Quantum State, Magnetism and Rotation[1]

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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 respect, it is first underlined that the symmetry of the motion of rotation reveals a corresponding axis on the electron, which cannot be independent from that of the proton. Furthermore, the relativity of motion requires that the same causes must be responsible for it in the space of the electron as well in that of the proton. This leads to suppose that the moments are due to exchange of inert mass between the electron and the proton in a 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.

1 Introduction

The interpretation of quantum state, wave function and of the doublets has led us to suppose, during the motion of the electron, a variable inert mass [2] keeping as well the corpuscular aspect of Sommerfeld model [3]. These results have allowed an interpretation of the valence role of the 4f shell and to shed new light on some crystal structures [4]. In this quantum model the proton and the electron are supposed mad 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 maintain their relative motion. This conception of the atom put in view the close connection between the mass and the degrees of freedom of motion; as a result it allows describing 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 energy of the motion.

[1] English translation of "L'état quantique, le magnétisme et la rotation", Annales de la Fondation Louis de Broglie, 34, 2, in press, (2009), http://www.ensmp.fr/aflb/AFLB-342/aflb342m678.pdf

Nevertheless there is still to shed light upon a difficulty, 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 introducing the rotation of the electron it is to introduce a motion which would not be independent of the rotation of the proton as suggested by the hypothesis of the two fluxes each one inverse of the other. It is that this study intend to exhibit completing that titled "The Symmetry of the Motion and the Mass" with the interpretation of the experiment of Stern and Gerlach [5], [6] and of the magnetic states. The *section* 2 revisits the absence of absolute space and the aspects of symmetry, *section* 3 discuss freedom degrees of the system electron proton, the *section* 4 interprets the experiment of Stern and Gerlach, the *section 5* discuss the different magnetic states.

2 The symmetry of the motion

The experimental study of the spectral lines emitted by an atom reveals that they are classified in series. Some lines of these series are double, called regular doublets. The traditional example is that of the D line of the sodium with the respective wavelengths λ_1 = 5890Å and λ_2 = 5896Å. The set of lines thus observed for various atoms forms the experimental base of the quantum state. To interpret the spectral lines Sommerfeld was brought to quantize, in the study of the motion of the electron around the proton, the angular and radial action [3]. Doing so leads to a great number of remarkable results but does not provide any answer as on the origin of the regular doublets and the existence of the half integer numbers [7]. Up to now only the introduction of the wave functions and the theoretical model of Dirac have allowed finding out the set of the quantum states and the energy levels associated with the regular doublets [8]. On the other hand, these two theories lead to the same expression of the energy of the levels of the various quantum states whereas the interpretation of the regular doublets escapes the corpuscular approach of Sommerfeld.

Now Sommerfeld's model with the concept of trajectory with its corollary the periodicity of the motion has a remarkable explanatory force that Dirac's model has not. For example it makes it possible to understand the attraction between atoms; on the other hand the trajectory of electron has allowed proposing an interpretation of the mechanism of conductivity and superconductivity in the superconducting oxides [9]. Furthermore the assumption of 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 [2]. To discuss of the rotation we will use hypothesises already proposed taking again the discussion of the symmetry of the motion.

In Sommerfeld's model the electron described as a point cannot exhibit volume properties as rotation axis. It is generally supposed orbiting around the proton in plane motion, this rotation is well described with a spherical potential, nevertheless there is a dissymmetry between 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.

The problem of the electron rotation reminds that of the earth rotation and the absence of absolute space. According to experiment the bodies in motion describe a trajectory, but this one is not built with matter, along a small interval of time there is no material bound between this trajectory and the two particles in motion the one in respect to the other. Indeed since the hypothesis of Newton $F = m\gamma$, we accept the away distance interactions without to have solved the question of their nature and thus this leads us to take hypothesises without realizing that the absolute space is still present in a way more or less obvious. Consider the hypothesis of Einstein 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 change, in the volume of the electron, just the variations of its inert mass can be suppose involved and reciprocally for the proton. Thus one has to consider that that they are the variations of the inert mass between the electron and the proton which are at the origin of the variations of the speed 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 the mechanical action leading the electron along its trajectory [10] et [11]. We suppose that this matter can be described with very small grains as compared to the mass of the electron as well of the proton.

Let us return then at 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 between the causes and the effects of the symmetry elements [12]. 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.

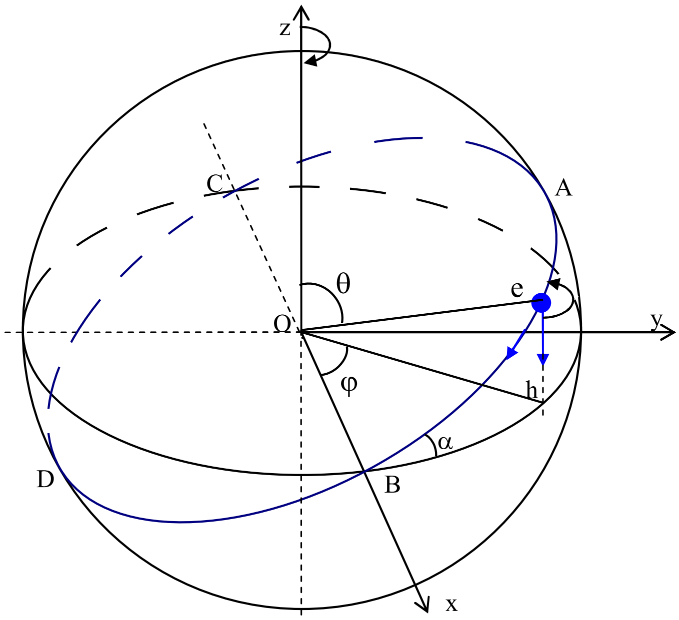

Figure 1. The motion of the electron: the point O is the centre of the potential, the plane of the motion ABCD, the equatorial plane Ox, Oy. The blue circle e represents the electron along its trajectory. The arrow on the half circle at the top of the figure indicates the way of rotation of the proton opposite to that of the electron e.

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, we must in addition to the potential, introduce the symmetry properties of the orbital motion into the volume of the electron. Consider a system of coordinates at rest in respect of the orbital motion; we suppose that this last is the result of the rotation of the electron called "intrinsic or own rotation". In fact 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. Thus if there is rotation of the electron around itself it reflects that of the proton. Thus we suppose that the own rotation of the electron is inseparable to that of the proton and that it is governed by **the quantum of intrinsic action "h"** called like this in spite of the ambiguity of the word, in addition we use intrinsic rather than rotation or spin because this quantum leads also a translation motion as we will see in section 3. Thus the rotation is a relative property which would not have two orientations in respect to that of the proton contrary to the hypothesis of Uhlenbeck and Goudsmit [13] and [14] where the momentum associated to the electron and called spin can be added or subtracted to orbital momentumwhich is in fact the momentum of the electron.

Thus this approach of the motion leads to consider between the proton and the electron two fluxes of matter in opposite ways and to suppose that their respective rotations are the result of action and reaction so that they turn in opposite way[1].

These aspects are represented with arrows of opposite ways on the *figure* 1.

3 The mass and the degrees of freedom of the motion

In Sommerfeld's model the motion is planar; there are only two independent degrees of freedom. On the other hand the exchanges of matter that determines the momentum and generates the orbital rotation are distributed in a volume. Consequently the action associated with rotation cannot be correctly described by the product of two vectors, the momentum and the displacement dl, both being contained in the plane of the trajectory. These two vectors must necessarily have one component not in the plane of the trajectory. The two components arrive 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 another one of getting out which determine the mass and the direction of the speed. The associated speeds to these two sums must necessary belong to two independent degrees of freedom, in such a way that the action of one does annihilate that of the other*. The two independent direction of the circular motion are one parallel to the axis of rotation and the other to the equatorial plane and determines by the angular speed $v(\varphi)$ of the angle φ (*figure 1*).

Then consider the two circular states "*1s*", they are generated with just one quantum of action ***h*** and one has to consider only the equatorial and axial actions, as a result this model leads to suppose that the **quantum of intrinsic action** induces two components of motion: circular and parallel to Oz axis. The motion of translation of the electron parallel to Oz, as well the motion of rotation, must result by action and reaction from the two fluxes of the motion, thus it is always opposed to that of the proton. It is the resultant of these two motions which quantified the associated action to the electron during its orbital motion by exchanges of matter that is of energy, we will call it ***the intrinsic motion***. These two components of the intrinsic motion correspond one to the sum of the entering grains, the others of the getting out

[1] We limit this study to the case of the proton, indeed if from 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 and it is another subject.

grains; as a result the two corresponding actions must be equal. It is from this sharing of the intrinsic action into two equal amounts that half integer quantum numbers are exhibited in the magnetic measures. It is like this that one has to understand, *by action reaction, the intrinsic motion*. The connection between the different components of the action is the inert mass of the electron during the motion, which is as a result a fourth degree of freedom.

Then consider a quantum state with variation of the radial speed. Such a state results of an initial speed which moves aside or closer the electron from the potential centre O. As a result the density of matter interacting with the electron decreases or increases thus the variations of mass. To keep constant the total energy, the motion leads to absorption of grains increasing the inert mass in going away of O and loss of grains diminishing the inert mass in becoming closer of O. For the circular motion of the "*1s*" states, their Oz speed component be come zero in A and D on the *figure* 1, there is equally variation of the interring or getting out mass to this dire tion.

It is then possible to complete the model of Sommerfeld, take for the positive direction of rotation that of the proton, then the intrinsic rotation of the electron has a negative direction. For the two "*1s*" states, *the kinetic energy of the motion coming from the proton is always developed in opposition to the intrinsic motion of the electron.* Thus this energy develops: either the rotation motion with the entering flux and induces that of translation with the getting out flux, it has the magnetic quantum number $m = 0$ and for momentum $-½\hbar$; either the linear motion with the entering flux and induces the rotation motion with the getting out flux, it has the magnetic quantum number $m = 1$ and for momentum $+½\hbar$. These two motions thus lead the electron in a rotational motion in the direction of that of the proton or in the opposite direction.

The others states correspond to an increase of the inert mass, the periodicity of the motion is that of the intrinsic rotation of the electron governed by the quantum of intrinsic action, which imposes an integer number of quantum of action. For a given number of quanta, the different quantum states correspond to their distribution between the three spatial degrees of freedom and the inert mass. In particular the doublets correspond for the same number of quanta, to a same momentum with two very close inert but different masses. On the other hand they do not correspond to two different way of intrinsic rotation, as the existence of equal and opposite magnetic moments have allowed believing it, indeed we know that the doublets are observed in spectroscopy without magnetic field. Consider then the action kh initially introduced by Sommerfeld [3] as that of the momentum of the plane motion; the number k represented the number of quanta of the momentum, this number still represents the number of quanta of the plane motion but with a momentum which differs of $\pm\frac{1}{2}\hbar$.

4 The spatial quantification 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 magnetic resultant null. Indeed when these atoms get out of an oven and cross a magnetic field as in the Stern and Gerlach experiments show [5], [15], one observes two levels. In these experiments, *figure 2*, a beam of atoms get out of an oven through the aperture O, it is delimited by the slit F, then passes through the field region to be received 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 to have crossed the non-homogeneous magnetic field gives rise to two traces on the plate used to detect them and that they are symmetrically disposed on the both side 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 observe 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 "*n*s" levels if *n* is the principal quantum number; this was called the space quantization.

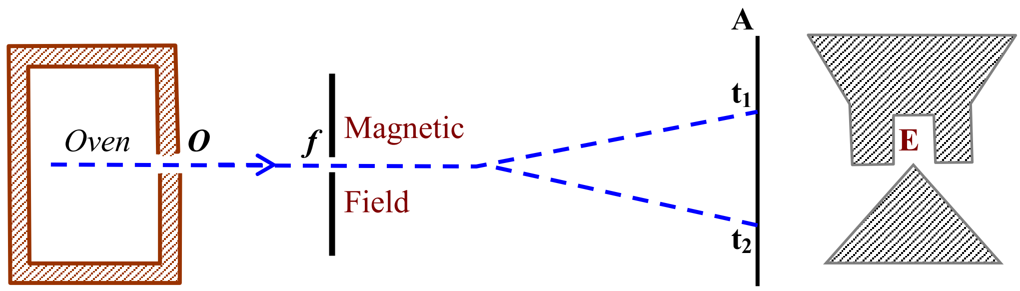

Figure 2. Diagram of Stern and Gerlach apparatus, according to Stoner [15].

Now the existence of two traces with atoms having just one outermost electron in an "*ns*" shows that in the atom, the orientation of the magnetic momentum of each two states "*s*" is specific of each state. There must have, 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 happening from the sharing of the* *outside or inside fluxes between the two degrees of freedom inversing the magnetic moment 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 inte action.

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 that all our experiment on interaction between electric current and magnetic field is based on field produced by macroscopic current that is by just one kind of flux of matter. As a result it seemed that two atomic current going in an opposite direction would be able to turn in a magnetic field in 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, the Stern and Gerlach experiment shows that it is not like this.

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 [7] and [2]. 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 [16].

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

5 The different quantum states

When there are one or several quanta in addition to the intrinsic quantum they give an additional momentum along one or several degrees of freedom.

1°) Consider the motion generates with just the intrinsic quantum, the action is share between the two degrees of freedom: the rotation and the translation, the angular momentum is thus $\frac{1}{2}\hbar$ in absolute value. One of the two "*1s*" states as we have seen *section 4* corre sponds to the acceleration of the rotation on the influence of a magnetic field, the quantum number call magnetic is $m = 1$ according to the notation used in Dirac's theory *tables I and II*; the other state corresponds to the deceleration with $m = 0$. In a similar way all the other states can be put together by pair. To understand the succession of the quantum states one has then to find the different ways to increase the number of quanta of action.

2°) When there is a second quantum of action, it can give a radial momentum to the electron, we have the two "*2s*" states; the radial component imposes an increase of the inert mass.

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

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

3°) The second quantum of action can be obtained by increase of the inert mass, the intrinsic quantum of action is shared in equal amount between the rotation and the translation; there is a decrease of the kinetic energy without radial component of the momentum. The angular speed of the rotation decreases. The orbital angular momentum increases of one unit without modifying the number of quantum states. We have $k = \ell = 1$ which is the alone unit allowing the orbital rotation, it is attached to the rotation. The angular momentum cannot be higher than the number of quanta of action; the angular momentum is thus $3/2\hbar$. We have the two $2p_{1/2}$ states, they correspond to the type II; for these two states the magnetic properties differ only of that of the two states "*1s*" by the factor f Landé $g = k(k + \frac{1}{2})^{-1}$ [16] et [2], since just mass has increased. This second quantum state modifies the radial properties of the wave function. The flying unit relation 20 in [2] belongs to the quantum number ρ (see *table I*) which determines the radial part of the wave function.

4°) The second quantum of action can still be obtained with increase of the inert mass and decrease of the kinetic energy with increase of the number of the quanta of rotation that is $(\ell + 1)$. When these states are in a magnetic field, the acceleration of the rotation can correspond to one or two quanta and inversely for deceleration. For these states the increase of the inert mass is very lightly higher to that of the $2p_{1/2}$ and the kinetic energy very lightly smaller [10]. The different magnetic moments correspond to *m = 2* and *m = -1* for $\mu_e = 3/2\,\mu_B$ and $\mu_e = -3/2\,\mu_B$ and *m = 1* and *m = 0* for $\mu_e = 1/2\,\mu_B$ and $\mu_e = -1/2\,\mu_B$. There are the four quantum states $2p_{3/2}$; they correspond to the type I.

Tableau III. The different 3d quantum states of the two subshells $3d_{3/2}$ and $3d_{5/2}$. The number *m* defining the wave function. The angular momentum *u* = - [*m* -(1/2)] in *ħ* units, the Landé g = k/(k+½) factor and the corresponding magnetic moment = *gu* in Bohr magneton. The 3*d* elements M with their corresponding number *ν* of $3d_{3/2}$ or $3d_{5/2}$ electrons. The place of the element M is such that the additional electron is supposed occupied 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

Tableau IV. The different 4f quantum states of the two subshells $4f_{5/2}$ and $4f_{7/2}$. The number *m* defining the wave function. The angular momentum *u* = - [*m* -(1/2)] in *ħ* units, the Landé g = k/(k+½) factor and the corresponding magnetic moment = *gu* in Bohr magneton. The 4f elements Ln with their corresponding number *ν* of $4f_{5/2}$ or $4f_{7/2}$ electrons. The place of the element Ln is such that the additional electron is supposed occupied the quantum state of column.

M	Ln	La	Ce	Pr	Nd	Pm	Sm
$4f_{5/2}$:	*m*	3	2	1	0	-1	-2
k = 3	*u*	5/2	3/2	1/2	-1/2	-3/2	-5/2
G = 6/7	*μ*	2.14	1.29	0.43	-0.43	-1.29	-2.14
	ν	1	2	3	4	5	6

M	Ln	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb
$4f_{7/2}$:	*m*	4	3	2	1	0	-1	-2	-3
K = -4	*u*	7/2	5/2	3/2	1/2	-1/2	-3/2	-5/2	-7/2
g = 8/7	*μ*	4.00	2.86	1.71	0.57	-0.57	-1.71	-2.86	-4.00
	ν	1	2	3	4	5	6	7	8

5°) The other increases of the action lead to the same consequences and explain the succession of the different quantum states. In particular the understanding of the filling of the 3d and 4f subshells *tables III and IV*, as they are exhibited with the calculation of the magnetic moments of different compounds [16] is an interesting question which allows corroborating the quantum model. We can consider that the most stable state of a subshell is that favours the exchanges in the direction of the rotation in accelerating it, thus it is the one having the highest momentum. The state corresponding to the decrease of one unit of the quanta of rotation appears thus in second. By recurrence the other states are explained in the same way up to the state m = 1, then with m = 0 the rotation is decelerated of one unit of action and so on up to the lowest value recalled in the *table I.*

6 Conclusion

Thus we have been able to propose a corpuscular quantum model. In this model the electron and of the proton turn around each other and always of opposite direction; parallel to the axis of rotation there is equally a motion of translation. To these two motion is associated a quantum of action shared in two equal parts between the rotation and the translation, as a result the half quantum numbers for the magnetic moments. The magnetic quantum properties appear as the result of possible acceleration or deceleration of the rotation of the electron. Thus the set of the possible states have a full corpuscular description that seems to escape up to now to the understanding of the Stern and Gerlach experiment.

In memory of Henri Oudet

Finishing this work I wish to mention the memory of my brother Henri of ten years younger than me: it is him who indicated me in 1968 that magnetism is first a relativist property. After this remark I have red the original papers starting with that of Einstein, then that of Dirac in the hope to understand the quantum mechanics. Henri was remarkably at ease in mathematical development but he lacked terribly of contact with the experiment. All those which have known him have spoken of a charming colleague that they egret since he has left us in 1989.

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