part, as waves and also as particles, and from this insight, he developed Bragg's law. The Bragg's showed that crystals of substances such as sodium chloride contain no actual NaCl molecules, but are simply sodium and chloride ions arranged with geometric regularity. This discovery revolutionized theoretical chemistry. William Lawrence Bragg analyzed the arrangements of atoms within the crystals, while his father designed an X-ray spectrometer and further explored X-ray radiation. Together, they created the new science of X-ray crystallography. In the case of KCl, the atoms are of approximately equal scattering power, which is reflected in the simple cubic lattice to which both, as it were, contribute. This is not the case for KBr, where the lattice is defined by the heavier Br atom. NaCl is an intermediate case, reflecting the greater but not predominant scattering power of the Cl atom. In July 1913, the Bragg's published the structure of diamond, showing the carbon atoms to be tetrahedral. William Lawrence Bragg showed that the further quantitative study of intensities could be used to determine the position of those atoms, which are not fixed with reference to symmetry considerations. In this paper, he solved the structures of FeS and $CaCO_3$, both with a single such parameter and the first of such structures to be solved. This work jointly earned William Lawrence Bragg and his father the Nobel Prize for Physics in 1915, "for their services in the analysis of crystal structure by means of X-rays". At twenty-five, William Lawrence Bragg was the youngest ever Nobel Laureate.

After the War, the close collaboration between father and son ended, but it was natural that their work would continue to overlap. To prevent a *casus belli* between father and son, they decided to divide up the available work and agreed to stick to separate areas of X-ray crystallography. William Lawrence Bragg was to focus on inorganic compounds, metals and silicates, while his father was to focus on organic compounds.

In 1948, Bragg became interested in the structure of proteins. After the war, William Lawrence Bragg established a unit for the study of the molecular structure of biological systems at the Cavendish Laboratory, with funding from the Medical Research Council. In 1953, Francis Crick and James Watson determined the double helical structure of DNA and were awarded the Nobel Prize in Physiology or Medicine in 1962. Max Perutz and John Kendew, working at both the Royal Institution and the Cavendish Laboratory, determined the structures of hemoglobin and myoglobin, for which they won the Nobel Prize in Chemistry in 1962. Working with William Lawrence Bragg during the 1960s at the Royal Institution, David Phillips determined the structure of an enzyme, lysozyme, for the first time.

In his career he published 257 papers and 13 books, many of which were translated into several languages, none more so than the write-up of his Royal Institution Christmas Lectures entitled "Electricity" in 1936, which was also published in Swedish (1937), Polish (1939), Czech (1940), Hungarian (1948), Finnish (1950), German (1951), Japanese (1951), and Italian (1953). Even after his retirement as a Director there in 1966, he composed many fine popular articles such as "The Art of Talking about Science", "The Spirit of Science", and "What Makes a Scientist", as well as his famous foreword to The Double Helix by Watson. In it he said that Watson "writes with a Pepys-like frankness. Those who figure in the book must read it in a very forgiving spirit."

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