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ON THE HISTORY OF HOLOGRAPHY

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IN 1970, the Lenin Prize for science and engineering was awarded to Yu. N. Denisyuk for his cycle of investigations "Holography With Recording in a Three-Dimensional Medium." These investigations are outstanding contributions to the development of a vigorously progressing field of applied optics, namely holography. This field is usually associated with the name of the British physicist Dennis Gabor, who made a large contribution to its development. However, the history of this new branch of optics is not so simple, and Gabor's work was preceded by other investigations, which also formulated the principles of holography.

The latest trend in the development of holography is as follows. The holographic method of recording and reproducing objects was proposed in 1948 by Gabor, as one of the methods of corpuscular (electron) optics, which was developed during the course of research aimed at perfecting electron microscopy and was tested in the optical band. As noted by Gabor himself,[1] the general idea of the holographic method in electron microscopy, as a two-step process "in which the object is registered with the aid of a beam of electrons and is reconstructed with the aid of a light beam" was a modification of an idea of W. L. Bragg, reported in 1942 in an article on "The X-ray Microscope,"[2] in which a method is proposed for visualizing a crystal lattice with the aid of diffraction by a diffraction pattern obtained with x-rays. In a more rudimentary form, this idea was formulated by W. L. Bragg even earlier, in 1939, in an article entitled, "A New Type of X-ray Microscope."[3] Gabor also mentions a 1938 article by a German optics specialist, H. Boersch, "On the Formation of Images in a Microscope."[4] In this article, Boersch shows how to obtain the image of a grating with the aid of a microscope without placing it on the stage of the microscope. This can be done by producing a light-flux distribution corresponding to the diffraction pattern obtained with the aid of the grating in the rear focal plane of the microscope objective.

Whereas it is frequently noted in the literature that Gabor developed Bragg's idea, no mention is made at all of another development of the idea, namely the work of E. Abbe and M. Wolfke. Without diminishing the great contribution made by Gabor to the development of holography, one can state quite assuredly that in principle the idea of the holographic method of obtaining images was advanced and verified experimentally by the Polish physicist Mieczyslaw Wolfke and published 28 years before Gabor's work, i.e., in 1920. In Wolfke's approach, the main principles and ideas of holography were the result of a natural synthesis of research in the field of x-ray structural analysis and the theory of the optical image produced by a microscope.

It is useful to stop and discuss the history of Wolfke's work and its contents, but first a few biographical data.

Mieczyslaw Wolfke was born in 1883 in the town of Lasek near Lodz; his father was an engineer. From 1901, when he finished secondary school, to 1904, he studied at the Mathematics and Science Department of the University of Liege (Belgium), where he passed the candidate's examination in 1904. In 1904–1907 he studied at the University of Paris. From 1907 through 1910 he worked in the physics department of the Wroclaw (Breslau) University under the direction of Professor Otto Lummer, the well known optics specialist. In 1910 he received his doctorate. In 1911 he worked at the Karl Zeiss plant in Jena, where he constructed a new mercury-cadmium lamp. He then worked as an assistant in the physics department of the Polytechnic Institute in Karlsruhe. From 1914 through 1922 he taught special courses in theoretical and experimental physics in Zurich, at the university and at the polytechnic institute. From 1922 to his death on 3 May 1947 he was professor of physics in the electrical engineering department of the Warsaw Polytechnic Institute. In 1924 and 1926 he stayed in Leyden, where he worked with Professor H. Kammerling-Onnes and Professor W. H. Keesom in the cryogenics laboratory, doing research on the dielectric constant of liquid helium, liquid and solid hydrogen, and the electric resistance of solid helium. In 1928 Keesom and Wolfke discovered two modifications of liquid helium, helium I and helium II, which, as is well known, played a tremendous role in the development of low-temperature physics, and led in particular to the discovery of superfluidity. Before the start of the Second World War, Wolfke organized a low-temperature institute in Warsaw. Wolfke was a member of the Polish Academy of Sciences and of the Academy of Technical Sciences. He was known for his democratic views. In 1936, he was attacked during a lecture by a group of fascist thugs, a fact that caused indignation in Polish society.

Wolfke became interested in the theory of the diffraction image during his work in Breslau in 1907–1910. His doctoral dissertation was devoted to the theory of the image of a grating. His investigation of this problem was based on the theory of the microscope image developed by Ernst Abbe. His results were published in 1911–1912.[5] He continued this research in Zurich and presented in 1914, as the thesis entitling him to occupy the post of a lecturer, the paper "General Theory of the Image of Self-Luminous and Non-Self-Luminous Objects," in which his results of 1912–1913 were reported.[6–11]

Culminating this cycle of research was the article "On the Possibility of the Optical Image of a Molecular Lattice."[7] In this paper, Wolfke raised the following question: "Is it possible, by using the diffraction pictures obtained when x-rays pass through a crystal, to obtain the optical image of a crystal lattice?" He answers this question in the affirmative, proposing to use the primary x-ray pattern as a diffraction grating for light waves. He then formulates a theorem that serves as the basic justification of his aforementioned proposal. The theorem in the original formulation runs as follows: "When illuminated with monochromatic parallel and perpendicular illumination, the diffraction pattern of the diffraction pattern of a symmetrical object without a phase structure is identical with the image of this object" ("Bei monochromatischer, paralleler, senkrechter Beleuchtung ist das Beugungsbild eines Beugungsbildes eines symmetrischen Objektes ohne Phasenstruktur identisch mit dem Abbild dieses Objektes"). He proves the theorem on the basis of his work of of his work of 1912–1914.

The theoretical conclusion was verified by Wolfke experimentally on different structures placed in parallel beams of the yellow spectral line of mercury. Wolfke wrote: "The theorem proved above was verified with different optical structures in a parallel beam of the light of the yellow mercury line, and it turned out to be correct for all cases. In this case, to obtain a sharp picture it was necessary to use as strong a light source as possible with a very narrow pointlike monochromator slit." Unfortunately, no other details of Wolfke's experiment are given in the article. The results of this experiment were obtained 28 years later by D. Gabor.[11] and in addition the latter observed that the reproduced image of the object rotates when the position of the observer relative to the illuminated diffraction picture changes.

In concluding his article, Wolfke mentioned that something similar to the reconstruction of the image was observed by E. Hupka in an investigation of the reflection of x-rays.[8]

Wolfke's work did not attract the interest of physicists, since it was in advance of the objective requirements of science at that time and was forgotten. Only this can explain why H. Boersch proposed 18 years later the development of the secondary-image method, without mentioning Wolfke's paper, although the latter was published in a widely circulated journal.*

The fundamental significance of Wolfke's work was pointed out by the present author some years after the start of the vigorous development of laser holography in a letter to the Polish newspaper "Polityka."[9] This stimulated the publication of a more detailed article by Professor Doctor Szczepan Szczeniowski, Corresponding Member of Polish Academy of Sciences and Director of the Institute of Physics of the Warsaw Polytechnic Institute, entitled "A Polish Physicist Was the Forerunner of Holography."[10]

In connection with correction of the history of the development of holography and its stimulating ideas, it is useful to mention also the further development of its fundamental premises.

The next new and principal stage in the development of holography, following the work of Wolfke and Gabor, was the 1962 investigations of the Soviet physicist Yu. N. Denisyuk,[11] Corresponding Member of the U.S.S.R. Academy of Sciences. In his papers, Denisyuk formulated succinctly the principle of optical holography, and generalized Gabor's method. The work by E. N. Leith and J. Upatnieks (1964)[12] which extends Gabor's method to optics, is a particular case of Denisyuk's results.

The gist of Denisyuk's method lies in recording the wave field produced when the flux of the direct coherent light is added to the light flux scattered by the observed body. The scattered and incident fluxes add up to form a standing-wave field, and registration of the latter can yield data on the shape of the scattering surface (the boundaries of the body) and on the field of the absorption coefficient on this surface. Subsequent passage of light through the record of the interference wave field makes it possible to reconstruct an image of the object. As noted by the author himself, this method is a further development of a color-photography method developed in 1892 by the French physicist G. Lippman,[13] as well as Gabor's method. The shape and coloring of the observed object are reconstructed simply by illuminating, with ordinary white light, the standing-wave field recorded in the form of a density distribution in a thick photographic emulsion.

Denisyuk wrote in 1962: "This phenomenon can turn out to be useful for the development of an image-production technique in which a complete illusion of the reality of the objects is created, in structural analysis, sonar, radar, ultrasonic flaw detection, and also for the construction of dispersive elements such as diffraction gratings." Whereas the idea that holography might be used in structural analysis had already been advanced by Wolfke, the prospects for its utilization in image-production technique were formulated in 1962 for the first time, and the same can be stated with respect to the indication of the remaining possibilities.

It should also be noted that Yu. N. Denisyuk's work was performed at the very dawn of laser development. The entire theory and experiment did not take into account the possibility of the use of lasers (in the experiment, as before in those of Wolfke and Gabor, the mercury emission-spectrum lines were used). In the following year, Denisyuk wrote: "Considerable progress in this direction should be afforded by the use of quantum generators, the radiation of which has great brightness and a very high degree of monochromaticity." The work of E. N. Leith and J. Upatnieks a year later confirmed this prediction.

The vigorous development of applications of holography and its perfection as a method make a deeper physical understanding of the image-production processes absolutely necessary. A detailed study of the history of holography and of the development of its principles cannot fail to contribute to more correct ideas concerning its physical foundations.

*In a personal letter, I called Professor Gabor's attention to the pioneering nature of Wolfke's paper [7]. In his response on 19 January 1968, Gabor wrote: "*I have now read Wolfke's paper and see that the priority for the "double Fourier transformation" must go to him and not to W. L. Bragg.*"

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