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Nobel Prize in Physics 1937

Clinton Joseph Davisson **George Paget Thomson**

The Nobel Prize in Physics 1937 was awarded jointly to Clinton Joseph Davisson and George Paget Thomson *"for their experimental discovery of the diffraction of electrons by crystals"*

RESEARCH INFORMATION:

The Nobel Prize for Physics for the year 1937 will today be delivered to Dr. C.J. Davisson and Professor G.P. Thomson for their discovery of the interference phenomena arising when crystals are exposed to electronic beams.

The study of the dispersion and diffraction phenomena produced by beams of electrons impinging on crystal surfaces was begun already in 1922 by Davisson and his collaborator Kunsman. These investigations soon obtained special actuality in connection with the theory of mechanical waves pronounced in 1923 by the Nobel Prize winner Prince de Broglie. According to this theory material particles are always linked with a system of travelling waves, a «wave-packet», forming the constituent parts of matter and determining its movements. We might get a popular picture of the relation between a material particle and the associated mechanical waves, if we assume space filled with wave systems travelling with somewhat different velocities. In general these waves neutralize one another, but at certain points it happens that a great number of waves are in such a position as to reinforce one another and form a marked wave crest. This wave crest then corresponds to a material particle. Since, however, the waves travel with different velocity they will part from one another, and the wave crest disappears to be found again at a nearby point. The material particle has moved. The wave crest will thus travel, but the velocity with which this is done is quite different from the one with which the underlying wave systems move. The material particle in general moves at right angles to the surfaces of the mechanical waves, just as a ray of light is, as a rule, directed at right angles to the surface planes of the light waves.

The theory of de Broglie derived from analogies between the laws ruling the movement of a material particle and those applying in the case of the passage of a ray of light.

A great number of phenomena observed in optics can neither be explained nor described by the aid of rays of light, and this holds true especially of the diffraction and dispersion phenomena produced when light passes through a narrow slit or by a sharp edge. To explain those phenomena it is necessary to have recourse to the hypothesis of the propagation of light by means of waves.

In recent times, the existence of diffraction and interference phenomena has settled a dispute regarding the nature of a certain radiation. This time the X-rays were concerned. The question was whether these rays consist of particles ejected with great velocity or of electromagnetic waves.

The mechanical grids utilized for studying interference phenomena in optics let through the X-rays without diffraction. This might be due to the wavelength of these rays being so short that the grids became too wide. The Nobel Prize winner von Laue then got the ingenious idea to use as grids, crystals, the regularly arranged atoms of which could serve as diffraction centres. It was also stated that the X-rays in those grids gave rise to diffraction and interference phenomena; the X-rays consequently consisted of waves.

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The mechanical waves of de Broglie now correspond to the waves of light and the path of the material particle to the passage of the ray of light.

In his theory de Broglie found a simple relation between the velocity of the material particle and the wavelength of the «wave-packet» associated with this particle. The greater the velocity of the particle the shorter is the wavelength. If the velocity of the particle is known, it is then possible to calculate, by means of the formula indicated by de Broglie, the wavelength and *vice versa*.

The theory of de Broglie of mechanical waves and the development of wave mechanics have been of radical importance to modern atom theory.

It is therefore quite natural that this revolutionary theory should become the object of assiduous research as to its consequences and of efforts to prove experimentally the existence of mechanical waves.

As has already been mentioned, Davisson had, together with his collaborator Kunsman, in the year before the theory of de Broglie was presented, started a series of experiments on the diffraction phenomena produced when a beam of electrons impinges with a certain velocity on the surface of a crystal. These experiments which were continued during the following years, gave, however, at the beginning results rather strange and hard to explain, probably due to the great experimental difficulties connected with the apparatus arrangement. In 1928, however, the investigations met with such a success that Davisson and his collaborator Germer were able to present the incontestable evidence, reached by experiments, of the existence of mechanical waves and of the correctness of the theory of de Broglie. Four months later Professor Thomson, who had been studying the same problem independently of Davisson and by the aid of a different apparatus equipment for his experiments, also confirmed de Broglie's theory.

For their experiments Davisson and Germer availed themselves of a cubic nickel crystal. Here the atoms are symmetrically arranged in planes parallel to the end surfaces of the crystal, the atoms forming a quadratic network in the planes. However, as radiation surface was not used the end plane of the cube but the triangular plane obtained, if an angle of the cube is symmetrically cut off. The atoms in this plane form a triangular network.

A minute bundle of electrons of determined velocity were emitted perpendicularly upon this plane. If we assume the incoming electrons replaced by mechanical waves, the planes of which are thus parallel to the surface of the crystal, these mechanical waves will strike the atoms lying in the surface simultaneously, and these atoms as centres will, in their turn, emit new mechanical waves in all directions. The waves going out in a certain direction can be studied and measured by the aid of a so-called Faraday chamber placed in this direction. In this chamber the mechanical waves cause the same effect as the corresponding electrons. In order to describe better how the outgoing radiation arises, let us suppose the receiving device placed so as to capture the waves going out parallel to the crystal plane and at right angles to one of the sides of the triangle. Parallel to this side the atoms lie in parallel rows with a certain distance between the rows, this distance having been determined beforehand by the aid of X-ray investigations. Every row now emits its wave. But the waves from the inner rows arrive later, due to the longer way they have to pass to reach the edge of the triangle. As a rule an irregular system of waves is thus obtained in which the waves neutralize each other, and consequently no outgoing wave is produced. If on the other hand the mechanical waves should be of such a wavelength that the distance between the rows of atoms becomes equal to the wavelength or to a multiple thereof, all the outgoing waves will be in phase and reinforce one another. In this case a wave system going out in the direction indicated is obtained or, if preferable, a bundle of outgoing electronic beams.

The experiments now showed at what velocities of the incoming electrons outgoing beams are produced, and these have, according to what has been stated above, a wavelength equal to the distance between the rows of atoms. Since thus the wavelength of the mechanical waves had been found and since the velocity of the corresponding electron was known, it was possible to check the formula of de Broglie. Davisson found that the theory agreed with the experiments except for 1 to 2%. Davisson and Germer examined the reflection of the electronic beams in various directions and obtained results which agreed with the wave theory.

During his experiments Davisson used electron beams with rather a low velocity corresponding to the one obtained when an electron is made to pass a voltage between 50 and 600 volts.

Thomson, on the other hand, for his experiments availed himself of swift electrons with a velocity corresponding to voltages between 10,000 and 80,000 volts. These swift electrons have afterwards proved to be of great use in connection with studies on the structure of matter.

For his experiments Thomson made use of exceedingly thin films of celluloid, gold, platinum, or aluminium. He made the electron beam fall perpendicularly upon the film and examined the diffraction figures produced on a fluorescent screen placed behind the film, or else had them reproduced on a photographic plate. The thickness of the films used for the experiments amounted to between 1/10,000 and 1/100,000 of a millimetre. Such a film now consists of innumerable small crystals of various directions. In accordance with what the theory indicates, there is generally obtained on the screen a series of concentric rings corresponding to the various directions of the planes in a crystal where a regularly arranged network of atoms can be found. From the diametre of a ring, the wavelength of the mechanical wave can be determined, and to make possible the production of a ring this wavelength must be in accordance with the spacing of the planes in the system of planes to which the ring corresponds. A similar method has been applied previously by Debye-Scherrer for X-rays analysis of the structure of crystals. Thomson found very good agreement with the theory of de Broglie. He further found that a magnetic field influencing the beams having passed the film produced a lateral movement of the image on the screen, which shows that these beams consist of bundles of electrons.

For the above-mentioned experiments electrons have been employed as matter; later investigations have confirmed the correctness of de Broglie's theory also for such cases where beams of molecules, atoms, and atom nuclei have been used.

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The purpose of the said experiments was to verify the theory of de Broglie, and to this end was utilized the knowledge of the arrangement of the atoms in a crystal, this knowledge having been previously acquired as a result of investigations by means of X-rays. Now that the law of de Broglie has become known and acknowledged, the opposite way has been taken. From the law of de Broglie we know the wavelength of the mechanical waves accompanying an electronic beam with a certain velocity of the electrons. By changing this velocity we can then obtain electronic waves with known wavelengths. By application of one or the other of the investigation methods mentioned above we can find the distances between the various atom planes within the crystal and thus also the structure of the crystal. The procedure is here the same as the one previously applied to determine the structure of crystals by means of X-rays. We have thus obtained a new method for such investigation, but the two methods have found very different fields of application due to the different nature of the beams employed. The X-rays are pure electromagnetic rays like the rays of light, and they therefore influence but slightly the atoms of the crystal, and owing to this circumstance easily traverse the crystal structure. From the same reason the diffracted rays are comparatively feeble, and many hours' exposure is therefore required to record X-ray diagrams. The mechanical waves, on the other hand, are associated with electrical charges which are very strongly influenced by the charges of the crystal atoms. The mechanical waves will therefore be rapidly absorbed in the crystal, and the interference figures obtained only come from an exceedingly thin surface layer. In return the intensity of the diffracted or reflected bundles of electrons becomes very great, and the time of exposure required is consequently extremely short, in many cases only a fraction of a second. These properties of the electronic beams make them an exceedingly important complement to the X-rays as far as researches on the structure of matter are concerned. At the important investigations of the structure of surfaces good results can be attained only by the new method, since the images of the X-rays are influenced by the matter lying behind the surface layer. By the aid of electronic beams it has thus been possible to explain how the structure of the surfaces of metals is changed by various mechanical, thermal, or chemical treatment. It has also been possible to ascertain the properties of thin layers of gases and powder. On account of the rapid exposure which the electronic beams permit, we can follow the course of the changes occurring in connection with the oxidization of metals and also observe the corrosion phenomenon in iron and steel for various thermal treatment as well as the chemical process ensuing when metals are attacked by corrosive substances. The intensity of radiation is so great that one can easily carry out investigations of the structure of crystals with a mass of less than a millionth of a gram. This has made it possible to discover in certain substances exceedingly minute crystalline structures, which it would not have been possible to find by means of X-ray investigations.

It would bring us too far here to enter upon the multitude of experimental results furnished by the method with electronic beams, especially as new fields of application of the electron beam are incessantly being opened up within the spheres of physical and chemical research.

Dr. Davisson. When you found that electron beams touching crystals give rise to phenomena of diffraction and interference, this signified in itself a discovery that widened essentially our knowledge of the nature of electrons. But this discovery has proved to be of still greater importance. Your researches concerning these phenomena resulted in your presenting the first positive, experimental evidence of the wave nature of matter. The investigation methods that you and Professor Thomson have elaborated and the further research work carried out by both of you have provided science with a new, exceedingly important instrument for examining the structure of matter, an instrument constituting a very valuable complement to the earlier method which makes use of the X-ray radiation. The new investigations have already furnished manifold new, significant results within the fields of physics and chemistry and of the practical application of these sciences.

On behalf of the Royal Swedish Academy of Sciences I congratulate you on your important discoveries, and I now ask you to receive your Nobel Prize from the hands of His Majesty.

The Royal Swedish Academy of Sciences much regrets that Professor Thomson has not had the opportunity of being present on this occasion to receive in person his Nobel Prize. The prize will now instead be delivered to His Excellency the Minister of Great Britain.

Your Excellency. Permit me to request you to receive on behalf of Professor Thomson the Nobel Prize for Physics from the hands of His Majesty.

For more details please visit:

http://www.nobelprize.org/nobel_prizes/physics/laureates/1937/press.html