Quantum State and Periodicity

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> The phenomena of electrodynamics as well as of mechanics possess no properties corresponding to the idea of absolute rest, Albert Einstein [1].

ABSTRACT. The notion of intrinsic rotation of the electron or spin is revisited. In this view it is underlined that the relativity of the motion imposes: to the rotation of the electron to reflect that of the proton and to the causes generating it to be the same in the space of the electron as well as in the proton one. This leads to suppose that the momenta are due to exchanges of inert mass between the electron and the proton in the form of very small grains compared to the mass of the electron. As a result, there are two fluxes of matter in opposite way between the electron and the proton; they lead to an interpretation of the Stern and Gerlach experiments where the magnetic field does not modify the same flux according to the considered state. It is then established that the Landé factor as given by Dirac results from a total angular momentum different from the one used by Sommerfeld.

RÉSUMÉ. La notion de rotation intrinsèque de l'électron ou spin est réexaminée. Dans ce but il est souligné que la relativité du mouvement impose : à la rotation de l'électron d'être le reflet de celle du proton, et que les causes qui l'engendrent soient les mêmes dans l'espace de l'électron et dans celui du proton. Ceci conduit à supposer que les quantités de mouvement sont le résultat de variations de masse inerte entre l'électron et le proton, sous forme de grains de matières très petit par rapport à la masse de l'électron. Il en résulte deux flux de matière de sens opposés entre l'électron et le proton qui conduisent à une interprétation de l'expérience de Stern et Gerlach où le champ magnétique ne modifie pas le même flux suivant l'état considéré. Il est ensuite établi que le facteur de Landé comme l'a établi Dirac, résulte du moment cinétique total différent de celui utilisé par Sommerfeld.

1 Introduction

In 1869, February 17 Mendeleyev distributed to numerous chemists its system of classification of the elements [2]. It was the herald discovery of the quantum properties of the electrons in the atoms. Indeed, it was after the discovery of the quantum properties of the electron that the organization of the table became understandable. It was first the works of Moseley work which, by the study of X-Rays frequencies, brought important results supporting the notion of atomic number. A very comprehensive account on the spectroscopy and quantum mechanics can be found in the reference book by White «Introduction to Atomic Spectra» [3]. It includes a great number of results and references concerning the spectral lines, the quantum mechanics and the periodic table. After the atomic number the numerous spectral lines of Balmer (1885), Rydberg, Paschen, just to quote the most known, were discovered. These researchers showed the role of an integer number in the frequency variations of the corresponding lines. Thanks to Bohr work (1913) this number was going to become the principal quantum number n having a close connection with the different rows of the periodic table [4]. Then the works of Sommerfeld (1916) have allowed to understand the classification of the series (sharps s, principals *p,* diffuses *d,* fundamentals *f)* as corresponding to the secondary quantum number ℓ (also called "orbital"). This last is associated to the momentum of the quantum state [4]. As a result these numbers explained the different lines and columns of the table. Except the shells *ns,* the shells are divided into two subshells, as indicated by the double spectral lines and recalled in tables I and II. However, the Sommerfeld approach did not allow to understand the origin of this division. It was Dirac's approach which allowed to solve the difficulty; it shows that there are two types of slightly different states for the same number k of rotational quanta [5]; de Broglie has given an extended discussion of Dirac's theory [6] with the solution of the equation following Darwin [7]. Finally it has been clear that each element corresponds to an additional proton and electron in comparison to the previous element. To each additional electron corresponds a distinct magnetic state characterized by the m quantum number which is specific of the element [8]. However, the Sommerfeld approach did not allow to understand the origin of this division. It was Dirac's approach which allowed to solve the difficulty; it shows that there are two types of slightly different states for the same number k of rotational quanta [5]; de Broglie has given an extended discussion of Dirac's theory [6] with the solution of the equation following Darwin [7]. Finally it has been clear that each element corresponds to an additional proton and electron in comparison to the previous element. To each additional electron corresponds a distinct magnetic state characterized by the m

quantum number which is specific of the element [8]. However this interpretation involves a difficulty; it seems not to take into account the interactions between the different electrons of a same atom, or, a fortiori, the case when several atoms interact.

In fact when we want to describe physical events, more or less implicitly we suppose that the space can be defined by the volumes of the observed objects. At the macroscopic scale the interactions having a small impact on the objects defining the space it is possible to neglect their influence upon the volume and the matter determining them. At the atomic scale there is no direct observation of the motion of the electrons; one has to suppose that the interactions are more important and we must specify them in order to be able to describe the space and the motion. These remarks relate back to the notion of relativity of the motion which has introduced in physics a remarkable progress, and where the mass became an additional degree of freedom. So it is allowed to suppose that variations of mass, necessarily progressive, are at the origin of the interactions thus justifying the differential equations of the quantum mechanics [10] without making obsolete the Sommerfeld model [5]. This hypothesis opens the way to introduce variations of speed i.e. acceleration of a body in quantum mechanics [12]. These results have allowed an interpretation of the valence role of the 4 f shell and to shed new light on some crystal structures [11]. In this quantum model the proton and the electron are supposed to be made of very small elements called grains of matter as the electric and magnetic field. Thus these grains make two opposite fluxes exchanged between the proton and the electron and support their relative motion. This conception of the hydrogen atom put in view the close connection between the mass and the degrees of freedom of motion; as a result it allows to describe the wave function in Dirac's equation as the mechanical action, its differential elements of space and time giving access to the components of the momentum and to the energy of the motion. The approach leads, as we will see, to consider that the motion is governed by an intrinsic constant action *h.* The interactions dues to mass fluxes modify the electron mass and then its kinetic energy in such a way to keep constant the intrinsic action, the overall process resulting in the macroscopic properties described by periodic table.

Nevertheless there is still a first difficulty which needs to be clarified. Indeed with a variable mass in addition to the identified states, the existence of the doublets comes from the possibility for the electron to absorb one quantum as inert mass, increasing as much the momentum and giving the doublet structure. As a result if the self rotation of the electron is a fundamental property, it is not the cause of the doublets. In fact the rotation of the electron is a

motion which would not be independent of the rotation of the proton, as suggested by the hypothesis of the two opposite fluxes. As we will see in the sequel, it is in fact the problem of the relativity of the motion which is in question.

This is just what this study - completing the one entitled "Quantum State, Magnetism and the Rotation"[12] with the interpretation of the Stern and Gerlach experiment [13], [14] - is aimed at, i.e. showing how the orbital action of the electron is added or subtracted to that of the intrinsic rotation, therefore leading to two distinct momenta. In the following *section* 2, we revisit topics as the absence of absolute space, symmetry aspects and the degrees of freedom of the electron-proton system; in *section* 3 the formation of the doublets and of the associated magnetic momenta is discussed; in *section* 4 the Stern and Gerlach experiment is revisited in the new light. In *section* 5 we come back to the periodic table, calculate the Landé factor and recall our physical interpretation of the magnetic momenta structure in different solids.

2 The symmetry of the motion

To define the space, Sommerfeld's model with the concept of trajectory and motion periodicity has a remarkable explanatory force that Dirac's model has not. For example it makes possible to understand the attraction between atoms; on the other hand basing on a trajectory concept we have been allowed to propose an interpretation of the mechanism of conductivity and superconductivity in the superconducting oxides [15]. Furthermore the assumption of a trajectory is suggested by the magnetic properties of the matter: indeed magnetism is all before a consequence of the motion of electric charges. These various remarks suggest that the equation of Dirac gives access to particular aspects of the trajectory [10]. To discuss the rotation, we will use the already proposed hypotheses, considering again the symmetry of the motion.

In Sommerfeld's model the electron described as a dimensionless point cannot exhibit volume properties as a rotation axis. It is supposed to orbit around the proton in plane motion. This rotation is well described by a spherical potential, yet there is a dissymmetry between the spherical potential and the plane motion characteristic of an axis of symmetry or at least of a direction of straight lines perpendicular to the plane.

2.1 Motion and exchanges of matter

The problem of the electron rotation reminds that of the earth rotation and the absence of absolute space. According to experiments the bodies in motion describe a trajectory, but this one is not built up with matter, and during a

small interval of time there is no material bond between this trajectory and the two particles in motion. Indeed, since the hypothesis of Newton $F = m\gamma$, we accept the distance interactions without having solved the question of their nature and this leads us to take hypotheses without realizing that the absolute space is still present therein in a more or less obvious way. Consider the Einstein hypothesis on the relativity of the motion [1] that we will thus express "In the study of the phenomena the causes of the physical laws must be independent of the place of the observation". Then consider the electron and the proton, and ask ourselves which variables are able to generate a force? When the speed of the electron changes, in the volume of the electron just the variations of its inert mass can be supposed to be involved, and reciprocally for the proton. So one has to consider that the variations of the inert mass between the electron and the proton are at the origin of the speed variations and thus of the corresponding momentum. To make this possible, the electron and the proton are supposed fluid matter and the wave function a wave of matter: that is the amount of matter determining, in a differential way, the mechanical action, and thus driving the electron along its trajectory [16], [17]. We suppose that this matter can be described with very small grains as compared to the mass of the electron as well as of the proton, and that they move with the speed of the light in the vacuum. So the motion is the result of exchanges of matter in the form of grains. This conception leads to consider the electromagnetic field proportional to the density of mass around the proton. Thus the mass of the proton fill up all the space excepted in the volume of the electron as indicates in 2.2.

2.2 Potential and exchanges of matter

To describe the motion of the electron around the proton we consider an atomic system of coordinates *Ra*, made of three orthogonal axes, the centre of gravity O of the proton being at the origin (figure 1). This centre O is also the centre of the potential acting on the electron. The intensity of the potential in a point P is inversely proportional to the distance OP that separates it from the centre. As a result the density of matter allowing to describe the potential is itself inversely proportional to this distance. Let then γ be the centre of gravity of the electron. The physical law must be independent of the place of observation, so as for the potential we suppose that in the space of the electron, the density of matter allowing to describe the electron charge is a function inversely proportional to the distance from γ. The surface delimiting the volume of the electron in the space of the proton corresponds consequently to the minimum of density. It is through this surface that the exchanges of mat-

ter determine the action and the trajectory. In a coordinates system where the potential centre is fixed the rotation of the proton is represented with an arrow opposite to the one symbolising the rotation of the electron.

Let us return then to the symmetry of the potential which does not correspond to that of the plane motion of rotation characteristic of a symmetry axis or of a direction of straight lines. Take up then the analysis by Pierre Curie of the symmetry elements between the causes and the effects [18]. His words were as follows:

When certain causes produce certain effects, the elements of symmetry of the causes must be found in the effects produced.
When certain effects reveal certain dissymmetry, this dissymmetry must be found in the causes, which have produced them.

In this spirit, taking into account the absence of absolute space, the orbital motion of the electron is inseparable from its motion of rotation around itself. To describe the motion of the electron, in addition to the potential we must introduce the symmetry properties of the orbital motion into the volume of the electron.

2.3 The intrinsic Quantum

Consider the electron in the atomic reference system Ra. Among the different quantum states one has to distinguish: on one side the two deepest states, called "1s", and on the other side those which are obtained from a "1s" state by, for instance, absorption of a photon. In these last the photon energy is condensed as mass and they differ from the "1s" states by their inert mass. The quantum present in the two "1s" states generates the motion of each of them, in the other states this quantum is still present but with an inert mass more important, as a result the increased number of quanta. We call intrinsic this quantum which generates the motion.

Considering the relativity of the motion, there is no intrinsic or own property. All that we know is defined in connection to another object or property, which is a different way to express the absence of absolute space; however, we will still use this term which recalls the notion of interior, when we will speak about the exchanges of matter inside the electron. Thus, in the study of the hydrogen atom, we can just speak of motion of the electron in comparison to the proton. With a fixed gravity centre O for the proton, we have to consider for the electron: the orbital motion around the centre O, a translation motion and an intrinsic rotation. Now when we consider the proton having

fixed its gravity centre O, there is no reason to suppose the absence of an intrinsic rotation for the proton. In expressing thus the relativity of the motion we implicitly suppose our-self being in the fixed reference system Ra. But we can do the same at the centre γ of the electron and like this the reciprocity of the different motion are easier to understand. Thus if there is an own rotation of the electron this rotation reflects that of the proton[1]. Furthermore, we have to consider a translational motion with respect to the proton: as that of the orbital rotation, quantified by the intrinsic quantum.

In addition, to have a periodic motion there is necessarily a particular kind of mass variation. To be periodic, the sum of the variations must be zero along a period. Furthermore these variations cannot be generated with the orbital rotation alone, in such a way that the increase and decrease of mass belong to only two different components, otherwise these increments will be cancelled each other out. As a result for the circular motion, there are necessarily alternative variations of mass which are generated with successive accelerations and decelerations perpendicular to the equatorial plane characteristic of the rotation.

These results can be deduced considering the exchanges of matter and Sommerfeld's model for the circular motion. In this model the circular motion is a planar one; there are only two independent degrees of freedom. On the other hand the exchanges of matter that determine the momentum and generate the orbital rotation are distributed in a volume. *Consequently the action associated with the rotation cannot be correctly described by the product of two vectors,* the momentum and the displacement dl, both contained in the plane of the trajectory. These two vectors must necessarily have one component out of the plane of the trajectory. The two components come from the two fluxes determining on the electron, along a short interval *dt* of time and *dl* of space, *one sum of entering grains and the other of those getting out. The associated speeds to these two sums must necessarily belong to two independent degrees of freedom, in such a way that the action of one does not annihilate that of the other. As a result for the "1s" states the actions pertaining*

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[1] We limit this study to the case of the proton: indeed if for several aspects it seems possible to extend it to the nucleus, the mass being supposed variable one would have to discuss the role of the neutrons compared to the protons but this is another subject.

to each of them are equal to ½ħ. The two fluxes can be reversed giving two possible states.

The independent directions of the circular motion are: one parallel to the axis of rotation and the two others determining the equatorial plane perpendicular to the rotation axis of the electron.

Thus the rotation of the electron and its translation are relative properties governed by the intrinsic quantum of action "h" this would not have two orientations with respect to that of the proton, in contrast with the hypothesis of Uhlenbeck and Goudsmit [19] [20] where the momentum associated to the electron and called spin can be added or subtracted to the orbital momentum.

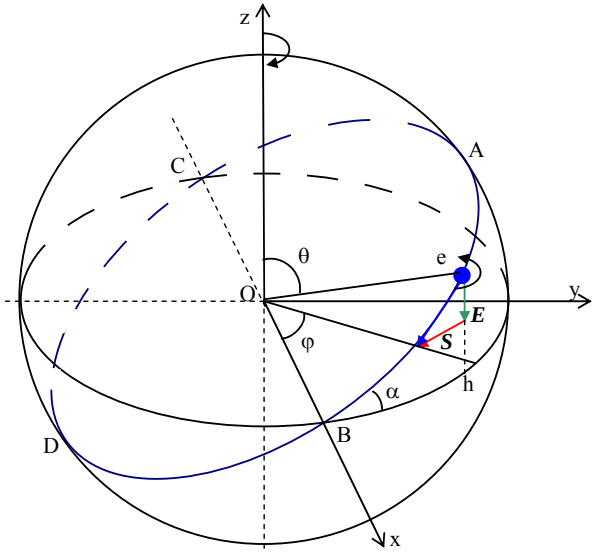

Figure 1. The motion of the electron for one "*1s*"; the point O is the centre of the potential, the plane of the motion ABCD, the equatorial plane Ox, Oy. The blue circle e represents the electron along its trajectory. The arrow on the half circle at the top of the figure indicates the way of rotation of the proton opposite to that of the electron e. The vectors E et S symbolise the momenta of the entering and outgoing fluxes.

Thus this approach to the motion leads to consider two fluxes of matter running in opposite ways between the proton and the electron and to suppose

that their respective rotations are the result of action and reaction so that they turn in opposite way.

The intrinsic quantum might also play the role of the fluctuation field in the "Bernoulli" oscillator model proposed by G. Mastrocinque [21]-[23] in view of approaching some quantum mechanical results by a classical view. It is the hypothesis of the existence of an intrinsic quantum as it has just been described which was missing in the model of Sommerfeld. Its introduction leads us to add the variable z as an additional degree of freedom, see [24] where it is called ω to underline its participation to the rotation.

3 The doublets and the angular momentum of the electron

Historically the "quantization" of the electronic orbits was introduced by Bohr [4] for the hydrogen atom. He was supposing circular orbits and the orbital angular momentum equal to an integer times Planck's constant of action $\hbar$. Thus calling *k* this number, the action along a period for these orbits is kh. This approach was taken again by Sommerfeld [5] as concerns the angular momentum of the plane motion for elliptic orbits; the quantum number *k* was supposed to represent the number of quanta of the angular momentum. This conception ignores the existence of the intrinsic motion having an action *h* shared into two equal quantities between the motions of translation and rotation, a fact modifying the angular momentum values.

3.1 The doublets.

To the intrinsic quantum correspond the two "1s" states; in addition there are other states with several quanta, including always the intrinsic quantum generating the rotation. They correspond to an increase of the inert mass by absorption of a photon; the periodicity of the motion is that of the intrinsic motion of rotation of the electron governed by the intrinsic quantum of action. The increase of the inert mass leads to a decrease of the kinetic energy.

In our view, the displacement dl is produced by the entering and getting out energy (see figure 1). Then along a short interval of time *dt* and space *dl* if ε is the exchanged energy, we have:

$$\mathcal{E}dt = pdl \tag{3.1}$$

Which leads to:

$$\mathcal{E} = mv^2 \tag{3.2}$$

This is just the double of the classical expression giving the kinetic energy. After all, this is the result of the way we determine the energy of the different levels. We consider the photon energy $E=h\nu$, that is for the considered level an additional energy $\pm dE=h\nu$. By this way we are concerned with the entering energy in the electron or with that getting out of it. On the other side in the expression (3.1) and thus (3.2) the displacement *dl* is produced by the entering and getting out energy (see *figure* 1) as a result the double of the classical expression for the kinetic energy.

For *n* quanta, the energy *E* and the period *T*(E), we have as ordinary:

$$\int E(T)dt = nh \tag{3.3}$$

Here *n* is the total number of quanta of the state called principal quantum number. For a given number of quanta, the different quantum states correspond to their sharing between the three degrees of freedom associated to the space and the degree of freedom associated to the mass, through angular, axial and radial momentum; thus for *n* quanta there will be ρ quanta for radial motion and *k* quanta for the motion of rotation, these last being themselves shared between *m* quanta for the equatorial motion and (k –m) for the axial motion. But now one aspect of this model is to introduce variation of mass as the origin of the acceleration; as a result, in addition to the quanta of rotation having their momentum parallel to the equatorial plane, *we can equally have an increase of the number of the quanta by acceleration of the axial component of the already existing states, the values of m remaining the same.*

So the distribution of quantum numbers slightly changes with respect to the ordinary one. It is in such a way that one has to understand the formation of the doublets. The states corresponding to quanta without increase of the acceleration are those of the type I in de Broglie [7], the others are those of the type II.

3.2 Angular Momentum and action.

Among the various possibilities to compare the theory and the experiment, the calculation of the magnetic moment of numerous compounds has been an interesting way [9]. In this calculation the momentum has an essential role, and it is important to determine it. In this view it is useful to underline that between the momentum M and the action A along one period there is the relation A = 2πM, so it can be easier to think about the action along a period

than in terms of momentum. *For example for each electronic trajectory, when one places an atom in an electromagnetic field, it is the energy of each quantum state which is modified; the translational and the rotational motions as governed by the intrinsic quantum then undergo a modification of the trajectory in such a way to keep constant the number of quanta of rotation.*

3.3 The two types of momentum

First consider a quantum state of the type I: among the different quanta, for the intrinsic quantum just one half of it contributes to the rotation and the magnetic field would modify just the energy associated to this action; so just the half intrinsic quantum contributes to the angular momentum. For the other quanta determining the number k, the mass is modified by the magnetic field; thus they contribute to the orbital rotation therefore to the momentum. For these quantum states the momentum must be reduced of ½$\hbar$.

Consider now a quantum state of the type II: in addition to the quanta determining the quantum states of the type I, there is an axial quantum corresponding to an additional acceleration; this quantum is obtained with a variation of mass which will be modified with a magnetic field, it contributes in its whole to the orbital rotation motion. This quantum adds to the quanta in number *k* of the orbital rotation as in type I; taking into account the half-contribution of the intrinsic action and the quanta as in type I, the momentum of the type II must be increases of ½$\hbar$.

Thus there are two types of momentum values. If we choose to count positively the intrinsic momentum that is +½$\hbar$, one has to consider an algebraic sign for the orbital momentum *k*. Let then ℓ be the number of quanta of rotation, it comes $k = \ell$ or $k = -(\ell+1)$ for the 1st or the 2nd subshell. The solutions $k = \ell$ correspond to those of the types II in de Broglie; for $k = \ell = 1$ they correspond to the states $2p_{1/2}$. The solutions $k = -(\ell+1)$ correspond to that of the type I in de Broglie, for $\ell = 1$ they correspond to the states $2p_{3/2}$. In addition the unit added to the number ℓ in the relation $k = -(\ell+1)$ corresponds to the intrinsic motion. The angular momentum is:

$$M = (k + ½)\hbar. \tag{3.4}$$

This relation shows that the number *k* of quanta in the plane of gravitation does not correspond to the angular momentum, a relation which was established by Dirac with the algebra of the operators [5].

Table I. The different quantum numbers in Dirac's model, their relation of order and ν the number of states of the subshell. The type II corresponds to the first subshell and the type I to the second. The principal n, orbital ℓ , radial r, magnetic m quantum numbers; the number ρ is introduced in the degree of the polynomials defining the radial functions component of the solutions of the equation of Dirac. To avoid any mix-up with the *np* shells giving doublets we use the Greek letter ρ instead of the letter p used by Louis de Broglie [6] and [9]. The limits of the m number result of the study of the solutions of the equation of Dirac and are experimentally confirmed with the measures of the magnetic moments [9].

$n \geqslant 1$	$\ell \leqslant n-1$	$\rho \leqslant n-1$	$n = \ell + r + 1$	ν
Type II first subshell	$k = \ell$	$\rho = r + 1$	$-(\ell - 1) \leqslant m \leqslant \ell$	2ℓ
Type I Second subshell	$k = -\ell - 1$	$\rho = r$	$-\ell \leqslant m \leqslant \ell + 1$	$2(\ell + 1)$

Considering the algebraic character of the relation (3.4), the expression of the angular momentum seems close to the hypothesis of Uhlenbeck and Goudsmit [18] and [19], this appearance is the result of the possibility for one additional quantum to modify by increase of the acceleration the existing states, which is different from the hypothesis of the spin to introduce the rotation. Nevertheless the hypothesis of the rotation of the electron is fundamental, but needs to be confronted to the principle of relativity the use of which in the approach of the phenomenon is still insufficient.

Thus the doublets correspond, for a given number ℓ of quanta, to a difference of axial acceleration leading to a same angular momentum in absolute value with very close but different masses. On the other hand they do not correspond to two different ways of rotation, as the existence of equal and opposite magnetic momentums has allowed to believe it; indeed we know that the doublets are exhibited in spectroscopy without magnetic field.

3.4 The component m of k and the angular action

The action k is shared between the angular magnetic contribution m and an axial contribution $|k|-|m|$ and it is useful to determine the possible values of m. The number m can be positive or negative according to the way taken by the flux between the proton and the electron. To respect the number k of quanta, the different possible values of m must satisfy the relation:

$$|m-½| \le |k| \tag{3.5}$$

This leads to the following relations:

For the 1st subshell $k = \ell$ $\qquad -\ell \le m \le \ell + 1$ (3.6)

For the second subshell $k = -(\ell+1)$ $\qquad -(\ell-1) \le m \le \ell$ (3.7)

These relations determine the set of known possible quantum states, which are recapitulated in the *tables* I and II.

Tableau II. The *s*, *p*, *d*, *f* shells *and* the corresponding subshells.

s ; $\ell = 0$	*p* ; $\ell = 1$		*d* ; $\ell = 2$		*f* ; $\ell = 3$	
$s_{1/2}$	$p_{1/2}$	$p_{3/2}$	$d_{3/2}$;	$d_{5/2}$	$f_{5/2}$	$f_{7/2}$
$k = -1$	$k = 1$	$k = -2$	$k = 2$	$k = -3$	$k = 3$	$k = -4$

The possible values in $\hbar$ unit of the equatorial action *u* of the movement are obtained subtracting -1/2 from those possible of *m*, it comes:

$$u = -(m-½) \tag{3.8}$$

The equatorial action is often incorrectly called projection of the angular momentum, but the action is in fact the sum along a period of the product $p \times dl$ of two collinear vectors, the momentum *p* and the displacement *dl*, of the motion in the gravitation plane. Their projections are p_φ and $rd\varphi$. Let α be the angle between the plane G of gravitation and the equatorial plane, the radial action does not modify the orientation of the circular trajectory. Thus it is the square cosines of α which determine the ratio between $|u|$ and $|k|$. It comes:

$$\cos^2 \alpha = \frac{p_\varphi r d\varphi}{p dl} = \left|\frac{u}{k}\right| = \left|\frac{m-½}{k}\right| \tag{3.9}$$

The relation (3.8) needed in the calculus of the magnetic moment μ_e of an electron is given by de Broglie [6], the calculus of μ_e is given in section 5. The α angles are used in the study of the crystal structures [10].

4 The space quantization and the Stern and Gerlach experiment

The behaviour of atoms in a magnetic field shows the existence of an even number of energy levels. In particular it is the case of identical atoms with just one electron in an *"ns"* state, the other electrons having a null magnetic resultant. Indeed when these atoms get out of an oven and cross a magnetic field as in the Stern and Gerlach experiments [12], [26], one observes two levels. In these experiments (*figure* 2) a beam of atoms gets out of an oven through the aperture O, is delimited by the slit F, then passes through the field region to be revealed on the plate A. The non-homogeneous field is produced by the electromagnet with pole piece of the wedge groove type, shown in section E. The experiment shows that the beam after crossing the non-homogeneous magnetic field gives rise to two traces on the detection plate, symmetrically disposed on both sides of the central trace obtained without magnetic field. For each of these traces the deviation corresponds to one Bohr magneton. These experiments were initially used to study the distribution of the velocity of the atoms in a beam. In Maxwell theory one would expect just one elongated trace, denser at the centre, the edges corresponding to atoms of low velocity. The observation of two traces established the existence of two distinct magnetic states for the *"ns"* levels; this was called the space quantization.

Now the existence of two traces with atoms having just one outermost electron in an *"ns"* state shows that in these atoms, the orientation of the magnetic momentum of each of the two states *"s"* is specific of each state. There must be, indeed, a property of the atom imposing to each one of the states to exhibit an opposite deflection. In this model *one has to suppose that is the characteristic rotation of the motion of the electron around the proton which stays the same whatever the orbital magnetic momentum is; the difference between the two states coming from the repartition of the outside or inside fluxes between the two degrees of freedom inverting their magnetic momenta according to the considered state.* Indeed the inert mass is continuously renewed with the exchanges of matter determining the rotation; it is much larger to that equivalent to the exchanges of matter determining the kinetic energy of a quantum state. As a result in a magnetic field these exchanges stabilize the axis of rotation in the direction of the field in such a way to increase or decrease the exchanges of matter that is the energy of the interaction.

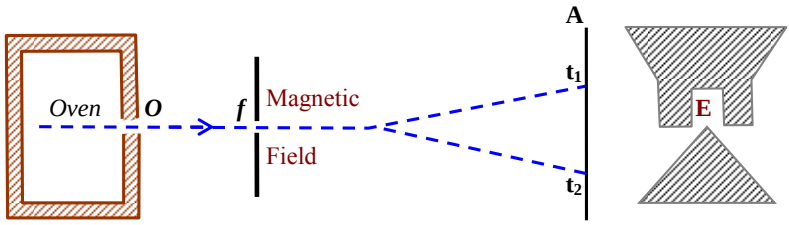

Figure 2. Diagram of Stern and Gerlach apparatus, according to Stoner [25].

In this way the magnetic field induces an additional flux, it modifies the flux corresponding to the equatorial plane which is different according to the "ns" quantum state considered. As a result there is a motion in an opposite direction for each of the two "ns" states. If the additional flux tends to accelerate the rotation, the atom is attracted toward the increasing magnetic field and inversely if the additional flux tends to slow down the rotation. On the other hand the continuous exchanges between the two fluxes tend to balance them.

To tackle this interpretation, the difficulty comes from the fact that all our experiments on the interaction between electric current and magnetic field are based on a field produced by a macroscopic current, that is by just a kind of flux of matter. As a result it might seem that two atomic currents going in an opposite direction would be able to turn into a magnetic field in the same direction, as it is exhibited in the study of the reciprocal influence of two electric circuits when one of the two can turn over on the influence of the magnetic field of the other; but the Stern and Gerlach experiment shows that it is not so.

5 Magnetic moment and Landé'factor

In "Total Angular Momentum and Atomic Magnetic Moments" [9] we suppose with Lochak that Dirac's model just valid for a hydrogenous atom is still useful in the calculation of the magnetic momenta at 0 °K of a complex atom in a solid and particularly in a crystal. It is interesting to underline that the model just developed sheds a new light on this property. Indeed, the exchanges of matter stabilising the number of quanta of the different degrees of freedom of a quantum state of a hydrogen atom, are not limited to an electron and its nucleus, not more than to a single atom and can equally play this role when there are several electrons on the atom and several atoms in the solid. So we suppose that they are always the exchanges of matter, which allow to

an atom to have physical as well as chemical properties, reflecting the quantum properties of the electrons most exposed to these exchanges.

5.1 The factor of Landé

Consider a magnetic field H generated by a solenoid. The modifications of density of grains that it provokes are described with the angular variable of the orthogonal planes to the field H. The measurement of the magnetic moment of a solid consists to determine the asymptotic value of this moment to null field, when it is possible to consider that all the atomic moments are parallel to the magnetic field. In this way the values of the angular momenta of the different quantum states are not modified by the field.

The angular momentum on which the magnetic field acts is different from $M = k\hbar$, the expression used in the classical calculations of the Sommerfeld model. To calculate the angular momentum of a quantum state, one has to use the expression of the magnetic momentum μ_e of a current in a single circuit, which is equal to the area of the circuit S times the current I (in electrostatic units) divided by the light velocity c:

$$\mu_e = IS/c \tag{5.1}$$

In terms of moving charge e and its period of revolution T, the current is givens by:

$$I=\frac{e}{T} \tag{5.2}$$

Then:
$$\mu_e = \frac{eS}{Tc} \tag{5.3}$$

Now the area of a Kepler ellipse in terms of mass m of the electron, its mechanical moment M, and the period T is:

$$2mS = T\,M \tag{5.4}$$

For $M = k\hbar$ the magnetic moment in the Sommerfeld approach is:

$$\mu_e = k\mu_B \tag{5.5}$$

where μ_B is the Bohr magneton:

$$\mu_B = \hbar \frac{e}{2mc} \tag{5.6}$$

and for the component $u = k\cos^2\alpha$ in the equatorial plane:

$$\mu_e = u\mu_B \tag{5.7}$$

Now in the Sommerfeld approach the orbital momentum *kh* is different from the total angular momentum $|k+½|$, so that one has to introduce a corrective factor *g* or Landé'factor. Indeed if the total momentum is lower or more important than the orbital moment *kh*, the moment μ_e will be either more important or lower, and one has to divide μ_e by the action of rotation; furthermore for the hypothetical value $M = kh$, the factor *g* must give again (5.5), so we have:

$$k = g(k+½) \tag{5.8}$$

Thus

$$\mu_e = gu\mu_B \tag{5.9}$$

This expression of Landé factor *g* was established in 1928 with the algebra of the operator by Dirac in the second part of his paper "Quantum Theory of the Electron." [24]. The set of the results following from Dirac theory are equally found again in this corpuscular approach, they are well corroborated by the measurement of magnetic moment of various metals and compounds [8].

5.2 The magnetic moments

For the states *ns* the relation (5.8) gives $g = 2$, the magnetic moment is equal to one Bohr magneton, they are the only states for which $\mu_e = 1\mu_B$; all the other states have a factor *g* no integer leading to no integer magnetic moment.

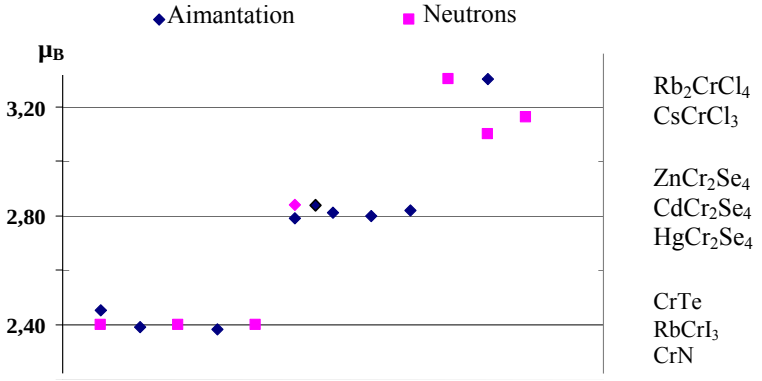

Figure 3. Chromium magnetic moment at 0°K in some compounds. The experimental data are given in appendix.

In particular for the chromium compounds the only electrons giving a magnetic contribution are the four of the first *3d* subshell *table* III. The possible values are $\mu = n(0.40\mu_B)$ with n integer such that $n \leq 8$. This is confirmed by the different experimental values of the compounds where the chromium, just in one crystal site, is the alone magnetic moment *figure* 3 [8]. As exhibited by these results the Pauli principle is not an absolute rule. If it is true that going along the filing of the electronic subshells and shells there is some magnetic neutrality of the corresponding electrons, the present model shows that it is not more that a guideline susceptible of exception.

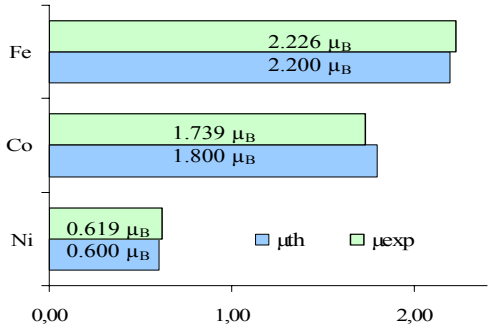

Figure 4. The magnetic moments of Fe, Co and Ni, [27].

In a similar way the magnetic moments of iron, cobalt and nickel are easily interpreted: μ(Fe) is the sum of the contribution of one electron of the first subshell *3d* with $\mu = 0.40\mu_B$ and of an electron of the second subshell with $\mu = 1.80\mu_B$. For the cobalt its moment corresponds to that of one of the two electrons having a moment $\mu = 1.80\mu_B$, finally for the nickel its moment corresponds to that of the two electrons with $\mu = 0.60\mu_B$. The case of the rare earth metals is given in [8].

Table III. The different 3d quantum states of the two subshells 3d3/2 and 3d5/2. The number m defining the wave function. The angular momentum u = - [m -(1/2)] in $\hbar$ units, the Landé g = k/(k+½) factor and the corresponding magnetic moment μ = gu in Bohr magnetons. The 3d elements M with their corresponding number ν of 3d3/2 or 3d5/2 electrons. The place of the element M is such that the additional electron is supposed to occupy the quantum state of column.

$3d_{3/2}$	$k = 2$		g = 4/5	
M	Sc	Ti	V	Cr
m	2	1	0	-1
u	-3/2	-1/2	1/2	3/2
μ	-1.2	-0.4	0.4	1.2
ν	1	2	3	4

$3d_{5/2}$	$k = -3$			g = 6/5		
M	Mn	Fe	Co	Ni	Cu	Zn
m	3	2	1	0	-1	-2
u	-5/2	-3/2	-1/2	1/2	3/2	5/2
μ	-3	-1.8	-0.6	0.6	1.8	3
ν	1	2	3	4	5	6

6 **Conclusion**

The relativity imposes to the physical laws to be independent of the place of observation, allows us to complete the model of Sommerfeld. In this model the electron and the proton turn around each other and always in opposite direction, with the same axis of rotation; there is equally a motion of translation. To these two motions is associated a quantum of action shared in two equal parts between the rotation and the translation; as a result we find

the half quantum numbers for the angular momentum and the magnetic moments. The magnetic quantum properties appear as the result of possible acceleration or deceleration of the translational motion of the electron. Thus the set of the possible states has a full corpuscular-like description which seemed to escape up to now to the common interpretation of the Stern and Gerlach experiment.

7 **Annexe**

Table AI. Magnetic moments of the chromium in some compounds. The values from the measurements of magnetisation and diffraction neutrons used in *figure* 3.

	μ	Ref.		μ	Ref.		μ	Ref.
Rb_2CrCl_4	3.30	1	$ZnCr_2Se_4$	2.79	5	CrTe	2.39	9
	3.30	2		2.84	6		2.45	10
	3.10	3					2.40	11
			$CdCr_2Se_4$	2.80	7	$RbCrI_3$	2.40	12
				2.81	8	CrN	2.38	13
$CsCrCl_3$	3.16	4	$HgCr_2Se_4$	2.82	9		2.40	14

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