Electronic waves

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by

George Paget Thompson

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Ever since last November, I have been wanting to express in person my gratitude to the generosity of Alfred Nobel, to whom I owe it that I am privileged to be here today, especially since illness prevented me from doing so at the proper time. The idealism which permeated his character led him to make his magnificent foundation for the benefit of a class of men with whose aims and viewpoint his own scientific instincts and ability had made him naturally sympathetic, but he was certainly at least as much concerned with helping science as a whole, as individual scientists. That his foundation has been as successful in the first as in the second, is due to the manner in which his wishes have been carried out. The Swedish people, under the leadership of the Royal Family, and through the medium of the Royal Academy of Sciences, have made the Nobel Prizes one of the chief causes of the growth of the prestige of science in the eyes of the world, which is a feature of our time. As a recipient of Nobel's generosity I owe sincerest thanks to them as well as to him.

The goddess of learning is fabled to have sprung full-grown from the brain of Zeus, but it is seldom that a scientific conception is born in its final form, or owns a single parent. More often it is the product of a series of minds, each in turn modifying the ideas of those that came before, and providing material for those that come after. The electron is no exception.

Although Faraday does not seem to have realized it, his work on electrolysis, by showing the unitary character of the charges on atoms in solution, was the first step. Clerk Maxwell in 1873 used the phrase a "molecule of electricity" and von Helmholtz in 1881 speaking of Faraday's work said "If we accept the hypothesis that elementary substances are composed of atoms, we cannot well avoid concluding that electricity also is divided into elementary portions which behave like atoms of electricity." The hypothetical atom received a name in the same year when Johnstone Stoney of Dublin christened it "electron", but so far the only property implied was an electron charge.

The last year of the nineteenth century saw the electron take a leading place amongst the conceptions of physics. It acquired not only mass but universality, it was not only electricity but an essential part of all matter. If among the many names associated with this advance I mention that of J.J. Thomson I hope you will forgive a natural pride. It is to the great work of Bohr that we owe the demonstration of the connection between electrons and Planck's quantum which gave the electron a dynamics of its own. A few years later, Goudsmit and Uhlenbeck, following on an earlier suggestion by A.H. Compton showed that it was necessary to suppose that the electron had spin. Yet even with the properties of charge, mass, spin and a special mechanics to help it, the electron was unable to carry the burden of explaining the large and detailed mass of experimental data which had accumulated. L. de Broglie, working originally on a theory of radiation, produced as a kind of by-product the conception that any particle and in particular an electron, was associated with a system of waves. It is with these waves, formulated more precisely by Schrödinger, and modified by Dirac to cover the idea of spin, that the rest of my lecture will deal.

The first published experiments to confirm de Broglie's theory were those of Davisson and Germer, but perhaps you will allow me to describe instead those to which my pupils and I were led by de Broglie's epoch-making conception.

A narrow beam of cathode rays was transmitted through a thin film of matter. In the earliest experiment of the late Mr. Reid this film was of celluloid, in my own experiment of metal. In both, the thickness was of the order of 10^{-6} cm. The scattered beam was received on a photographic plate normal to the beam, and when developed showed a pattern of rings, recalling optical halos and the Debye-Scherrer rings well known in the corresponding experiment with X-rays. An interference phenomenon is at once suggested. This would occur if each atom of the film scattered in phase a wavelet from an advancing wave associated with the electrons forming the cathode rays. Since the atoms in each small crystal of the metal are regularly spaced, the phases of the wavelets scattered in any fixed direction will have a definite relationship to one another. In some directions they will agree in phase and build up a strong scattered wave, in others they will destroy one another by interference. The strong waves are analogous to the beams of light diffracted by an optical grating. At the time, the arrangement of the atoms in celluloid was not known with certainty and only general conclusions could be drawn, but for the metals it had been determined previously by the use of X-rays. According to de Broglie's theory the wavelength associated with an electron is h/mv which for the electrons used (cathode rays of 20 to 60,000 volts energy) comes out from 8 X 10^{-9} to 5 X 10^{-9} cm. I do not wish to trouble you with detailed figures and it will be enough to

Before discussing the theoretical implications of these results there are two modifications of the experiments which should be mentioned. In the one, the electrons after passing through the film are subject to a uniform magnetic field which deflects them. It is found that the electrons whose impact on the plate forms the ring pattern are deflected equally with those which have passed through holes in the film. Thus the pattern is due to electrons which have preserved unchanged the property of being deflected by a magnet. This distinguishes the effect from anything produced by X-rays and shows that it is a true property of electrons. The other point is a practical one, to avoid the need for preparing the very thin films which are needed to transmit the electrons, an apparatus has been devised to work by reflection, the electrons striking the diffracting surface at a small glancing angle. It appears that in many cases the patterns so obtained are really due to electrons transmitted through small projections on the surface. In other cases, for example when the cleavage surface of a crystal is used, true reflection occurs from the Bragg planes.

Although the experiments in diffraction confirm so beautifully the de Broglie-Schrödinger wave theory, the position is less satisfactory as regards the extended theory due to Dirac. On this theory the electron possesses magnetic properties and the wave requires four quantities instead of one for its specification. This satisfies those needs of spectroscopy which led to the invention of the spinning electron. It suggests however that electronic waves could be polarized and that the polarized waves might interact with matter in an anisotropic manner. In fact detailed calculations by Mott indicate that if Dirac electrons of 140 kV energy are scattered twice through 90° by the nuclei of gold atoms the intensity of the scattered beam will differ by 16% according to whether the two scatterings are in the same or in opposite directions. Experiments by Dymond and by myself have established independently that no effect of this order of magnitude exists, when the scattering is done by gold foils. While there

I should be sorry to leave you with the impression that electron diffraction was of interest only to those concerned with the fundamentals of physics. It has important practical applications to the study of surface effects. You know how X-ray diffraction has made it possible to determine the arrangement of the atoms in a great variety of solids and even liquids. X-rays are very penetrating, and any structure peculiar to the surface of a body will be likely to be overlooked, for its effect is swamped in that of the much greater mass of underlying material. Electrons only affect layers of a few atoms, or at most tens of atoms, in thickness, and so are eminently suited for the purpose. The position of the beams diffracted from a surface enables us, at least in many cases, to determine the arrangement of the atoms in the surface. Among the many cases which have already been studied I have only time to refer to one, the state of the surface of polished metals. Many years ago Sir George Beilby suggested that this resembled a supercooled liquid which had flowed under the stress of polishing. A series of experiments by electron diffraction carried out at the Imperial College in London has confirmed this conclusion. The most recent work due to Dr. Cochrane has shown that though this amorphous layer is stable at ordinary temperature as long as it remains fixed to the mass of the metal, it is unstable when removed, and recrystalizes after a few hours. Work by Professor Finch on these lines has led to valuable conclusions as to the wear on the surfaces of cylinders and pistons in petrol engines.

It is in keeping with the universal character of physical science that this single small branch of it should touch on the one hand on the fundamentals of scientific philosophy and on the other, questions of everyday life.

Biography

Professor
Sir George Paget Thomson
FRS

Thomson in 1937

Born	3 May 1892 Cambridge, England
Died	10 September 1975 (aged 83) Cambridge, England
Alma mater	Trinity College, Cambridge
Known for	Electron diffraction
Spouse	Kathleen Buchanan Smith (m. 1924; died 1941)
Children	4
Father	J. J. Thomson
Relatives	George Edward Paget (grandfather) George Adam Smith (father-in-law)
Awards	Howard N. Potts Medal (1932) Nobel Prize in Physics (1937) Hughes Medal (1939) Royal Medal (1949) Faraday Medal (1960)
	Scientific career
Fields	Physics
Institutions	University of Aberdeen Corpus Christi College, Cambridge Imperial College London
Academic advisors	J. J. Thomson

Thank you!