1.10: Biographical outlines

In the context of this chapter, you will also be invited to visit these sections...

- **Nobel Laureates through Crystallography**
- **Ewald Prize Laureates by the IUCr**

As mentioned in the **introduction**, Crystallography is one of the scientific disciplines that has most clearly influenced the development of Chemistry, Biology, Biochemistry and Biomedicine. Although in other pages we made some reference to the scientists directly involved at the early stages, this chapter is aimed at presenting short biographical outlines.

As a supplement of the biographical notes presented in this chapter, the reader can also consult the **early historical notes about crystals and Crystallography offered in another section**.

The biographical outlines object of the present chapter (shown below) have been distributed in groups, in chronological order, using the terminology of some musical sections and tempos, trying to describe their relevance, at least from a historical perspective.

- **Prelude (1901)**
- **Overture (1914)**
- **Allegro ma non tropo (1915)**
- **Allegro molto (1934-1935)**
- **Andante (1940-1960)**
- **Finale (1970-1980...)**

1901"Prelude", by Wilhelm Conrad Röntgen

Wilhelm Conrad Röntgen

Wilhelm Conrad Röntgen (1845-1923). None of this would have been possible without the contribution of Wilhelm Conrad Röntge***n,*** who won the first Nobel Prize in Physics (1901) for his discovery of X-rays.

Although many other biographical personal references to Röntgen **can be found on the internet**, we **recommend visiting the site prepared by Jose L. Fresquet** (in Spanish). In the following paragraphs we summarize the most relevant details and add a few others.

Wilhelm Conrad Röntgen was born on March 27, 1845, at Lennep in the Lower Rhine Province of Germany, as the only child of a manufacturer and merchant of cloth. His mother was Charlotte Constanze Frowein of Amsterdam, a member of an old Lennep family which had settled in Amsterdam. When he was 3 years old his family moved to Holland. From 16 to 20 years old he studied at the *Technical School in Utrecht*, and he then moved to Zurich where he got the corresponding academic degree in mechanical engineering.

After some years in Zurich, as assistant professor of physics under August Kundt, in 1872 (27 years old), he moved to the University of Würzburg. However, as he couldn't find any job (he previously couldn't pass his exams in Latin and Greek) he moved to Strasbourg where he finally got a position as professor in 1874. Five years later he accepted a teaching position at the *University of Giessen* and finally at 45 years old, he obtained a professorship in physics at Würzburg, where he became Rector.

His work on cathode rays led him to the discovery of a new and different kind of rays. On the evening of November 8, 1895, working with an enclosed and sealed discharge tube (to exclude all light), he found that a paper plate (covered on one side with barium platinocyanide and placed accidentally in the path of the rays) became unexpectedly fluorescent, even when it was as far as two metres from the discharge tube.

It took a month until Röntgen understood the importance of this new radiation and he immediately sent a scientific communication to the *Society for Physics and Medicine* in Würzburg...Specifically, the first sentences of his official statement (written in a nice German language) read:

Lässt man durch eine Hittorf'sche Vacuumröhre, oder einen genügend evacuirten Lenard'schen, Crookes'schen oder ähnlichen Apparat die Entladungen eines grösseren Ruhmkorff's gehen und bedeckt die Röhre mit einem ziemlich eng anliegenden Mantel aus dünnem, schwarzem Carton, so sieht man in dem vollständig verdunkelten Zimmer einen in die Nähe des Apparates gebrachten, mit Bariumplatincyanür angestrichenen Papierschirm bei jeder Entladung hell aufleuchten, fluoresciren, gleichgültig *ob die angestrichene oder die andere Seite des Schirmes dem Entladungsapparat zugewendet ist. Die Fluorescenz ist noch in 2 m Entfernung vom Apparat bemerkbar. Man überzeugt sich leicht, dass die Ursache der Fluorescenz vom Entladungsapparat und von keiner anderen Stelle der Leitung ausgeht.*

*After producing an electrical discharge with a **Ruhmkorff's coil** through a **Hittorf**'s vacuum tube, or a sufficiently evacuated **Lenard**, **Crookes** or similar apparatus, covered with a fairly tight-fitting jacket made of thin, black paperboard, one sees that a cardboard sheet coated with a layer of platinum and barium cyanide, located in the vicinity of the apparatus, lights up brightly in the completely darkened room regardless of whether the coated side is pointing or not to the tube. This fluorescence occurs up to 2 meters away from the apparatus. One can easily be convinced that the cause of the fluorescence proceeds from the discharge apparatus and not from any other source of the line.*

Una nueva clase de rayos... Comunicación científica para la Sociedad de Física y Medicina

Comunicación oficial a la Sociedad de Medicina Física de Würzburg. Obtenga un copia de este artículo

Incredible light! WC Röntgen. His high flight stops! The Nobel Prize in the press Death notice

Röntgen's discovery quickly produced a social commotion... "Incredible light!". However, almost at the same speed, his public celebrity dropped to a minimum... "his high-flying stopped...". It was during the first months of 1896, after sending to the *British Medical Journal* an X-ray photograph of a broken arm, that Röntgen began to regain the public's confidence, demonstrating the diagnostic capacity of his discovery. However, it took still many years until his "incredible light" was recognized as of medical interest. It was awarded the first **Nobel Prize for Physics in 1901**. Wilhelm Conrad Röntgen died in Munich on 10 February 1923 from carcinoma of the intestine. It is not believed his carcinoma was a result of his work with ionizing radiation because of the brief time spent on those investigations and because he was one of the few pioneers in the field who used protective lead shields routinely.

If you can read Spanish, there is also an extensive chapter dedicated to both the **historical details around Röntgen and his discovery.**

1914 ***"Overture", by Max von Laue, with accompaniment by Paul P. Ewald***

Max von Laue

Max von Laue (1879-1960). If Röntgen's discovery was important for the development of Crystallography, the second qualitative step forward was due to another German, Max von Laue, Nobel Prize for Physics in 1914, who trying to demonstrate the undulatory nature of X-rays, discovered the phenomenon of X-ray diffraction by crystals. A complete **biographical description can also be found through this link**.

Max von Laue was born on October 9, 1879 at Pfaffendorf, in a little town near Koblenz. He was the son of Julius von Laue, an official in the German military administration, who was raised to hereditary nobility in 1913 and who was often sent to various towns, so that von Laue spent his youth in Brandenburg, Altona, Posen, Berlin and Strassburg, going to school in the three last-named cities. At the Protestant school at Strassburg he came under the influence of Professor Goering, who introduced him to the exact sciences, where he studied Mathematics, Physics and Chemistry. However, he soon moved to the *University of Göttingen* and in 1902 to the *University of Berlin*, where he began working with Max Planck. A year later, after obtaining his doctorate degree, he returned to Gottingen, and in 1905 he went back to Berlin as assistant to **Max Planck, who also won the Nobel Prize for Physics in 1918**, ie four years after von Laue. Between 1909 and 1919 he went through the Universities of Munich, Zurich, Frankfurt and Würzburg, and he finally returned to Berlin where he earned a position as a professor.

Paul Peter Ewald

Paul Peter Ewald (1888-1985). It was during this last period, namely in 1912, when he met Paul Peter Ewald in Munich. Ewald was then finishing his doctoral thesis under **Arnold Sommerfeld (1868-1951)**, and he got Laue interested in his experiments on the interference between radiations with large wavelengths (practically visible light) on a "crystalline" model based on resonators. Note that at that time the question on wave-particle duality was also under discussion.

The idea then came to Laue that the much shorter electromagnetic rays, which X-rays were supposed to be, would cause some kind of diffraction or interference phenomena in a medium and that a crystal could provide this medium. An excellent historical description of these facts and the corresponding experiments, conducted by Walter Friedrich and Paul Knipping under the direction of Max von Laue, can be found in an **article by Michael Eckert**. The original article of that experiment, signed by Friedrich, W., Knipping, P. and Laue, M., was published with the reference: **Sitzungsberichte der Kgl. Bayer. Akad. der Wiss. (1912) 303–322**, although it was later collected by **Annalen der Physik (1913) 346, 971-988**.

It's amazing how quickly Ewald developed the interpretation of Max von Laue experiments, as it can be seen in **his original article, published in 1913 (in German), available through this link**. Recognizing the role played by Ewald for the development of Crystallography, **the International Union of Crystallography grants the Prize and Medal that carry the name of Paul Peter Ewald**.

And so was it that using a crystal of copper sulfate and some others from zinc blende, in front of an X-ray beam, how Laue got the confirmation on the undulatory nature of the rays discovered by Röntgen (see images below). For this discovery, and **its interpretation**, Max von Laue received the **Nobel Prize for Physics in 1914**. But at the same time, his experiment created many questions on the nature of crystals...

Primer diagrama de difracción que obtuvo Laue con un cristal de sulfato de cobre

Uno de los primeros diagramas de difracción que obtuvo Laue usando un cristal de Blenda

Left: *First X-ray diffraction pattern obtained by Laue and his collaborators using a crystal of copper sulphate*

Right: *One of the first X-ray diffraction patterns obtained by Laue and his collaborators using some crystals of the mineral Blende*

Laue was always opposed to National Socialism, and after the Second World War he was brought to England for a short time with several other German scientists contributing to the **International Union of Crystallography**. He returned to Germany in 1946 as director of the *Max Planck Institute* and professor at the *University of Göttingen*. He retired in 1958 as director of the *Institute of Physical Chemistry Fritz Haber* in Berlin, a position to which he had been elected in 1951. On 8 April, 1960, while driving to his laboratory, Laue’s car was struck by a motorcyclist in Berlin, The cyclist, who had received his license only two days earlier, was killed and Laue’s car flipped. Max von Laue (80 years old) died from his injuries sixteen days later on April 24.

1915"Allegro, ma non troppo", by Bragg *(father & son)*

William Henry Bragg William Lawrence Bragg

Izquierda: **William Henry Bragg (1862-1942)**

Derecha: **William Lawrence Bragg (1890-1971)**

This time it did not happen as with Röntgen. Max von Laue's discovery became immediately known, at least by the British **William Henry Bragg (1862-1942)** and his son **William Lawrence Bragg (1890-1971)**, who in 1915 shared the Nobel Prize for Physics for demonstrating the usefulness of the phenomenon discovered by von Laue (X-ray diffraction) in studying the internal structure of crystals. They showed that X-rays diffraction can be described as specular reflection by a set of parallel planes through all lattice elements in such a way that a diffracted beam is obtained if:

$$2.d.\sin\theta = n.\lambda$$

where d is the distance between the planes, θ is the angle of incidence, n is an integer and λ is the wavelength. Through this simple approach the determination of crystal structures was made possible.

William Henry Bragg studied Mathematics at the *Trinity College* in Cambridge and subsequently Physics at the Cavendish Laboratory. At the end of 1885, he was appointed professor at the *University of Adelaide* (Australia), where his son (William Lawrence Bragg) was born. W. Henry Bragg became successively Cavendish Professor of Physics at Leeds (1909-1915), Quain Professor of Physics at the University College London (1915-1925), and Fullerian Professor of Chemistry in the Royal Institution.

His son, William Lawrence, studied Mathematics at the University of Adelaide. In 1909, the family returned to England and W. Lawrence Bragg entered as a fellow at *Trinity College* in Cambridge. In the autumn of 1912, during the same year that **Max von Laue** made public his experiment, the young W. Lawrence Bragg started examining the phenomenon that occurs when putting a crystal in front of the X-rays, presenting its first results (**The diffraction of short electromagnetic waves by a crystal**) at the headquarters of the Cambridge Philosophical Society during its meeting in November 11th, 1912.

In 1914, W. Lawrence Bragg was appointed Professor of Natural Sciences at *Trinity College*, and that same year he was awarded the Barnard Medal. The two years (1912-1914) he worked with his father on the experiments of refraction and diffraction by crystals led to a lecture of W.H. Bragg (**Bakerian Lecture: X-Rays and Crystal Structure**) and to the famous article **X-rays and Crystal Structure**, also published in 1915. That same year, he (25 years old!) and his father, shared the Nobel Prize in Physics.

Father and son were able to explain the phenomenon of X-ray diffraction in crystals through crystallographic planes acting as special mirrors for X-rays (**Bragg's Law**), and showed that the crystals of substances such as sodium chloride (NaCl or common salt) do not contain molecules of NaCl, but simply ions of Na^+ and Cl^-, both regularly ordered. These ideas revolutionized Theoretical Chemistry and caused the birth of a new science: X-ray Crystallography.

Unfortunately, after the First World War, some difficulties arose between William Lawrence and his father when the general public did not directly credit W. Lawrence with his contributions to their discoveries. Lawrence Bragg desperately wanted to make his own name in research, but he sensed the triumph of their discoveries passing to his father, as the senior man. W. Henry Bragg tried his best to remedy the situation, always pointing out which aspects of their work were his son's ideas; however, much of their work was in the form of joint papers, which made the situation more difficult. Sadly, they never discussed the problem, and the trouble lingered for many years. The close collaboration between father and son ended, but it was natural that their work would continue to overlap. They decided to divide up the available work, and agreed to focus on separate areas of X-ray crystallography. W. Lawrence was to focus on inorganic compounds, metals and silicates, whereas William H. Bragg was to focus on organic compounds.

In 1919, William Lawrence was made Langworthy Professor of Physics at *Victoria University*, Manchester, where he married and remained until 1937. There, in 1929, he published an excellent article on the use of the Fourier series to determine crystal structures, **The Determination of Parameters in Crystal Structures by means of Fourier Series**.

In 1941 father and son were knighted (Sir) and a year later (1942) William Henry died. In subsequent years, William Lawrence was interested in the structure of silicates, metals, and especially in the chemistry of proteins. He was appointed Director of the *National Physical Laboratory* in Teddington and professor of Experimental Physics at the *Cavendish Laboratory* (Cambridge). In 1954, he was appointed Director of the *Royal Institution* in London, establishing his own research group aimed at studying the structure of proteins using X-rays. William Lawrence Bragg died in 1971, aged 81. The **IUCr** published an **obituary that you can reach through this link**.

The year 2012 represents the centennial of the first single crystal X-ray experiments, performed at the Ludwig Maximilian Universität, Munich (Germany), by Paul Knipping and Walter Friedrich under the supervision of Max von Laue, and especiallythe the experiments done by the Braggs. **The interested reader can enjoy reading the chapters published as a reminder by the International Union of Crystallography, to be found through the links shown below.**

34-1935"Allegro molto", *by Arthur Lindo Patterson, and David Harker as soloist*

Arthur Lindo Patterson

Arthur Lindo Patterson (1902-1966). It is unexplainable how the name of Arthur LIndo Patterson is slowly fading and entering history almost as a stranger, at least since the last decade of the Twentieth Century. Probably his name remains associated only with some crystallographic calculation subroutine. However, as **mentioned in another chapter**, the contribution of Patterson to Crystallography can be seen as the single most important development after the discovery of **X rays by Röntgen** in 1895.

Arthur Lindo Patherson was born in the early years of the Twentieth Century in New Zealand, but his family soon emigrated to Canada, where he spent his youth. For some unknown reason, he went to school in England before returning to Montreal (Canada) to study Physics at *McGuill University*, where he obtained his master's degree with a thesis on the production of hard X-rays (with small wavelengths) using the interaction of Radio β radiation with solids. He performed his first experiments on X-ray diffraction during a period of two years at the laboratory of **W.H. Bragg** at the *Royal Institution* in London. At that time he was aware that, although in small crystal structures the location of atoms in the unit cell was a relatively simple problem, the situation was virtually unfeasible in the case of molecular compounds, or in general with more complex compounds.

After a stay in the lab of **W.H. Bragg**, Lindo Patterson spent a very productive year in the *Kaiser-Wilhelm Institute* in Berlin, with a grant from the **National Research Council** of Canada to work under **Hermann Mark**. With his work, he contributed decisively to the determination of particle size using X-ray diffraction, and started to become interested in the theory of the Fourier transform, an idea that some years later would become his obsession in connection with the resolution of crystal structures.

In 1927, he returned to Canada and a year later completed his PhD at *McGuill University*. After two years with R.W.G. Wyckoff in the *Rockefeller Institute* in New York, he accepted a position at the *Johnson Foundation for Medical Physics*in Philadelphia which gave him the chance to learn X-ray diffraction applied to biological materials. In 1931 he published two articles on Fourier series as a tool to interpret X-ray diffraction data: **Methods in Crystal Analysis: I. Fourier Series and the Interpretation of X-ray Data** and **Methods in Crystal Analysis: II. The Enhancement Principle and the Fourier Series of Certain Types of Function**.

In 1933, he moved to the *MIT* (*Massachusetts Institute of Technology*) where, through his friendship with the mathematician **Norbert Wiener**, he started learning Fourier theory, and especially the properties of the Fourier transform and convolution. That was how, in 1934, his equation (the **Patterson Function**) was formulated in an article entitled **A Fourier Series Method for the Determination of the Components of Interatomic Distances in Crystals**, opening enormous expectations for the resolution of crystal structures. However, due to the technological precariousness of those days in addressing the large amount of sums involved in his function, it took some years until his discovery became effective in indirectly resolving **the phase problem**.

Patterson's death, in November 1966, resulted from a massive cerebral hemorrhage.

David Harker

In addition to the technical difficulties existing at that time in solving complex mathematical equations, the function introduced by **Arthur L. Patterson**, clearly presented significant difficulties in the case of complex structures. At least it was so until, in 1935, **David Harker (1906-1991)**, a "trainee", realized the existence of special circumstances that significantly facilitated the interpretation of the **Patterson Function**, and of which **Arthur L. Patterson** had not been aware.

David Harker was born in California, and graduated in 1928 as a chemist at Berkeley. In 1930, he accepted a job as a technician in the laboratory of the Atmospheric Nitrogen Corp. in New York, where, through the reading of articles related to crystal structures, his interest in crystallography increased. Due to the great economic depression in 1933, he lost the job and returned to California. Using some savings, he was able to enter the California Institute of Technology. There, supervised by **Linus Pauling**, he began to experiment with the resolution of some simple crystal structures.

During one of the weekly talks in **Pauling's** lab, the **function recently introduced by Arthur L. Patterson** was described and Harker was immediately aware of the difficulties implied in the many calculations in attaining the Patterson map, but especially the difficulty in interpreting it in structures with many atoms. However, a few nights after the speech, he woke up suddenly and said it has to work!. Indeed, it became clear to Harker that the Patterson map contains regions where the interatomic vectors (between atoms related by symmetry elements) are concentrated. Therefore, in order to look for interatomic vectors, one has only to explore certain areas of the map, and not the entire Patterson unit cell, which simplifies the interpretation qualitatively.

From 1936 until 1941, Harker had a professor position to teach Physical Chemistry at Johns Hopkins University, where he learned classical Crystallography and Mineralogy. During the remaining years of the 1940's, he obtained a research position at the General Electric Company and from there, together with his colleague, John S. Kasper, made another important contribution to Crystallography: **the Harker-Kasper inequalities**, the first contribution to the so-called **direct methods** for solving the **phase problem**.

During the 1950's, Harker accepted the offer of joining the Irwin Langmuir Brooklyn Polytechnic Institute to solve the structure of ribonuclease. This opportunity helped him to **establish the methodology** that, years later (1962), was used by **Max Perutz** and **John Kendrew** to solve the structure of hemoglobin. In 1959, Harker moved his team and project to the Roswell Park Cancer Institute and completed the ribonuclease structure in 1967. He retired officially in 1976, but remained somewhat active at the Medical Foundation of Buffalo (today the Hauptman-Woodward Institute), until his death in 1991 from pneumonia. There is a nice **Harker's obituary** written by William Duax.

1940-1960"Andante", score by John D. Bernal

John Desmond Bernal

John Desmond Bernal (1901-1971). Following the findings and developments by Arthur Lindo Patterson and David Harker, interest was directed to the structure of molecules, especially those related to life: proteins. And in this movement an Irishman settled in England, John Desmond Bernal, played a crucial role to the further development of crystallography.

John Desmond Bernal was born in Nenagh, Co. Tipperar, in 1901. The Bernals were originally Sephardic Jews who came to Ireland in 1840 from Spain via Amsterdam and London. They converted to Catholicism and John was Jesuit-educated. John enthusiastically supported the Easter Rising, and, as a boy, organized a Society for Perpetual Adoration. He moved away from religion as an adult, becoming an atheist. Bernal was strongly influenced by the Russian Revolution of 1917 and became a very active member of the Communist Party of Britain.

John graduated in 1919 in Mineralogy and Mathematics (applied to symmetry) at the *University of Cambridge*. In 1923, he obtained a position as assistant in the laboratory of **W.H. Bragg** at the *Royal Institution* in London, and in 1927, he returned as a professor to Cambridge. His fellow students in Cambridge nicknamed him ‘Sage’ because of his great knowledge. From there, he attracted many young researchers from *Birkbeck College* and *King's College* to the field of macromolecular crystallography. In 1937, he obtained a professor position in London at *Birkbeck College*, from where he trained many crystallographers (Rosalind Franklin, Dorothy Hodgkin, Aaron Klug and Max Perutz, among others). Undoubtedly, John D. Bernal has earned a prominent position in the Science of the Twentieth Century. He showed that, under appropriate conditions, a protein crystal can maintain its crystallinity under exposure to X-rays. Some of his students were able to solve complex structures such as hemoglobin and other biological materials of importance, such that crystallographic analysis started to revolutionize Biology. John Bernal, who died at the age of 70, was also the engine of crystallographic studies on viruses, together with his collaborator, Isadore Fankuchen.

The developments of the **Bragg's**, based on the previous discovery of **Laue** and the work by **Patterson and Harker**, raised the expectations of structural biology. Due to the Second World War, England became an attractive center, especially around **John D. Bernal**.

Max Ferdinand Perutz

Max Ferdinand Perutz (1914-2002) was born in Vienna, on May 19th, 1914, into a family of textile manufacturers. They had made their fortune in the 19th Century by the introduction of mechanical spinning and weaving to the Austrian monarchy. Max was sent to school at the Theresianum, a grammar school derived from an officers' academy at the time of the empress Maria Theresia. His parents suggested that he should study law in preparation for entering the family business. However, a good schoolmaster awakened his interest in chemistry and he entered the *University of Vienna* where he, in his own words, "wasted five semesters in an exacting course of inorganic analysis". His curiosity was aroused, however, by organic chemistry, and especially by a course of organic biochemistry, given by F. von Wessely, in which Sir F.G. Hopkins' work at Cambridge was mentioned. It was here that Perutz decided that Cambridge was the place he wanted to work on his Ph.D. thesis.

With financial help from his father, in September 1936, Perutz became a research student at the *Cavendish Laboratory* in Cambridge under **John D. Bernal**. His relationship with **Lawrence Bragg** was also critical, and in 1937 he conducted the first diffraction experiments with hemoglobin crystals which had been crystallized in *Keilin's Molteno Institute*. Thus, from 1938 until the early fifties, the protein chemistry was done at *Keilin's Molteno Institute* and the X-ray work at the *Cavendish*, with Perutz busily bridging the gap between biology and physics on his bicycle.

After the invasion of Austria by Hitler, the family business was expropriated, his parents became refugees, and his own funds were soon exhausted. Max Perutz was saved by being appointed research assistant to **Lawrence Bragg**, under a grant from the *Rockefeller Foundation*, on January 1st, 1939. The grant continued, with various interruptions due to the war, until 1945, when Perutz was given an *Imperial Chemical Industries Research* Fellowship. In October 1947, he was made head of the newly constituted *Medical Research Council Unit for Molecular Biology*. His collaboration with Sir Lawrence Bragg continued through many years. As a memorial to Perutz you probably may consult this **obituary published in *Nature* on the occasion of his death in 2002** (otherwise you always may **download this obituary written in Spanish**).

John Cowdery Kendrew

John Cowdery Kendrew (1917-1997) was born on 24th March, 1917, in Oxford. He graduated in Chemistry in 1939 from *Trinity College*. He spent the first few months of the war doing research on reaction kinetics in the *Department of Physical Chemistry* at Cambridge under the supervision of E.A. Moelwyn-Hughes. The personal influence of **John D. Bernal** led him to work on the structure of proteins and in 1946 he joined the *Cavendish Laboratory*, working with **Max Perutz** under the direction of **Lawrence Bragg**, where he received his Ph.D. in 1949. Kendrew and Perutz formed the entire staff of the Molecular Biology Unit of the recently established (1947) *Medical Research Council*.

Although the work of Kendrew focused on myoglobin, **Max Ferdinand Perutz** and **John Cowdery Kendrew** received the Nobel Prize in Chemistry in 1962 for their work on the structure of hemoglobin and both were the first to successfully implement the **MIR methodology** introduced by **David Harker**.

Rosalond Frabklin

Rosalind Elsie Franklin (1920-1958). One of the great scientists of those years who also emerged under the direct influence of **John D. Bernal**, was the controversial and unfortunate Rosalind Franklin. There are many texts concerning Rosalind, but perhaps it is worthwhile to read the detailed pages (in Spanish) prepared by Miguel Vicente: **La dama ausente: Rosalind Franklin y la doble hélice** and **Jaque a la dama: Rosalind Franklin en King's College**, both of which do justice to her personality and to her short but fruitful work in the science of the mid-twentieth century.

In the summer of 1938, Rosalind Franklin went to *Newnham College*, Cambridge. She passed her finals in 1941, but was only awarded a titular degree, as women were not entitled to degrees from Cambridge at the time. In 1945, Franklin received her PhD from *Cambridge University*. After the war Franklin accepted an offer to work in Paris at the *Laboratoire de Services Chimiques de L'Etat* with Jacques Mering, where she learned X-ray diffraction techniques on coal and related inorganic materials. In January 1951, Franklin started working as a research associate at *King's College*, London, in the *Medical Research Council*, in the Biophysics Unit, directed by **John Randall**. Although originally she was to have worked on X-ray diffraction of proteins and lipids in solution, Randall redirected her work to DNA fibers before she started working at King's, as Franklin was to be the only experienced experimental diffraction researcher at King's in 1951.

In Randall's laboratory, Rosalind's trajectory crossed with that of **Maurice Wilkins (1916-2004)**, as both were dedicated to DNA research. Unfortunately, unfair competition led to a conflict with Wilkins which finally "took its toll". In Rosalind's absence, Wilkins showed the diffraction diagrams, which Rosalind had taken from DNA fibers, to two young scientists lacking excessive scruples... **James Watson** and **Francis Crick**.

Diagrama de difracción de una fibra de ADN, obtenido por Rosalind Franklin

Segmento de doble hélice de ADN

John Bernal called her DNA X-ray photographs "the most beautiful X-ray photographs of any substance ever taken." Rosalind's DNA diagrams provided the establishment of the double helical structure of DNA. It might be interesting for the reader to **see this short video prepared by "My Favourite Scientist"** (**also available through this link**). Using a laser pen and some bent wire Andrew Marmery from the Royal Institution in London demonstrates the principles of diffraction and **reproduces the characteristic diffraction pattern of the helical structure of DNA** (**use this other link in case of problems**). The interested reader can also access **the original manuscripts prepared by Rosalind Franklin on the structure of DNA**. Rosalind Franklin died very young, at age 37, from ovarian cancer.

Maurice Wilkins

Maurice Wilkins (1916-2004) was born in New Zealand. He graduated as a physicist in 1938 from *St. John's College*, Cambridge, and joined **John Randall** at the *University of Birmingham*. After obtaining his PhD in 1940, he joined the Manhattan Project in California. After World War II, in 1945, he returned to Europe when **John Randall** was organizing the study of biophysics at the *University of St. Andrew* in Scotland. A year later, he obtained a position at *King's College*, London, in the newly created *Medical Research Council*, where he became deputy director in 1950.

James Watson

James Dewey Watson (1928-), born in Chicago, obtained a PhD in Zoology in 1950 at the *University of Indiana*. He spent a year in Copenhagen as a Merck Fellow and during a symposium held in 1951 in Naples, met **Maurice Wilkins**, who awoke his interest in the structure of proteins and nucleic acids. Thanks to the intervention of his director (**Salvador E. Luria**), Watson in the same year got a position to work with **John Kendrew** at the *Cavendish Laboratory*, where he also met **Francis Crick**. After two years at the *California Institute of Technology*, Watson returned to England in 1955 to work one more year in the *Cavendish Laboratory* with Crick. In 1956 he joined the *Department of Biology* at Harvard.

Francis Crick

Francis Crick (1916-2004) was born in England and studied Physics at *London University College*. During the war, he worked for the *British Admiralty* and later went to the laboratory of **W. Cochran** to study biology and the principles of crystallography. In 1949, through a grant from the *Medical Research Council*, he joined the laboratory of **Max Perutz**, where, in 1954, he completed his doctoral thesis. There he met **James Watson**, who later would determine his career. He spent his last years at the *Salk Institute for Biological Studies* in California.

In connection with the unfortunate story of Rosalind Franklin, **Maurice Wilkins**, **James Watson** and **Francis Crick** received the Nobel Prize in Physiology or Medicine in 1962 for the discovery of the right handed double helix structure of DNA. The decisive role of **Rosalind Franklin** was forgotten. it is very instructive to observe the video that **hhmi biointeractive** offers about this discovery.

Dorothy C. Hodgkin

Dorothy C. Hodgkin (1910-1994), was born in Cairo, but she also spent part of her youth in Sudan and Israel, where her father became director of the *British School of Archeology* in Jerusalem. From 1928 to 1932 she settled in Oxford thanks to a grant from *Sommerville College*, where she learned the methods of crystallography and diffraction, and soon was attracted by the character and work of **John D. Bernal**. In 1933, she moved to Cambridge where she spent two happy years, making many friends and exploring a variety of problems with Bernal.

In 1934, she returned to Oxford, from where she never left, except for short periods. In 1946, she obtained a position as Associate Professor for Crystallography and although she was initially linked to Mineralogy, her work soon pointed towards the area which had always interested her and which she had learned under **John D. Bernal**: sterols and other interesting biological molecules. Dorothy Hodgkin took part in the meetings in 1946 which led to the foundation of the **International Union of Crystallography** and she visited many countries for scientific purposes, including China, the USA and the USSR. She was elected a Fellow of the *Royal Society* in 1947, a foreign member of the *Royal Netherlands Academy of Sciences* in 1956, and of the *American Academy of Arts and Sciences* (Boston) in 1958. In 1964 she was awarded the Nobel Prize in Chemistry.

1970-1980..."Finale", with an unfinished melody...

Although what happened in the first 60 years of the Twentieth Century is astonishing and somewhat unique, the "crystallographic melody" continued, and in this sense it is still worthwhile to mention other scientists who made Crystallography go further.

William N. Lipscomb

William Nunn Lipscomb (1919-2011) was born in Cleveland, Ohio, USA, but moved to Kentucky in 1920, and lived in Lexington throughout his university years. After his bachelors degree at the *University of Kentucky*, he entered graduate school at the *California Institute of Technology* in 1941, first in physics. Under the influence of Linus Pauling, he returned to chemistry in early 1942. From then until the end of 1945 he was involved in research and development related to the war. After completing his Ph.D., he joined the *University of Minnesota* in 1946, and moved to *Harvard University*in 1959. Harvard recognitions include the Abbott and James Lawrence Professorship in 1971, and the George Ledlie Prize, also in 1971. In 1976 Lipscomp was awarded the Nobel Prize in Chemistry for his contributions to the structural chemistry of boranes.

This chapter cannot be concluded without mentioning the efforts made by other crystallographers, who during many years tried to solve the **phase problem** with approaches different from those provided by the **Patterson method**, ie, trying to solve the problem directly from the intensities of the diffraction pattern and based on probability equations: **direct methods**.

Herbert A. Hauptman

Herbert A. Hauptman (1917-2011), born in New York, graduated in 1939 as a mathematician from *Columbia University*. His collaboration with **Jerome Karle** began in 1947 at the *Naval Research Laboratory* in Washington DC. He earned his PhD in 1954 from the *University of Maryland*. In 1970, he joined the crystallographers group at the *Medical Foundation* in Buffalo, where he became research director in 1972. Hauptman was the second non-chemist to win a Chemistry Nobel Prize (the first one was the physicist Ernest Rutherford).

Jerome Karle

Jerome Karle (1918-2013), also from New York, studied mathematics, physics, chemistry and biology, obtaining his master's degree in Biology from *Harvard University* in 1938. In 1940, he moved to the *University of Michigan*, where he met and married Isabella Lugosky. He worked on the *Manhattan Project* at the *University of Chicago* and earned a doctoral degree in 1944. Finally, in 1946, he moved to the *Naval Research Laboratory* in Washington DC, where he met **Herbert Hauptman**.

Isabella Karle

The monograph published in 1953 by Hauptman and Karle, *Solution of the Phase Problem I. The Centrosymmetric Crystal,* already contained the most important ideas on probabilistic methods which, applied to the **phase problem**, made them worthy of the Nobel Prize in Chemistry in 1985. However, it would be unfair not to mention the role of Jerome's wife, **Isabella Karle (1921-2017)**, who played an important role, putting the theory into practice.

Karle & Hauptman during the XIII Iberoamerican Meeting of Crystallography, Montevideo, 1994

In memory of these important persons, we show this photograph taken in 1994, during the *XIII Iberomerican Congress of Crystallography* (Montevideo, Uruguay).

Left (front to back): *Jerome Karle, Isabella Karle and Martin Martinez-Ripoll (author of these pages).*

Right (front to back): *Herbert A. Hauptman and* **Ray A. Young** *(neutron expert and one of the pioneers of the Rietveld method)*

Crystallography is (and has been) one of the most inter- and multidisciplinary sciences. It links together frontier areas of research and has, directly or indirectly, produced **the largest number of Nobel Laureates throughout history**.

Additionally, the **International Union of Crystallography (IUCr)** established, since 1986, the existence of the **Ewald Prize awarded every three years for outstanding contributions to the science of Crystallography**.

This chapter is dedicated to the many scientists who have made Crystallography one of the most powerful and competitive branches of Science for looking into the "tiny" world of atoms and molecules. It could definitely have been more extensive and detailed, because we cannot forget the participation and effort of many other scientists, past and present, but the important issue is that, after our "finale", "crystallographic music" plays on ...

2014: International Year of Crystallography The United Nations in its General Assembly A/66/L.51 (issued on 15 June 2012), after considering the relevant role of Crystallography in Science decided to proclaim **2014 International Year of Crystallography**. Click also on the left image!

We send congratulations to Gautam R. Desiraju, President of the **IUCr**, and Sine Larsen, former President of the **IUCr**, when this initiative was launched!

In this context, 11 November 2012 marked the centenary of the presentation of the paper by a young **William Lawrence Bragg (1890-1971)**, where the foundations of X-ray crystallography where outlined. For this reason, the International Union of Crystallography (**IUCr**) published a fascinating set of articles that the reader can find via the following links:

- **Celebrating 100 years of X-ray crystallography (S.W. Wilkins)**
- **A tribute to W.L. Bragg by his younger daughter (Patience Thomson)**
- **Sir Lawrence Bragg (M.F. Perutz)**
- **Background to the Nobel Prize to the Braggs (Anders Liljas)**
- **Lawrence Bragg's interest in the deformation of metals and 1950–1953 in the Cavendish – a worm's-eye view (Anthony Kelly)**
- **Lawrence Bragg, microdiffraction and X-ray lasers (J.C.H. Spence)**
- **The Bragg legacy: early days in macromolecular crystallography (Brian W. Matthews)**
- **The early development of neutron diffraction: science in the wings of the Manhattan Project (T.E. Mason, T.J. Gawne, S.E. Nagler, M.B. Nestor and J.M. Carpenter)**
- **The significance of Bragg's law in electron diffraction and microscopy, and Bragg's second law (C.J. Humphreys)**
- **Evolution of diffraction methods for solving crystal structures (Wayne A. Hendrickson)**
- **Early days in drug discovery by crystallography – personal recollections (Peter M. Colman)**

The first 50 years of X-ray diffraction were commemorated in 1962 by the International Union of Crystallography (**IUCr**) with the publication of an interesting book entitled **Fifty Years of X-Ray Diffraction, edited by Paul Peter Ewald**.

Bart Kahr and Alexander G. Shtukenberg wrote an interesting chapter, **Histories of Crystallography by Shafranovskii and Schuh**, (included in **Recent Advances in Crystallography**, where they offer a short summary of the two volumes on the *History of Crystallography* written by **Ilarion Ilarionovich Shafranovskii** (1907-1994), a Russian crystallographer who assumed the **E.S. Fedorov** (1853-1919) Chair of Crystallography at the Leningrad Mining Institute. The chapter of Kahr and Shtukenberg also include many other references, especially those taken from Curtis P. Schuh, author of at least a remarkable book entitled **Mineralogy & crystallography: an annotated bio-bibliography of books published 1469 through 1919**.

M.A. Cuevas-Diarte and S. Alvarez Reverter.are the authors of an **extensive and commented chronology on crystallography and structural chemistry**, starting in the IV Century BC.

It is noteworthy **the exhibition offered by the University of Illinois** (Vera V. Mainz and Gregory S. Girolami, *Crystallography - Defining the Shape of Our Modern World*, University of Illinois at Urbana-Champaign), commemorating the 100th Anniversary of the Discovery of X-ray Diffraction, as well as a lecture of Prof. Seymour Mauskopf from the Duke University, to be found also directly through these links: **PowerPoint format** or **pdf format**.

It is also very interesting to read the articles collected in the **special issue of Nature (2014)**, dedicated to Crystallography, especially:

- **Crystallography: Atomic secrets**

- **X-ray science: The big guns**
- **Policy: Crystallography needs a governing body**
- **History: Women in crystallography**

among other from the archive **included in the same special issue**. Nearly in the same context, Nature has also released this interesting article, entitled **Structural biology: More than a crystallographer**, about the training currently expected from crystallographers working in the field of structural biology.

Science, the journal, also joined the celebration of the **International Year of Crystallography**, devoting **a special issue that you can find via this link**.

- **Going from Strength to Strength**
- **Cutting-Edge Techniques Used for the Structural Investigation of Single Crystals**
- **Developments in X-ray Crystallographic Structure Determination of Biological Macromolecules**
- **Femtosecond Crystallography with Ultrabright Electrons and X-rays: Capturing Chemistry in Action**
- **Crystallography and Geopolitics**
