# Spinning Electrons and the Structure of Spectra

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So far as we know, the idea of a quantised spinning of the electron was put forward for the first time by A.K. Compton (*Jour. Frankl. Inst.,* Aug. 1921 p. 145 ), who pointed out the possible bearing of this idea on the origin of the natural unit of magnetism. Without being aware of Compton's suggestion, we have directed attention in a recent note (*Naturwissenschaften,* Nov. 20, 1925 ) to the possibility of applying the spinning electron to interpret a number of features of the quantum theory of the Zeeman effect, which were brought to light by the work especially of van Lohuizen, Sommerfeld, Landé and Pauli, and also of the analysis of complex spectra in general.In this letter we shall try to show how our hypothesis enables us to overcome certain fundamental difficulties which have hitherto hindered the interpretation of the results arrived by those authors.

To start with, we shall consider the effect of the spin on the manifold of the stationary states which corresponds to motion of an electron round a nucleus. On account of it's magnetic moment,the electron will be acted on by a couple just as if it were placed at rest in a magnetic field of magnetic field of magnitude equal to the vector product of the nuclear electric fields and velocity of the electron relative to the nucleus divided by the velocity of light. This couple will cause a slow precession of the spin axis, the the conservation of the angular momentum of the atom being ensured by a compensating precession of the orbital plane of the electron. This complexity of the motion requires that, corresponding to each stationary state of an imaginary atom, in which the electron has no spin, there shall in general exist a set of states which differ in the orientation of the spin axis relative to the orbital plane, the other characteristics of the motion remaining unchanged. If the spin corresponds to a one quantum rotation, there will be in general two such states. Further, the energy difference of these states. Further, the energy difference of these states will, as a simple calculation shows, be proportional to the fourth power of the nuclear charge. It will also depend on the quantum numbers which define the state of motion of the non-spinning electron in a way very similar to the energy differences connected with the rotation of the orbit in its own plane arising from the relativity variation of the electronic mass. We are indebted to Dr. Heisenberg for a letter containing some calculations on the quantitative side of the problem.

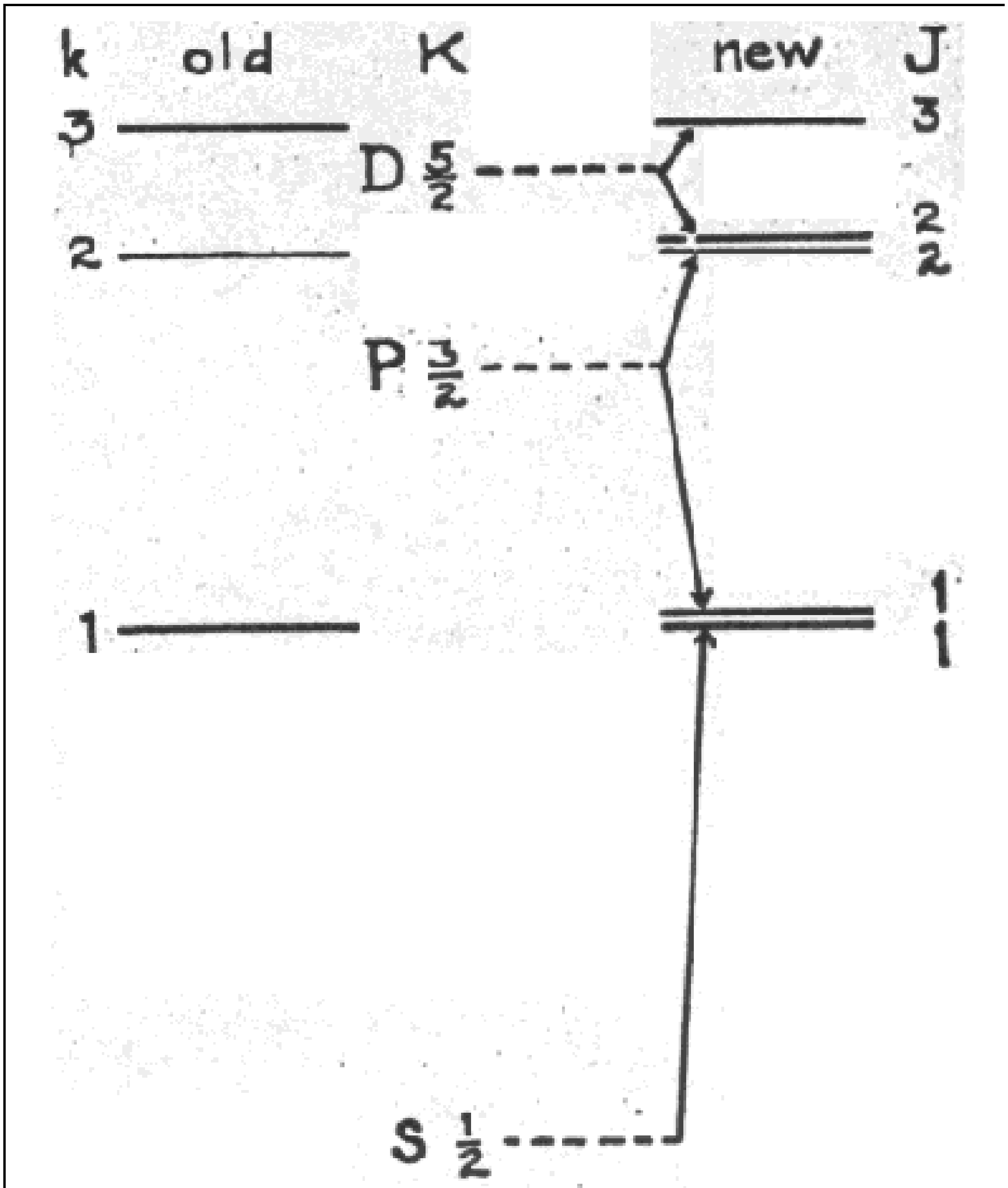


FIG. 1.

This results suggests an essential modification of the explanation hitherto given of the fine structure of the hydrogen-like spectra. As an illustration we may consider the energy levels corresponding to electronic orbits for which the principal quantum number is equal to three. The scheme on the left side of the accompanying figure (Fig. 1) corresponding to the results to be expected from Sommerfeld's theory. The so called azimuthal quantum number *k* is defined by the quantity of moment of momentum of the electron about the nucleus, $kh/2\pi$, where $k = 1, 2, 3$. According to the new theory, depicted in the scheme[1] on the right, [1] Quite independently of the ideas discussed here, a scheme of levels corresponding to this figure has been previously proposed by the writers (*Physics*, 5, 266, 1925), on the ground of the formal analogy between spectral structures. From similar formal considerations, this scheme has recently also been arrived at by J.C. Slater (*Proc. Washington Acad.*, December 1925).

this moment of momentum is given by $Kh / 2\pi$, where K = 1/2, 5/2, 5/2. The total angular momentum of the atom is J*h*/2π, where J = 1, 2, 3. The symbols K and J correspond to those used by Landé in his classification of the Zeeman effects of the optical spectra which we consider below. The dotted lines represent the position of the energy levels to be expected in the absence of the spin of the electron. As the arrows indicated, this spin now spits each levels into two, with the exception of the level K= 1/2, which is only displaced.

In order to account for the experimental facts, the resulting levels must fall in must fall in just the same places as the levels given by the older theory. Nevertheless, the two schemes differ fundamentally. In particular, the new theory explains at once the occurrence of certain components in the fine structure of the hydrogen spectrum and of the helium spark spectrum which according to the old scheme would correspond to transitions where K remains uncharged. Unless these transitions could me ascribed to the action of electric forces in the discharge which would perturb the electronic motion, their occurrence would be in disagreement with the correspondence principle, which only allows transitions in which the azimuthal quantum number changes by one unit and only J will remain unchanged. Their occurrence is, therefore, quite in conformity with the correspondence principle.

The modification proposed is specially important for explaining the structure of X - ray spectra. These spectra differ from the hydrogen-like spectra by the appearance of so called "screening" doublets, which are ascribed to the interactions of electrons within the atom, effective mainly through reducing the effect of nuclear attraction. In our view, these screening doublets correspond to pair of levels which have the same angular momentum J but different azimuthal quantum numbers K. Consequently, the orbits will penetrate to different distances from the nucleus, so that the screening of the nuclear charge by the other electrons in the atom will have different effects. This screening effect will, however, be the same for a pair of levels which have the same K but different J's and correspond to the same orbital shape. Such pairs of levels were, on the older theory, labeled with values of k different by one unit, and it was quite impossible to understand why these so called " relativity " doublets should appear separately from the screening doublets. On our view, the doublets in question may more properly be termed "spin" doublets, since the sole reason for their appearance is the difference in the orientation of the spin axis relative to the orbital plane. It should be emphasized that our interpretation is in complete accordance with the correspondence principle as regards the rules of combination of X- ray levels.

The assumption of the spinning electron leads to a new insight into the remarkable analogy between the multiplet structure of the optical spectra and the structure of the X - ray spectra, which was emphasized especially by Landé and Millikan. While the attempt to refer this analogy to a relatively effect common to all the structures was most unsatisfactory, it obtains an immediate explanation on the hypothesis of the spin electron. If, for example, we consider the spectra of the alkaline type, we are led to recognise in the well known doublets regular spin doublets of the character described above. In fact, this enables us to explain the dependence of the doublet width on the effective nuclear charge and the quantum numbers describing the orbit, as well as the rules of combination.

The simplicity of the alkaline spectra is due to the fact that the atom consists of an electron revolving round an atomic residue which contains only completed electronic groups, which are magnetically inert. When we pass to atoms in which several electrons revolve round a residue of this kind we meet with new features since we have to take account of other directing influences on the spin axis of each electron besides the couple due to its own motion in the electric field. Not only does this enable us to account for the appearance of multiplets of higher complexity, but it also seems to throw light on the so-called "branching" of spectra, which usually accompanies the adding of a further electron to the atom, and for which hitherto no satisfactory explanation has been given. In fact it seems that the introduction of the concept of the spinning electron makes it possible throughout to maintain the principle of the successive building up of atoms utilised by Bohr in his general discussion of the relations between spectra and the natural system of the elements. Above all, it may be possible to account for the important results arrived at by Pauli, without having to assume an unmechanical "duality" in the binding of the electrons.

So far we have not mentioned the Zeeman effect, although the introduction of the spinning electron was primarily suggested by the analysis of the anomalous Zeeman effects shown by the components of multiplet structures. From the point of view of the correspondence principle, this effect shows that the influence of a magnetic field on the motion of the atom differs considerably form that to be expected if the electron had no spin. In fact, from the well-known theorem of Larmor we would expect the effect on any spectral line to be one of the simple Lorentz type, quite independently of the character of the multiplet structure. Therefore the appearance of the anomalous Zeeman effects has hitherto presented very grave difficulties. However, these difficulties disappear at once when as assumed, the electron has a spin and the ration between magnetic moment and angular momentum of this spin is different from that corresponding to the revolution of the electron in an orbit large compared with its own size. On this assumption the spin axis of an electron not affected by other forces would precess with a frequency different from the Larmor rotation. It is easily shown that the resultant motion of the atom for magnetic fields of small intensity will be of just the type revealed by Landé's analysis. If the field is so strong that its influence on the precession of the spin axis is comparable with that due to the orbital motion in the atom, this motion will be charged in a way which directly explains the gradual transformation of the multiplet structure for increasing fields known as the Paschen-Back effect.

It seems possible on these lines to develop a quantitative theory of the Zeeman effect, if it is assumed that the ratio between magnetic moment and angular momentum due to the spin is twice the ratio corresponding to an orbital revolution. At present, however, it seems difficult to reconcile this assumption with a quantitative analysis of our explanation of the fine structure of levels. In fact it leads, in a preliminary calculation, to widths of the spin doublets just twice as large as those required by observation. It must be remembered, however, that we are here dealing with problems which for their final solution require a closer study of quantum mechanics and perhaps also of questions concerning the structure of the electron.

In conclusion, we wish to acknowledge our indebtedness to Prof. Niels Bohr for an enlightening discussion, and for criticisms which helped us distinguish between the essential points and the more technical details of the new interpretation.

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