WILLIAM LAWRENCE BRAGG

The diffraction of X-rays by crystals

*Nobel Lecture, September 6, 1922**

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Harshita Nagar

You have already honoured with the Nobel Prize Prof. von Laue, to whom we owe the great discovery which has made possible all progress in a new realm of science, the study of the structure of matter by the diffraction of X-rays. Prof von Laue, in his Nobel Lecture, has described to you how he was led to make his epochal discovery. In trying to think of some way in which diffraction effects with X-rays might be found, and the question of their true nature answered, he came to the realization that Nature had provided, in a crystal, a diffraction grating exactly suited for the purpose. It had

centimetre. The relation between this spacing and the conjectured wavelength of the X-rays was precisely that required to give diffraction effects.

In saying something about the work for which we were awarded the Nobel Prize, I feel that I cannot but speak for both my father and myself. It was with his inspiration and under his guidance that any contributions of my own were made, and it was one of the proudest moments of my life when I heard that you had associated my name with his and awarded the prize to us jointly.

Prof. von Laue had made some of his earliest experiments with a crystal of zinc sulphide, and had obtained results which proved that the diffracted pencils showed the symmetry of the underlying crystal structure, which in this case was cubic. He developed a mathematical theory of diffraction by a space lattice, and proved that these diffracted pencils were in directions which were to be expected for a series of diffracting points arranged on a cubic space lattice. In pursuing the analysis still further, he tried to account for the fact for diffracting these wavelengths. In studying his work, it occurred to me that perhaps we ought to look for the origin of this selection of certain directions of diffraction in the peculiarities of the crystal structure, and not in the constitution of the X-ray beam; this might be of the nature of white light and be composed of a continuous range of wavelengths. I tried to attack the problem from a slightly different point of view, and to see what would happen if a series of irregular pulses fell on diffracting points arranged on a regular space lattice. This led naturally to the consideration of the diffraction effects as a reflexion of the pulses by the planes of the crystal structure. The points of a space lattice may be arranged in series of planes, parallel and equidistant from each other. As a pulse passes over each diffracting point, it scatters a wave, and if a number of points are arranged on a plane the diffracted wavelets will combine together to form a reflected wave front, according to the well-known Huygens construction.

The pulses reflected by successive planes build up a wave train, which analysis shows to be composed of the wavelengths given by the formula

$$n\lambda = 2d \sin \vartheta$$

Although it seemed certain that the von Laue effect was due to the diffraction of very short waves, there remained the possibility that there might not be the X-rays. My father, in order to test this, examined whether the beam reflected by a crystal ionized a gas; this he found to be the case. He examined the strength of the reflexion at various angles, and the instrument which was first used for the purpose was developed later into the X-ray spectrometer with which we have done the greater part of our work. In this instrument the X-rays coming from a tube are limited to a narrow beam by slits, and fall on a crystal at the centre of the spectrometer table by which they are reflected; the reflected beam is received and measured in an ionization chamber.

The examination of crystal structure, with the aid of X-rays has given us for the first time an insight into the actual arrangement of the atoms in solid bodies. The study of structure by means of a microscope is limited by the coarseness of the light which illuminates the object, for we can never hope to see details smaller than the wavelength of the light. By using X-rays with their very short wavelengths, this limit of minuteness has at one step been decreased ten thousand times, for the wavelength of the X-rays is of a smaller order than the dimensions of the atomic structure. We are actually looking into the interior of the molecule and the atom with this fine-grained form of light.

The limits of the crystal pattern are arranged on a space lattice. Each limit is repeated over and over again in an identical fashion throughout the structure, at regular intervals in all directions. In analysing a crystal structure by X-rays, it is first necessary to find the dimensions of the unit cell of this space lattice, which has for its sides the primitive translation which the structure may be supposed to undergo in order to be brought into self-coincidence. It is a simple matter to achieve this. We find the angle at which a monochromatic beam of X-rays of known wavelength is reflected by the various faces of the crystal. Reflexion takes place only when the relation

$$n\lambda = 2d \sin \vartheta$$

is satisfied, and so the spacing d of the planes parallel to any face under examination can be found by measuring the angle ϑ. The dimensions of the unit

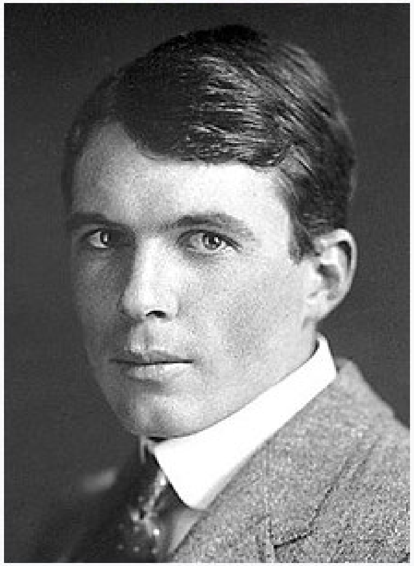
In our early work we made certain assumptions in order to unravel the complex tangle which the reflexions from some crystals represented. We supposed that the diffraction took place at the centre of each atom, as if the whole effect were localized there. Further, we supposed that the effect of an atom was proportional to its atomic weight. Neither of these assumptions is more than very approximately true, as deeper analysis has shown. However, theory shows that the strength of the scattered beams varies so greatly with slight changes in the relative positions of the atoms, that these assumptions will serve to give an accurate determination of these positions. We analysed a number of simple crystals in this way, examples of which are given in the

them too much. A small crystal can be set at the centre of the instrument, adjusted so that a zone is parallel to the axis, and then turned round so that the reflexion of various faces is observed in turn. The X-ray spectrometer may be thus used in a manner very similar to that employed by a crystallographer when he measures a crystal with a goniometer. It is a more search-

Finally, there is a still deeper application of the X-ray analysis, to the structure of the atom itself. Since the wavelength of the X-rays is less than the "atomic diameter", as it is somewhat vaguely termed, and since the rays are presumably diffracted by the electrons in the atom, we ought to be able to get some idea of the distribution of these electrons in the same way that we draw conclusions as to the grouping of the atoms. Interference between the

I have only given in this account a very brief description of the many lines of investigation which have arisen from von Laue's discovery. I wish that there were more contributions of my own to this subject which I could have described to you, to justify the supreme compliment which you paid me in giving me your award, but the war interrupted work for so many years, and since then there has been so much reorganization of all university work in England that research has been difficult to achieve. I will conclude, then, in expressing my thanks to you for giving me this opportunity of addressing you, and my gratitude for all which I owe to you.

Sir
Lawrence Bragg
CH OBE MC FRS


Lawrence Bragg in 1915

Born	William Lawrence Bragg 31 March 1890 Adelaide, South Australia
Died	1 July 1971 (aged 81) Waldringfield, Ipswich, Suffolk, England
Education	St Peter's College, Adelaide
Alma mater	University of Adelaide Trinity College, Cambridge
Known for	X-ray diffraction X-ray spectroscopy X-ray microscopy Bubble raft Bragg's law Bragg-Gray cavity theory Bragg-Williams approximation
Awards	Nobel Prize in Physics (1915) Barnard Medal (1915) Matteucci Medal (1915) Fellow of the Royal Society (1921)[1] Hughes Medal (1931) Dalton Medal (1942) International Member of the American Philosophical Society (1943) Foreign Associate of the National Academy of Sciences (1945) Royal Medal (1946) Roebling Medal (1948) International Member of the American Academy of Arts and Sciences (1959) Copley Medal (1966)

Scientific career

Fields	Physics
Institutions	University of Adelaide University of Manchester University of Cambridge
Academic advisors	J. J. Thomson W. H. Bragg
Doctoral students	John Crank Samuel Tolansky Ronald Wilfred Gurney Alex Stokes[2] Evan James Williams[3]

> The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them.
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> — *William Lawrence Bragg* —