

A Tribute to Max von Laue

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Just an idea: take a crystal, surround it with photographic plates, and direct a pencil of X-rays at it, perpendicularly. It was one of those thrilling ideas that made new science. Max Laue was the proponent, in April 1912. The experiment as such had been tried out before by Röntgen himself, but without avail. Friedrich and Knipping, however, took their time and waited long enough. Overnight, the *atomic* variant of lattice theory—which had worked its way at the outskirts of crystallography—became fashionable. And, not to forget, X-rays proved to be wave-like indeed.

Max Laue originated from Pfaffendorf, a village now part of Koblenz. After his *Abitur* he enrolled at the university of Strasbourg, moving on, in 1899, to Göttingen, the place to be for theoreticians. Optics became his favourite subject. Waldemar Voigt and Otto Lummer showed the way to go. His PhD subject brought him to Berlin to study with Max Planck. In 1903 Laue defended a thesis about the diffraction which occurs during interference caused by plane parallel plates. It was Planck who asked him, in 1906, to become his assistant. Laue's *Habilitation* assessed the entropy of interfering pencils of rays. It was the time that one Albert Einstein's freshly appeared paper 'Zur Elektrodynamik bewegter Körper' was favorably discussed by Planck in a lecture at the Colloquium of Berlin's Physical Society.

Relativity: theory and experiment

Laue was in the audience. It took some time, but his conversion was unconditional. He went to see Einstein in Switzerland, soon after his *Habilitation*, to discuss details. His was one of the first experimental arguments if not proofs (1907), in the sense that he identified Einstein's 'addition theorem' with a formula derived by Fizeau (1851) for the velocity of light in flowing water. Fizeau, it is recalled, first established (together with Foucault) that in denser media light is slowed down—in conformity with the wave-theory—while the motion of some such medium may be used to move an interference pattern: the fringes produced by coherent light led through the two arms of a water circuitry slightly shifted when the flow direction was changed. Fizeau did not insist and left others the task to improve his method. It was Michelson and Morley who did so in 1887. There were some problems with the turbulence of the flowing water and Pieter Zeeman, therefore, used a movable glass stick instead. Laue produced the first general account of the recent developments in *Das Relativitätsprinzip* (1911) and succeeded in familiarizing many an estranged physicist with the broad context—and the paradoxes—of what came to be known as *special* relativity. In 1920 he would publish, as a supplement, a similar account of Einstein's latest breakthrough, *general* relativity.

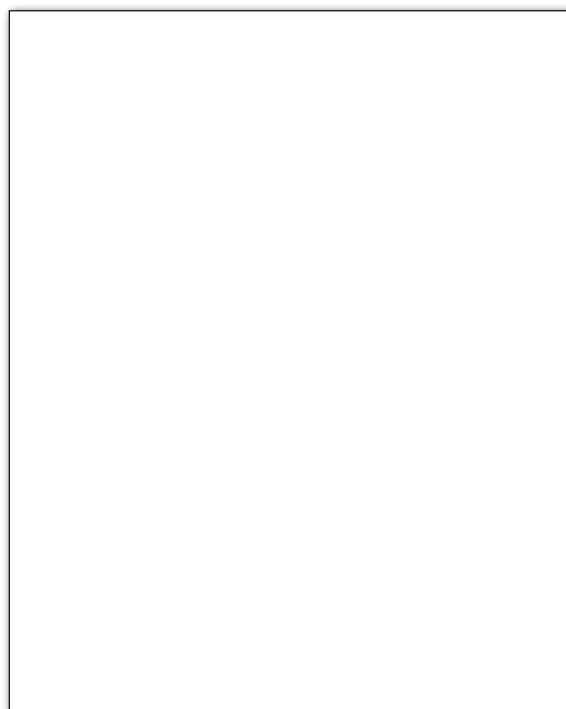
Rays and rays and... X-rays

At the turn of the XIXth and XXth century a whole series of seemingly distinct, though more or less related radiation phenomena disputed each other's priority in the physicists' attention. One of the most enigmatic was, without doubt, the one revealed by Wilhelm Röntgen in the fall of 1896. For the general public, however, it had been overshadowed, by some natural rays, spontaneously emitted by materials that could be concentrated by chemical means. Laue got involved in 1909 when he entered, as a *Privatdozent*, in the service of Arnold Sommerfeld, at the University of Munich. Sommerfeld himself had been nominated a few years before to provide the theoretical background to Röntgen's rays. Röntgen was still around, but left Sommerfeld and the latter's students free to use his instruments, among which a 50 cm Rühmkorff-inductor and a whole collection of bulbs.

Lattice theory in crystallography

The 19th century had lived with the rise of lattice theory. Crystals had been conceived of, by René-Juste Haüy (1743-1822), as well-ordered 'assemblages' of polyhedral

◀ P18 Blende (ZnS; covered with calcite) from Freiberg (Saxony). Aquarelle by Otto Caspari (1911-1980). Reproduced from H. Schröcke and K.I. Weiner, *Mineralien* (Hamburg: E. Camer, 1967).



◀ FIG. 1: ~~St~~ von Laue (1920; courtesy Nobel Foundation).

molecules composed of the atoms of the elements. Those of pyrite, for instance, were presented as 'assemblages' of cubic FeS_2 -molecules. Such 'assemblages' could take the form of a cube or orthogonal parallelepiped, naturally, but also that of a dodecahedron or octahedron, depending on the regularities during the growth. It was a personal triumph for Haüy not only that the interfacial angles could be calculated in advance, but also that they agreed closely with those measured on natural crystals, for instance, in the case of dodecahedral pyrite. His successors gradually replaced the molecules by their centres of gravity. In this way the crystal became an abstract point lattice whose symmetry properties defied the imagination of men like Delafosse, Bravais and Jordan. Particular compounds, like the alums, though, suggested the existence of *superimposed* molecular lattices: after all, the crystal water of these so-called hydrates could be easily separated from the rest, while a crystal of the original form emerged on evaporating a solution. It was Leonhard Sohncke (1842-1897) who concluded, in 1888, that any crystal could be considered as an array of as many lattices as there are atomic species in it. In the 1890's

the exact number of a priori possible *atomic* lattices (230) was rigorously deduced by mathematicians like Evgrad Fyodorov and Arthur Schönflies. When Laue arrived in Munich Sohncke's spirit was still in the air, while the latter's lattice models had survived and were regularly used in classes. There was a third lucky coincidence.

Encyclopedia of the mathematical sciences

Felix Klein and Sommerfeld had launched, in 1896, the great *Encyclopedia of the mathematical sciences*, which became the indispensable toolkit for any physicist, let's say, together with the ever growing *Physikalisch-Chemische Tabellen* of Landolt and Börnstein. Once established in Munich, Laue was chartered to assess the theory and practice of wave-optics and had, naturally, amongst many other things, to assess interference phenomena [1]. That wave-optics was part of volume V of the *Encyclopedia...*, which for all kind of reasons—*i.a.* the Great War—would not appear in print before the 1920's. The text, it is true, only assessed line gratings, but during its preparation Laue had become familiar with experiments with crossed gratings, when square arrays of identical spots show up,

▼ FIG. 2 The original set-up as used by Friedrich and Knipping to see the effect of X-ray spots, that is. The stage was set. From left to right on the table: Röntgen bulb (too low here), first diaphragm (lead foil), collimator, round turntable with the crystal at its centre and an enveloped photographic plate. A huge wooden tripod is used to rise and reset a shielding cover. Source [2]. This set-up is part of the collection of the Deutsches Museum, München (courtesy: Deutsches Museum).

Crystals and X-rays

Having finished his *Encyclopedia...* contribution, it occurred to Laue, early in 1912, that something interesting might happen when a pencil of X-rays would be directed at a crystal, the more so since the estimated wavelength of Röntgen's rays (on spectral grounds: 10^{-8} - 10^{-9} cm) was equal if not smaller than the interatomic distance (10^{-8} cm). An exchange of ideas, in February 1912, with Paul Ewald triggered a wider discussion at the Institute. An experiment, then, was staged, by Walther Friedrich and Paul Knipping. In a search for effects an easily grown copper sulphate crystal (triclinic) was first bombarded with X-rays, with photographic plates at various positions around it (Figure 2). They found that a plate *behind* the crystal manifested distinct black spots suggesting some kind of regularity. It was a small step, then, to replace the raw crystallized copper sulphate crystal by a thin 001 platelet of highly symmetric zinc sulfide (thickness: 0.5 mm; Figure 3). The result was a breathtakingly regular pattern of spots, manifesting the same symmetry elements as those deduced earlier for the crystal itself (Figure 4): a fourfold main rotation axis and four twofold rotation axes (four planes of symmetry). On enlarging the distance between the crystal and the photographic plate (say, P_5 instead of P_4), the spots kept their bigness and form, though the scale of the pattern was enlarged in the same proportion: apparently a parallel beam of rays was responsible for each spot. In the publication Laue would show how the distance between the centres of gravity of two neighbouring ZnS -molecules could be calculated, using the density $\rho = 4.06 \text{ g.cm}^{-3}$, the molar weight $M = 97.4 \text{ g}$ and Avogadro's constant, $N_A = 6.17 \times 10^{23}$:

$[97.4/\{4.06 \times (6.17 \times 10^{23})\}]^{1/3} = 3.38 \times 10^{-8}$ cm. This would be the lattice constant. It brought Laue, Friedrich and Knipping instantaneous fame. In 1913 and, again, in 1914, Laue was nominated for the Nobel Prize for Physics. There were but few nominations, it is true, but these were enough for the Selection Committee to decide in 1914 in favor of Laue.

In the 1930's Laue, in his position of chairman of the German Physical Society and deputy director of the Kaiser-Wilhelm Institute for Physics, got involved in politics, like any other German. His fierce struggle against the nomination of Johannes Stark, a fervent Nazi, at various powerful positions became emblematic for civil courage. These were also the days that he favoured the development of a new, extremely promising visualisation technique for submicron entities: the electron microscope. After the war this technique would feature among the first subjects to be launched in the new German physics. ■

Acknowledgment

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Henk Kubbinga is a historian of science at the University of Groningen and member of the EPS History of Physics Group. He is currently editing *The Collected Papers of Frits Zernike (1888-1966)*, the first two volumes of which were recently published by Groningen University Press (ISBN 978-90-814428-3-1).

Notes and References

For the broad context see *Acta Crystallographica A* 68 (1) (2012) and *Zeitschrift für Kristallographie* 227, 1 (2012), a joint issue edited by Wolfgang Schmahl and Walter Steurer.

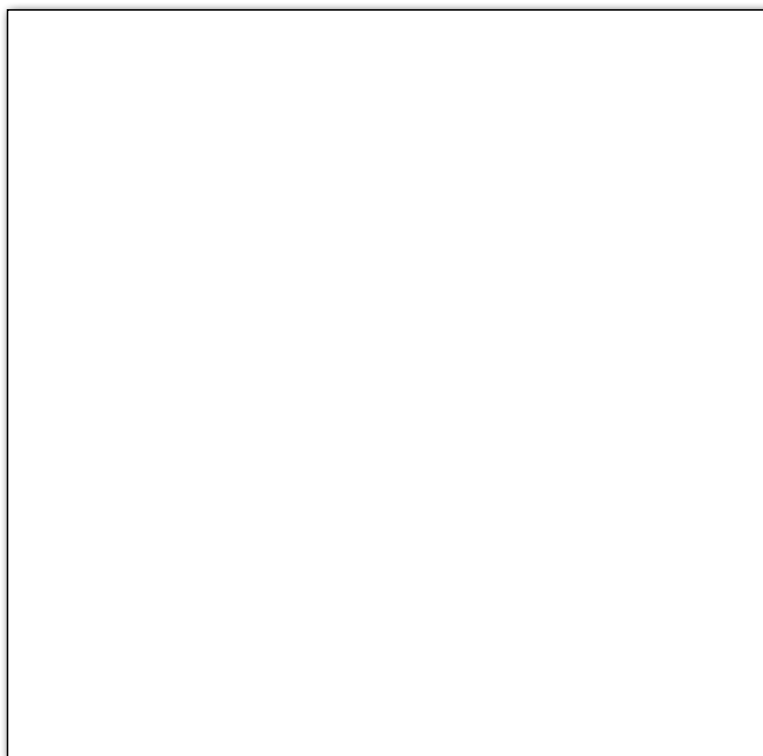
[1] M. Laue, 'Wellenoptik', in: F. Klein and Sommerfeld (eds.), *Encyklopaedie der mathematischen Wissenschaften, mit Einschluss ihrer Anwendungen*, Leipzig: Teubner, 1898-1926, volume V.3, 362 (finished by July 1915).

[2] W. Friedrich, P. Knipping and M. Laue, *Sitzungsberichte* (München) 1912, 303.



▲ FIG. 3: Final set-up of Friedrich, Knipping and Laue for the 001 platelet of ZnS. The Zösiggen bulb is now water-cooled. The platelet is glued at Kr on a newly tunable round turntable G (seen from above; interrupted line), with photographic plates as sensitive Saphragms, B1-4, narrow down the beam coming from anti-cathode A; R is a tube-of-no-return (from ref. [2]).

▼ FIG. 4: The first photogram of an 001 platelet of ZnS as made by Friedrich and Knipping and Laue (from ref. [2]).



2014: INTERNATIONAL YEAR OF CRYSTALLOGRAPHY

The UN decision was announced on 4 July 2012 by the discovery of X-ray diffraction by Max von Laue in 1912 and of the formulation of Bragg's Law in 1913. For more information, see the Website of the IUCr: www.iucr.org ■