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# Nobel Prize in Physics 1932

**Werner Karl Heisenberg**

The Nobel Prize in Physics 1932 was awarded to Werner Heisenberg *"for the creation of quantum mechanics, the application of which has, inter alia, led to the discovery of the allotropic forms of hydrogen"*.

## RESEARCH INFORMATION:

This year's Nobel Prizes for Physics are dedicated to the new atomic physics. The prizes, which the Academy of Sciences has at its disposal, have namely been awarded to those men, Heisenberg, Schrödinger, and Dirac, who have created and developed the basic ideas of modern atomic physics.

It was Planck who, in 1900, first expressed the thought that light had atomic properties, and the theory put forward by Planck was later more exhaustively developed by Einstein. The conviction, arrived at by different paths, was that matter could not create or absorb light, other than in quantities of energy which represented the multiple of a specific unit of energy. This unit of energy received the name of light quantum or photon. The magnitude of the photon is different for different colours of light, but if the quantity of energy of a photon is divided by the frequency of oscillation of the ray of light, the same number is always obtained, the so-called Planck's constant *h*. This constant is thus of a universal nature and forms one of the foundation stones for modern atomic physics.

Since light too was thus divided into atoms it appeared that all phenomena could be explained as interactions between atoms of various kinds. Mass was also attributed to the atom of light, and the effects which were observed when light rays were incident upon matter could be explained with the help of the law for the impact of bodies.

Not many years passed before the found connection between the photon and the light ray led to an analogous connection between the motion of matter and the propagation of waves being sought for.

For a long time it had been known that the customary description of the propagation of light in the form of rays of light, which are diffracted and reflected on transmission from one medium to another, was only an approximation to the true circumstances, which only held good so long as the wavelength of the light was infinitesimally small compared with the dimensions of the body through which the light passed, and of the instruments with which it was observed. In reality light is propagated in the form of waves which spread out in all directions according to the laws for the propagation of waves.

Prince Louis de Broglie concieved the brilliant idea of seeking an analogy between the path of the light ray and the track of a material point. He wondered whether the track of a particle of matter, like the path of a ray of light, might only be an approximate expression for reality, prescribed by the coarseness of our senses, and whether one here was not also dealing with wave motion. Using Einstein's theory of relativity, he was equally successful in representing the motion of matter as a combination of waves which were propagating themselves with velocities greater than that of light. Matter is formed or represented by a great number of this kind of waves which have somewhat different velocities of propagation and such phase that they combine at the point in question. Such a system of waves forms a crest which propagates itself with quite a different velocity from that of its component waves, this velocity being the so-called group velocity. Such a wave crest represents a material point which is thus either formed by it or connected with it, and is called a wave packet. De Broglie now found that the velocity of the material point was in fact the group velocity of the matter-wave.

De Broglie's theory of matter-waves subsequently received experimental confirmation. If a relatively slowly travelling electron meets a crystal surface, diffraction and reflection phenomena appear in the same way as if an incident beam of waves were concerned.

As a result of this theory on is forced to the conclusion to conceive of matter as not being durable, or that it can have definite extension in space. The waves, which form the matter, travel, infact, with different velocity and must, therefore, sooner or later separate. Matter changes form and extent in space. The picture which has been created, of matter being composed of unchangeable particles, must be modified.

One of the physical phenomena whose correct explanation has proved most difficult, is the apperance of the spectra of countless lines and bands which are obtained if light is split up by optical instruments when produced by atoms and molecules as a result of their vibrations. It has been known for a long time that each such line corresponds to light of a certain frequency, which varies according to where the line appears in the various parts of the colour spectrum.

A correct explanation of the intensities of all these lines and their positions in the spectrum is of fundamental significance since it gives an insight into the structure of the atoms and molecules and the relationships within them.

It was Bohr who, in 1913, expressed the idea that Planck's constant should be taken as the determining factor for movements within the atom, as well as for the emission and absorption of light waves.

Bohr assumed, after Rutherford, that an atom consists of an inner, heavy, positively charged particle, around which is negative, light electrons circulate in closed paths, held to the nucleus by the attraction. According to whether the path of the electron is further away, or closer from the nucleus, the electron possesses different velocitiy and different energy.

Bohr now put forward the hypothesis that only such path exist where the energy of the electron, as a result of its motion in the path, is a whole multiple of a quantum of light corresponding to the rotation frequency of the electron. Light, Bohr now assumed, appears if an electron suddenly transfers from one path to another, and the frequency of the light ray is emitted, is obtained if the change of energy experienced during transferis divided by Planck's constant. The frequencies which Bohr thus obtained held good for a hydrogen atom which has only one electron, but when his method was applied to more complicated atoms and to certain optical phenomena, theory and practice did not agree. The fact that Bohr's hypothesis met the case for the hydrogen atom, however, suggests that Planck's constant was, in one way or another, a determining factor for the light-vibratons of the atoms. On the other hand, one had the feeling that it could not be right to apply the laws of classical mechanics to the rapid movements in the atom. Efforts made from various sides to develop and improve Bohr's theory proved also in vain. New ideas were required to solve the problem of oscillations of atoms and molecules.

This solution followed in 1925 upon the works of Heisenberg, Schödinger, and Dirac in which different starting-points and methods were applied. I will first of all dwell upon Schrödinger's contribution since it is more closely than the others connected to the state of the development which atomic physics had attained at that period of time, particularly as a result of de Broglie's above-mentioned theory of matter-waves.

Since the electrons were the seat of outgoing waves, Schrödinger thought that it should be possible to find a wave equation for the motions executed by the electrons which would define these waves in the same way as the wave equation which determined the propagation of light. From the solution of this wave equation one should be able to select those oscillations which were feasible for the motons within the atoms. He was successful, too, in determining the wave equation for a series of different motions of the electron, and it turned out that these equations gave finite solutions only when the energy of the system had specific discrete values, determined by Planck's constant. In Bohr's theory these discrete energy values of the electron paths were only hypothetical, but in Schrödinger's,

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on the contrary, they appeared as completely determined by the form of the wave equation. Schrödinger himself, and others after him, have applied his wave theory to various optical problems including the interpretation of the phenomena accompanying the impact between light rays and electrons, investigations into the behaviour of atoms in electric and magnetic fields, the diffraction of light rays, etc. In every direction, values and formulae have been obtained using Schrödinger's theory, which have been in closer agreement with experience than the older theories were. Schrödinger's wave equation has provided a convenient and simple method for handling problems to do with light spectra, and has become an indispensible tool for the present-day physicist.

Somewhat before the appearance of Schrödinger's theory Heisenberg brought out his famous quantum mechanics. Heisenberg started off from quite different standpoints and viewed his problem, from the very beginning, from so broad an angle that it took care of systems of electrons, atoms, and molecules. According to Heisenberg one must start from such physical quantities as permit of direct observation, and the task consists of finding the laws which link these quantities together. The quantities first of all to be considered are the frequencies and intensities of the lines in the spectra of atoms and molecules. Heisenberg now considered the combination of all the oscillations of such a spectrum as one system, for the mathematical handling of which, he set out certain symbolical rules of calculation. It had formerly been determined already that certain kinds of motions within the atom must be viewed as independent from one another to a certain degree, in the same way that a specific difference is made in classical mechanics between parallel motion and rotational motion. It should be mentioned in this connection that in order to explain the properties of a spectrum it had been necessary to assume self-rotation of the positive nuclei and the electrons. These different kinds of motion for atoms and molecules produce different systems in Heisenberg's quantum mechanics. As the fundamental factor of Heisenberg's theory can be put forward the rule set out by him with reference to the relationship between the position coordinate and the velocity of an electron, by which rule Planck's constant is introduced into the quantum-mechanics calculations as a determining factor.

Although Heisenberg's and Schrödinger's theories had different starting points and were developed by the use of different processes of thought, they produced the same results for problems treated by both theories.

Heisenberg's quantum mechanics has been applied by himself and others to the study of the properties of the spectra of atoms and molecules, and has yielded results which agree with experimental research. It can be said that Heisenberg's quantum mechanics has made possible a systemization of spectra of atoms. It should also be mentioned that Heisenberg, when he applied his theory to molecules consisting of two similar atoms, found among other things that the hydrogen molecule must exist in two different forms which should appear in some given ratio to each other. This prediction of Heisenberg's was later also experimentally confirmed.

Dirac has set up a wave mechanics which starts from the most general conditions. From the start he put forward the requirement that the postulate of the relativity theory be furfilled. Viewed from this general formulation of the problems it appeared that the self-rotation of the electron which had previously come into the theory as an hypothesis stipulated by experimental facts, now appeared as a result of the general theory of Dirac.

Dirac divided the initial wave equation into two simpler ones, each providing solutions independently. It now appeared that one of the solution systems required the existence of positive electrons having the same mass and charge as the known negative electrons. This initially posed considerable difficulty for Dirac's theory, since positively charged particles were known only in the form of the heavy atom nucleus. This difficulty which at first opposed the theory has now become a brilliant confirmation of its validity. For later on, positive electrons, the positrons, whose existence was stipulated in Dirac's theoretical investigation, have been found by experiment.

The new quantum mechanics has changed to a great extent all our concepts of the relationships existing within the microscopic world, made up of atoms and molecules. We have already mentioned that as a result of the new wave mechanics we have had to modify our conception on the unchangeability of material particles. But more than this. Heisenberg has shown that according to quantum mechanics it is inconceivable to determine, at a given instant of time, both the position taken up by a particle and its velocity. Closer study of quantum mechanics shows in fact that the more one attempts to fix exactly the position of a particle, the more uncertain the determination of its velocity becomes, and vice versa. It must be further considered, that it is impossible to carry out the measurement of the situation in an atom or molecule without the employed instruments, ilrumination, etc.themselves altering the situation which is under examination. The light emitted from the electrons becomes modified in the optical instruments. The relationships go still deeper however. As a result of the introduction of light quanta, quantum mechanics must abandon the requirement of causality within the microcosmic world. A ray of light on being incident upon an optical instrument is resolved. However, the photon is indivisible. It must be realized then, that some photons will behave in one way, others in another way at the resolution. The only assertion that can be made regarding causality is that the physical laws signify a certain probability that one or another incident will take place. Since we can only perceive average values because of the imperfection of our senses and instruments, it is probabilities which are covered in our physical laws, and the question has been raised, whether in the physical world there is in fact any other accordance with laws than a statistical one.

Professor Heisenberg. It has fallen to you whilst young in years, to have given to physics, by means of the theory of quantum mechanics established by you, a general method for the solution of the manifold problems which have come to the fore as a result of restless experimental researches into the theory of radiation. From a study of the properties of the molecules, you have succeeded, among other things, in predicting that the hydrogen molecules would appear in two forms, which later has been confirmed. Your quantum mechanics has created new concepts, and has led physics into fresh trains of thought, which have now already proved of fundamental importance for our knowledge of the phenomena of physics.

The Royal Academy of Sciences has awarded you the Nobel Prize for Physics for 1932 in recognition of these studies, and I beg you to accept this distinction from the hands of His Majesty the King.

Professor Schrödinger. Through a study of the wave properties of matter you have succeeded in establishing a new system of mechanics which also holds good for motion within the atoms and molecules. With the aid of this so-called wave mechanics you have found the solution to a number of problems in atomic physics. Your theory provides a simple and convenient method for the study of the properties of atoms and molecules under various external conditions and it has become a great aid to the development of physics. For your discovery of new fruitful forms of atomic physics and the application of these, the Royal Academy of Sciences has decided to award you the Nobel Prize. I request you to receive this from the hands of His Majesty the King.

Professor Dirac. The theory of wave mechanics which you have developed is characterized by its universality, since from the beginning you have imposed the condition that the postulate of the theory of relativity has to be furfilled. In this way you have shown that the existence of the spin of electrons and its qualities are a consequence of this theory and not merely a hypothesis.

Further you have succeeded in dividing the wave equation into two, which results in two systems of solutions one of which requires the existence of a positive electron of the same size and charge as the negative electron. The experimental discovery of the existence of the positron has in a brilliant way confirmed your theory.

For the discovery of new fertile forms of the theory of atoms presented by you and for its applications the Royal Academy of Sciences has awarded you the Nobel Prize, and I now ask you to receive this prize from the hands of His Majesty the King.

***For more details please visit:***

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