

# On a Non-Standard Atomic Model Developed in the Context of Bridge Electromagnetic Theory

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## ABSTRACT

In the context of the bridge electromagnetic theory, a quantum-relativistic theory based on Maxwellian electromagnetism, it has recently been shown that the characteristics of a hydrogen atom can be obtained through an electron-proton orbital capture process forming a non-radial emitting dipolar electromagnetic source. The model structurally different to the Bohr-Sommerfeld and Schrodinger models has now been deepened and completed by testing it on the properties of hydrogen and deuterium atoms and of helium and lithium in hydrogenoid form. These last two atoms are of cosmological interest as they are the heaviest elements produced by electron capture in the early universe. The theoretical results obtained regarding the atomic structure and spectra are in excellent agreement with the observational data by suggesting the implicit correctness of this electromagnetic model. It is also highlighted that the electron-nucleus interaction is influenced on an isotopic basis as a function of the value of the inertial mass of the nuclei considered.

**Keywords:** Non-standard atomic model; Bridge theory; Electron capture; Energy levels; Spectroscopy

## INTRODUCTION

Atomic ancient theory based on the Rutherford model has changed over the years both conceptually and formally. In spectroscopy, the current atomic model is fundamentally based on the Bohr-Sommerfeld theory [1], although the formulas for the determination of spectral lines and energy levels use the Rydberg-Ritz principle [2], which allows the calculation of the wavelengths of the emission spectra by means of ad hoc parameters identified on the basis of the atomic element considered. From the point of view of quantum mechanics, first the Schrodinger model, then the Dirac equation, were used to take into account the dual wave-matter phenomenology of atomic electrons, thus providing a probabilistic description of their momentum and position at each individual atomic level.

In this work, we propose a new approach to atomic model based on the Bridge Electromagnetic Theory (BT) principles, which has all its foundations in Maxwellian electromagnetism [3-5]. In this model, quantum and relativistic phenomena, as well as wave-matter dualism, emerge consistently from the theory used without forcing their introduction, in fact, it is known that quantum mechanics and relativity work well together even if their foundations are not compatible at all.

Bridge theory is a consistent and complete theory originating from the conjecture [3] on the role of the Transverse Component of the Poynting Vector (TCPV) of the Dipolar Electromagnetic Source (DEMS) formed during the direct interaction between two approaching charged particles of opposite sign [4,5]. The TCPV is able to localize the amount of energy and momentum inside the DEMS in the quantum form  $hc/\lambda$  with a wavelength equal to the minimum distance of interaction achieved by the two interacting particles and with the theoretical value of the action constant  $h$  characterizing the electromagnetic interaction of the two particles. The extraordinary result obtained in the past is the value of the action constant  $h$  calculated using the theory is in agreement with the standard value of Planck's constant, thus demonstrating that quantization is not a principle but a phenomenon that derives from the particular way of interaction of a pair of charged particles.

The conjecture [3] on TCPV was subsequently proved by Auci [4,5] by the calculation of Sommerfeld's constant and consequently by the determination of the physical origin of Planck's constant, subsequently allowing the development of an unconventional electromagnetic quantum theory [6]. Later it was shown that relativistic phenomenology can also be explained using the same theoretical approach [7]. Therefore, despite appearances,

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Maxwellian electromagnetism, quantum theory and special relativity are fully compatible theories and can therefore be used together in the form of an electromagnetic quantum-relativistic theory, the BT, whose formalism does not differ from that commonly used in quantum electrodynamics, but offers new insights into interpreting the physical phenomena observed.

## LITERATURE REVIEW

### Bridge Electromagnetic Theory (BT)

In BT, the interactions that produce quantum phenomena occur exclusively between pairs of charged particles of opposite signs that are defined as pairs of charge and anticharge, as the quantum behavior does not depend on the value of their original inertial mass, the mechanical nature of which has been studied separately [8].

The important point in BT is the formation of Dipole Electromagnetic Source (DEMS), which bonds pairs of charges by producing an electromagnetic entanglement independent of the distance achieved by the two particles. In fact, when DEMS is formed, any change in energy and momentum on the particles that form it would produce a change in energy in the DEMS which, however, for conservation can no longer occur as it would violate the principle of causality. This implies that a direct interaction in a pair of charges cannot be considered completely Coulombian because two interacting charges are always in motion with respect to each other, producing not only the Coulomb interaction but also an electromagnetic interaction that generates a non-point perpetual dipole source, *i.e.*, the DEMS, which moving with respect to every other inertial observer, produces with each of them a different Doppler effect that gives rise to the relativistic phenomenology.

The electromagnetic field of the DEMS does not have, therefore, spherical symmetry as the Coulombian one but cylindrical symmetry with the symmetry axis coinciding with the dipole moment axis, so the Poynting vector is not everywhere radial and the emerging wave can be considered a composition of a spherical radial wave that describes the classical field with a plane transverse wave circulating around the virtual centre of the DEMS that originates quantum effects. Each observer external to the direct interaction receives a superposition of both waves characterized and the value of which defines the observed energy and momentum in full accordance with special relativity.

### Quantum behavior: Poynting vector, action and energy of a DEMS

The electric field of the dipole can be described by a local three-dimensional vector centered in the dipole having at each point P of the space time three unitary components ( $\hat{i}, \hat{j}, \hat{k}$ ): Lateral, transverse and radial, of which the lateral component is always zero [5,6].

In Gaussian units, the electric field of the dipole is:

$$\mathbf{E} = \frac{e}{r^2} \begin{pmatrix} 0 \\ \frac{4\rho \sin\theta}{(4+\rho^2+4\rho \cos\theta)^{3/2}} + \frac{4\rho \sin\theta}{(4+\rho^2-4\rho \cos\theta)^{3/2}} \\ \frac{4(2+\rho \cos\theta)}{(4+\rho^2+4\rho \cos\theta)^{3/2}} - \frac{4(2-\rho \cos\theta)}{(4+\rho^2-4\rho \cos\theta)^{3/2}} \end{pmatrix} \quad (1)$$

whose only two non-null components are functions of the parameters  $(\rho, \theta)$ . The first is the most important and is defined by the ratio  $\rho = \lambda/R$ , where, R is the variable distance between the two interacting charges, corresponding to the length of the dipole moment for the unit of charge and the wavelength of the electromagnetic wave that will be emitted by the DEMS produced. The second is the polar angle between the radial vector pointing to a point of spacetime and the dipole axis, whereas the magnetic field of the DEMS in the dipole wave zone is

$$\mathbf{B} = \begin{pmatrix} -|\mathbf{E}| \\ 0 \\ 0 \end{pmatrix} \quad (2)$$

Consequently, the Poynting vector of the electromagnetic field

$$\mathbf{S} = \frac{c}{4\pi} \mathbf{E} \times \mathbf{B} = \begin{pmatrix} 0 \\ \mathbf{S}_t \\ \mathbf{S}_r \end{pmatrix} = \frac{c}{4\pi} \frac{e^2}{r^4} \begin{pmatrix} 0 \\ f_t(\rho, \theta) \\ f_r(\rho, \theta) \end{pmatrix} \quad (3)$$

is characterized by a nonzero transverse component  $\mathbf{S}_t$  that localizes within the wavefront of the DEMS, an amount of energy and momentum, and by a classical radial component  $\mathbf{S}_r$  associated with the spherical radial wave.

For each interaction occurring between a pair of particles, the physical conditions change. Therefore, the value of the parameter  $\rho$  must be recalculated using a stochastic process defined by the constraints produced by the external forces acting on the DEMS. In the case of free interaction, when a pair of particles interacts without external constraints, the value of the ratio  $\rho$  was statistically accurately estimated [5,6] and the best value obtained is  $\bar{\rho} = 1.2755578749164$ . In this case, with reference to equation (3), let,  $\Theta_i(\bar{\rho}, \theta) = |f_i(\bar{\rho}, \theta)|$ , the energy of the localized quantum is calculated by the expression

$$E = \left( \frac{4\pi}{3} \int_0^\pi \Theta_i(\bar{\rho}, \theta) d\theta + \frac{1}{4\pi\bar{\rho}^2} \right) \frac{e^2}{c} \omega \\ = (\sigma_{em} + \sigma_{es}) \frac{e^2}{c} \omega = \hbar \omega \quad (4)$$

Where,  $\hbar = 1.05457266 \cdot 10^{-34} \text{ J Hz}^{-1}$  is the theoretical value of Planck's constant for free interactions described in Dirac form. Equation (4) describes the energy and momentum exchanged in the form of a photon by two interacting charges.

The energy, as shown in the second row of equation (4), is described by two dimensionless contributions, one electrostatic (es) and one electromagnetic (em), which define and estimate the value of the total structure constant  $\sigma = \sigma_{em} + \sigma_{es} = \alpha^{-1}$  as a function of the mean value  $\bar{\rho}$  characterizing the DEMS.

Because the value of the structure constant during a free interaction is equal to the reciprocal value of Sommerfeld's constant, the coupling constant  $\alpha$  can be considered a universal constant with which it is possible to define the value of Planck's constant.

For what has been written above, in BT the values of  $\sigma$ ,  $\alpha$ ,  $\hbar$  are not true constants because they can vary, even if only slightly, as a function of the boundary conditions that define the physical reality in which the DEMS is formed, *i.e.*, as a function of the forces acting on the interacting charges. In fact, for free interactions, Sommerfeld theoretical constant is in very good agreement with the one calculated experimentally, except for a very small difference due, in the case of theoretical calculation, to

the lack of direct interaction of the DEMS with the observer. In other cases, the boundary conditions can significantly modify the value of  $\sigma$  and consequently, the values of the coupling constant and action unit.

Considering electron-proton interactions, the energy and momentum that characterize the DEMS are the energy and momentum associated with the initial reciprocal free motion of the particles before electron-proton capture takes place and represent the energy and momentum exchanged in the interaction in a limited time interval. In fact, contrary to what occurs in the strictly Coulombian interaction, the interaction associated with a DEMS has a finite duration and occupies a finite space [6].

During the electromagnetic interaction of a pair of particles, the start of the interaction corresponds to the zero-energy emission from the source, which is associated with an initial zero value of the radial Poynting vector. In agreement with BT, the value of the radial component of the Poynting vector increases over time by increasing the brightness of the source as the distance of the wavefront from the virtual center of the DEMS increases, reaching the maximum emission after a characteristic time  $T/2$  equal to half of the total interaction time; then, the energy emission starts to decrease when the particles reach the minimum interaction distance, which is equal to the wavelength of the source, and begins to move away, increasing their interaction distance. Under these conditions, an electron and a proton forming a DEMS exchange a photon of energy and momentum [4], equal to that which the DEMS will gradually emit by means of the radial component of the Poynting vector; therefore, the DEMS cannot be a stable system.

As previously described, the Sommerfeld constant in the context of BT is calculated from the characteristics of the electromagnetic field structure of the DEMS in spacetime. Its value in the case of free interaction between pairs of particles or particles of different masses but with charge and anticharge corresponds to  $\alpha = 1/137.035989$ , whose value is in agreement with the most recent value measured experimentally [9].

The most recent theoretical value of Sommerfeld's constant was calculated in the context of BT because of the formation of a hydrogen atom during the electron-proton capture process [10]. The estimate obtained with the formation of the hydrogen atom gives an extremely precise and stable value of the coupling constant  $\alpha = 1/137.035950244954$ , which differs from that obtained in the case of the free interaction of  $2.1 \cdot 10^{-3}$  ppm and from that obtained experimentally from  $2.6 \cdot 10^{-3}$  ppm [9]. The difference between the theoretical and experimental values was due to different physical contexts. In fact, the theoretical value of the fine structure constant is obtained in the interaction process without the system interacting with external observers, and thus, is altered.

### Relativistic behavior: Energy and momentum of a DEMS

Because the observation of a DEMS involves the measurement of the energy and momentum of each its component, in the simple case of a hydrogen atom formed by an electron and a proton, both are perceived by an external observer as two moving particles, each with its own energy and momentum, and with velocities referred to the lab.

An observer placed on one of the two particles in interaction feels the other as carrying all the energy and momentum that will form the DEMS [7]. This has already been applied in [10] to simulate hydrogen formation with electron-proton capture, therefore, the total energy and momentum of hydrogen in formation correspond in according with the BT to those of a material particle with energy and momentum equal to those of the relativistic approaching particle:

$$\begin{cases} E = \gamma \varepsilon \\ \mathbf{p} = \gamma \boldsymbol{\beta} \frac{\varepsilon}{c} \end{cases} \quad (5)$$

From the point of view of the proton,  $\varepsilon$  is the resting mass energy of the electron in motion,  $\gamma$  and  $\boldsymbol{\beta}$  are the Lorentz factor and the velocity of the electron divided by the light speed  $c$  at the time of the interaction, respectively.

### Atom described by DEMS with zero radial emission

In general, when a DEMS is formed it emits a wave which propagate in all direction energy and momentum. To obtain the conditions under which the DEMS has null radial emission becoming a stable atomic system, it is necessary to examine the emissive conditions of the dipole.

Let us begin considering the local electromagnetic contribution to the radiated energy for a DEMS in a given direction:

$$\delta \varepsilon_{rad} = \frac{1}{c} \int_{V_{\infty}} S d^3x \quad (6)$$

Equation (6) can be usefully analyzed by introducing the local brightness vector  $\mathbf{Y}$ , defined as:

$$\nabla \cdot \mathbf{Y} = \frac{1}{c} S = \frac{1}{4\pi} |\boldsymbol{\varepsilon} \times \mathbf{B}| \quad (7)$$

So that equation (6) can be rewritten as:

$$\delta \varepsilon_{rad} = \int_{\Sigma_z} \mathbf{Y} \cdot d\mathbf{a} \quad (8)$$

With  $d\mathbf{a}$  infinitesimal element of the surface of the ideal sphere  $\Sigma$ , through which the luminosity is flowing.

By setting  $|\boldsymbol{\varepsilon} \times \mathbf{B}| = R(r)\Theta(\theta)$ , where  $R(r)$  and  $\Theta(\theta) = |f(\theta)|$  describe the radial and angular behavior of the Poynting vector, respectively. To have a physically correct behavior for the emission of energy from the source with  $q$  arbitrary value of electric charge, it is necessary that:

$$R(r) \approx \frac{q^2}{r^4} \quad (9)$$

The length  $S$  of the Poynting vector in equation (7), which transports the energy of the source, coincides with the radial component of the Poynting vector of the dipole.

$$S \equiv S_r \equiv \frac{cq^2\Theta_r(\theta)}{4\pi r^4} \quad (10)$$

Where,  $\Theta_r(\theta) = |f_r(\theta)|$  denotes the angular distribution of the radial part of the Poynting vector. To analyze the radial emissions of a DEMS, equation (7) can be written in polar coordinates as follows:

$$\frac{1}{r^2} \frac{\partial}{\partial r} r^2 Y(r, \theta) = \frac{q^2 \Theta_r(\theta)}{4\pi r^4} \quad (11)$$

By setting the depth of field variable  $z = kr$  and neglecting the

angular behavior, we define:

$$y = \frac{4\pi Y(r, \theta)}{q^2 \Theta_r(\theta) k^3} \tag{12}$$

Using equation (12) the (11) can be rewritten as:

$$\frac{dy}{dz} + \frac{2}{z}y - \frac{1}{z^4} = 0 \tag{13}$$

The general solution of which

$$y = \frac{1}{z^3}(\xi_0 z - 1) \tag{14}$$

describes the behavior of the local brightness on the surface of the spherical shell  $\sum_{z/k}$  as a function of Z.

For fixed wave number k and for  $r \geq \lambda$ , the wave converges to that emitted by an ideal point source; therefore, considering the asymptotic behavior of equation (14), we obtain the luminosity on the surface  $\sum_{z/k}$  as

$$y_{id} \approx \frac{\xi_0}{z^2} \tag{15}$$

Comparing equation (14) and equation (15), we can see that a DEMS emits less energy than a point source, and the difference in brightness is

$$\Delta y = y_{id} - y \approx \frac{1}{z^3} \tag{16}$$

This implies that an amount of energy proportional to equation (16) was retained within the surface  $\sum_{z/k}$  and was located in the volume around the DEMS. As the emission of energy from the source is continuous, there is a spherical surface of balance for which the energy emitted through the surface is equal to that not yet emitted. Because the wavelength characterizes the period of the wave, it is assumed that equilibrium is reached on the first wavefront of the DEMS for  $r=\lambda$ . Using equation (15) and equation (16), one can then writes the equilibrium condition as

$$\Delta y = y \tag{17}$$

The solution of (17) gives  $\xi_0=1/\pi$ . Consequently, the brightness Y turns out to be

$$Y = \frac{q^2}{4\pi r^3} \left( \frac{2r}{\lambda} - 1 \right) \Theta_r(\theta) \tag{18}$$

That it is equal to zero in  $r_0 = \lambda/2$  for each angular direction by reaching the maximum brightness for  $r_{max} = 3\lambda/4$ . The extremes of the interval  $[r_0, r_{max}]$  delimits the spherical crown defining the Source Zone (SZ) of the DEMS, so for  $r < r_0$  the radial emission of the DEMS is not active, and the DEMS absorbs energy and momentum from the impinging interacting particles and for  $r > r_{max}$  the production of energy of the DEMS is ended.

Considering an atom formed by the mutual electron-nucleus capture of charges  $(-e+Ze)$ , both associated with an inertial mass with a proper value of energy at rest, the total input energy described by equation (5) can be used to power the rotational energy of the system around the centre of mass of the source [10]. When capture occurs and the electron orbits around the nucleus at a fixed orbital distance  $\lambda_0 = 2r_0$ , the round bracket in equation (18) becomes null,

$$\left( \frac{2r_0}{\lambda_0} - 1 \right) = 0 \tag{19}$$

Therefore, the dipole cannot emit radially and the brightness in equation (18) becomes zero. In this case the electron and nucleus form a bound state in which the wave propagation occurs only with the transverse component of the Poynting vector along a circular path inside the spherical surface  $\sum_0$  delimiting the internal border of the SZ of radius  $r_0 = \lambda_0/2$ .

Remembering that the electron-nucleus interaction localizes fundamental energy and momentum  $E=hc/\lambda_0 = \hbar k_1 c$  with  $k_1 = 2\pi/\lambda_0$ , by generalizing the interaction energy at a multiple of the fundamental energy as  $E_n = nE = \hbar k_n c$  with  $k_n = nk_1$ , using the radial field depth variable  $z = k_n r$ , equation (14) becomes

$$y = \frac{1}{z^3} \left( \frac{z}{\pi} - 1 \right) \tag{20}$$

That cancels for  $z = \pi$ . Therefore, the spherical shell  $\sum_{/\pi k_n}$  bounding the virtual center of the source is a surface with zero radial emission. A captured electron in motion on this surface maintains a constant distance  $\lambda_0$  from the nucleus, so that the DEMS does not emit radially. It follows that the surface  $\sum_{/\pi k_n}$  represents a sphere on which the radial component of the Poynting vector is everywhere zero and the transversal one propagates the electron as a local stationary wave of energy  $E_n$ . From the perspective of the nucleus, which has a higher mass than the electron, the captured electron forms a circular path centered on the nucleus with a radius  $\lambda_0$ . Under these conditions, the complete DEMS rotates around the nucleus taken as like a fixed point describing an electromagnetic field within a toroidal spacetime of extreme radius  $\lambda_0$  by defining the outer radius of the stable atom with energy equal to that of the  $n^{\text{th}}$  energy level with effective orbital radius  $r_n \leq \lambda_0$ .

In the ground state, the DEMS will emit radially only when the electron is stimulated by external fields to change the energy. In fact, during the transition between two different energy levels, a non-zero radial component of the Poynting vector is produced. After the emission of the excess of energy, the atom becomes stable again, returning to the ground state; if the system is destabilized by the transfer of more energy than that which characterizes the electron bond, the atom ionizes, returning the captured electron to the environment.

### Concepts of electron spin and atomic spin in BT for two fermions

In quantum mechanics, spin is a fundamental characteristic of the particles. It is considered a form of angular momentum that is intrinsic to particles and is independent of their motion or position. This phenomenon of quantum mechanics has no equivalent in classical physics.

Following BT, the spin is explained considering that each particle of charge q is entangled with all the anti-charges  $\bar{q}$  with which they are causally connected forming independent DEMS independently by their distance of interaction [6,7]. For an atom of hydrogen, using the field vector  $f$  defined in equation (3), the angular momenta associated with the hemispheric zones of a DEMS containing the positive or the negative Interacting Charges (IC) forming the DEMS, in units of  $\hbar$ , are defined as the field spin down and up of the IC:

$$L_{ic} = \frac{1}{\hbar} \int_0^\pi d\phi \int_{-\pi/2}^{\pi/2} \frac{2e^2}{3c} \begin{pmatrix} f_r(\theta) \\ \hat{f}_i(\theta) \end{pmatrix} d\theta \equiv \begin{pmatrix} -\frac{1}{2} \\ +\frac{1}{2} \end{pmatrix} \tag{21}$$



The function  $f_t(\theta)$  in the equation (21) is the transverse component of the vector  $\mathbf{f}$  and  $\tilde{f}_t(\theta) = -f_t(\theta)$  is the same component for switched charges [6]. Thus, the sign of the spin of the particles depends on the frame in which the interaction is observed. Extending the calculation to the complete SZ and assuming the dipole axis as the axis of symmetry, by integrating the angular functions over all directions, we obtain a null total spin for both unswitched and switched charges:

$$\mathbf{L}_{SZ} \equiv \mathbf{L}_{ph}^{(0)} = \frac{1}{\hbar} \int_0^{2\pi} d\phi \int_{-\pi/2}^{\pi/2} \frac{2e^2}{3c} \begin{pmatrix} f_t(\theta) \\ \tilde{f}_t(\theta) \end{pmatrix} d\theta = \begin{pmatrix} 0 \\ 0 \end{pmatrix} \quad (22)$$

In this case, the frame invariance provides the null spin values of the source as a unique effective component.

Considering the electromagnetic emission of the source, the directions of propagation of the photons are along the wave number  $\mathbf{k}$  direction, which is normal to the dipole axis. Then, for an observer, the angular momentum can be naturally calculated using the propagation axis as the axis of symmetry around which the dipole moment spins during the interaction. By calling  $\phi'$  the angle measured around this axis, we obtain:

$$\mathbf{L}_{ph}^{(1)} = \frac{1}{\hbar} \int_0^{2\pi} d\phi' \int_{-\pi/2}^{\pi/2} \frac{2e^2}{3c} \begin{pmatrix} f_t(\theta) \\ \tilde{f}_t(\theta) \end{pmatrix} d\theta = \begin{pmatrix} -1 \\ +1 \end{pmatrix} \quad (23)$$

The two components of this vector are the spin components corresponding to the left and right circular polarizations of the wave, that is, of the emitted photons; however, in this case, an atom does not emit; therefore, the spin component i.e., equation (23) for an atom of hydrogen in stable conditions may not be considered.

Therefore, for an atom of hydrogen there are  $Z=1$  DEMS components and it is possible to define three types of spins: Atomic spin equation (22)  $L_{SZ}=0$  for atoms in the fundamental state which is unobservable; electron spin equation (21)  $L_{IC} = \pm 1/2$  for the two particles forming the DEMS; and emission spin equation (23)  $L_{ph} = \pm 1$  for non-stable atoms. This spin value defines the orientation of the emission axis of DEMS. It is important to emphasize that the spin of a single particle continues to exist even when the particles have reached a great distance because the DEMS continue to exist also if the amount of localized energy is near to zero; therefore, spin is a property of the particle and indicates the existence of an interconnection with other particles. In this sense, the DEMS group all electromagnetically connected particles into pairs, creating a type of electromagnetic entanglement [7].

In summary, two interacting particles in pair can have spin  $s = (-1/2, +1/2)$ , whereas the DEMS formed using  $L_{SZ}$  and  $L_{ph}$  can have spin  $L = (-1, 0, +1)$ , where the null value always refers to the unobservable ground state of the hydrogen.

## THE ATOMIC MODEL

### Kinetic energy of the orbiting system after electronic capture

In compliance with one of the fundamental principles of BT [6], the capture of one electron by the nucleus during the atom formation takes place in the form of a charge-anticharge interaction, forming a number  $Z$  of independent DEMS.

For simplification, we consider the atom of hydrogen in formation as an isolated system electron-proton, with the transverse component of the momentum of the electromagnetic field associated with the TCPV of the DEMS.

$$p_t = \frac{1}{c^2} \int_{V_{sz}} |\mathbf{S}_t| d^3x \quad (24)$$

From a mechanical point of view, the electron in motion along its trajectory has respect the proton total momentum  $\mathbf{p} = \mathbf{p}_e + \mathbf{p}_p$  with angular momentum.

$$\mathbf{L} = \mathbf{r} \times \mathbf{p} = r p_t \hat{\mathbf{i}} \quad (25)$$

Before capture when the electron is at a great distance from the proton  $p_t \cong 0$ , therefore  $\mathbf{L}=0$ , for the conservation principle the time derivative of equation (25) must be equal zero maintaining constant the original null angular momentum.

$$\left| \frac{d\mathbf{L}}{dt} \right| = r \frac{dp_t}{dt} + \frac{dr}{dt} p_t = 0 \quad (26)$$

That implies that even after the formation of the atom, in the ground state the angular momentum in equation (25) must be zero. In fact, the spin of a DEMS in equation (22) returns as a value  $l \equiv L_{SZ} = 0$ .

For a DEMS, the two addends in equation (26) can be interpreted as the sum of two opposite energies [4,6]. The first  $T_{exp} = r \frac{dp_t}{dt} < 0$  is the expansion energy of the SZ due to the radial propagation of the electromagnetic field of the DEMS, while the second  $T_{spin} = \frac{dr}{dt} p_t > 0$  is the rotational energy associated with the spin of the field due to the circular propagation of the transverse component of the Poynting vector around the centre of the DEMS.

From a mechanical point of view, during DEMS formation,  $T_{spin}$  is provided by a force acting radially on the electron-proton system. In fact, the strength of the radial force  $F = \frac{dp_t}{dt} < 0$  being less than zero is attractive in such a way that energy  $T_{spin} = -T_{exp} = -rF$  is positive. Considering the DEMS point of view, the velocity of propagation of the electromagnetic field along the radial direction is  $\frac{dr}{dt} = c$ . From equation (26) and from the definition of the force acting on the moving electron, we can write

$$dp_t = -\frac{1}{c} F dr > 0 \quad (27)$$

During the capture process, the Coulombian interaction is always active; instead, the electromagnetic interaction mediated by the DEMS connecting the two particles is active only during a short period of time defined from the instant at which the Source Zone (SZ) of the DEMS starts at a reciprocal distance  $3\lambda_0/2$  until the SZ stops producing energy at the reciprocal minimum distance of interaction  $\lambda_0$ . Therefore, the total mechanical momentum acquired by the system at the end of the capture process is given by:

$$P = -\frac{1}{c} \int_0^{2\pi} d\phi \int_{\lambda_0}^{\infty} \mathbf{F} \cdot d\mathbf{r} > 0 \quad (28)$$

that correspond to the conservation of the total transverse component of the momentum acquired by the electromagnetic field of the DEMS, therefore using equation (27) and equation

(24), the total momentum in equation (28) associated with the field spin is obtained by integration in the form.

$$P = \frac{1}{c^2} \int_0^{2\pi} d\varphi \int_{r_{sz}} |S_t| d^3x \tag{29}$$

In general, considering the Coulombian force active between electron and nucleus,

$$F = -\frac{Ze^2}{4\pi\epsilon_0 r^2} \tag{30}$$

In SI unit's equation (28) yields the total field spin energy  $E_{spin} = Pc$  acquired by the system:

$$E_{spin} = \frac{Ze^2}{4\pi\epsilon_0} \int_0^{2\pi} d\varphi \int_{\lambda_o}^{\infty} \frac{dr}{r^2} = \frac{Ze^2}{2\epsilon_0 \lambda_o} \tag{31}$$

When the electron and nucleus reach a minimum interaction distance corresponding to the de Broglie wavelength  $\lambda_o = \lambda_{el} \beta^{-1} \gamma^{-1}$  of the electron [7,10], the energy

$$E = Pc = 2\pi \frac{\hbar c}{\lambda_o} \tag{32}$$

of the quantum exchanged between the electron and the nucleus acquired by DEMS, propagates by the TCPV on the internal surface of the SZ of the DEMS keeping the energy of the atom stable.

In equation (32) is used as the standard symbol of the Planck action in Dirac form  $\hbar$ , because in this case, the photon refers to a free interaction between charge pairs where the value of the action constant corresponds to Planck's one, and in the case of the use of the Sommerfeld fine-structure constant the symbol is  $\alpha$ , when necessary, the symbol for the different orbit levels will be diversified to avoid confusion.

Because the total energy as per equation (32) exchanged during the interaction cannot involve photons with energies greater than that which characterize the DEMS of a single electron-proton interaction given in equation (32), the total energy exchanged in the process of electron capture can only be a multiple of this fundamental energy:

$$E_{capt} \equiv E_n = nE \tag{33}$$

Since the center of mass of the atom refers to an observer placed in the laboratory system, using equations (31,32,33), in accordance with the four-momentum invariant [10], the total mass energy at rest calculated in the center of mass of the system is given by:

$$\epsilon = \sqrt{E_{capt}^2 - E_{spin}^2} \tag{34}$$

Substituting in equation (34) and the respective equations (31,32 and 33), the rest energy of the atom gives

$$\epsilon = E_{capt} \sqrt{1 - \left(\frac{Z}{n} \frac{e^2}{4\pi\epsilon_0 \hbar c}\right)^2} \tag{35}$$

The round squares in the equation (35) represent the speed ratio beta of the electron

$$\beta_n = \frac{Z}{n} \frac{e^2}{4\pi\epsilon_0 \hbar c} = \frac{Z}{n} \alpha \tag{36}$$

It follows the orbital Lorentz factor,  $\gamma_n = 1/\sqrt{1-\beta_n^2}$ . From equation (31,35 and 36), the capture energy as per equation (33) of the electron can be written as the identity

$$E_n = 2\pi \frac{\hbar c}{\lambda_n} \equiv \gamma_n \epsilon \tag{37}$$

In the equation (37) the minimum interaction distance  $\lambda_n = \lambda_o/n$  is the de Broglie wavelength of the electron in the  $n^{th}$  energy level, that is, from the relativistic point of view,  $\lambda_n = \lambda_{el} \beta_n^{-1} \gamma_n^{-1}$  gives

$$\lambda_n = \lambda_{el} \sqrt{\frac{n^2 \sigma^2}{Z^2} - 1} \tag{38}$$

From equation (38) the fundamental pseudo-orbit wavelength is calculated as

$$\lambda_o = \lambda_{el} n \sqrt{\frac{n^2 \sigma^2}{Z^2} - 1} \tag{39}$$

It is convenient to observe now that equation (39) gives as the natural limit of the atomic number for the formation of a stable atom  $Z \leq 137$ . The existence of this limit in agreement with Chandrasekhar prediction [12] that normally has to do with the nucleus stability, let us to suppose that the formation of the atom is more related of how one can think to the nucleus formation.

The calculus of the orbital radius for the  $n^{th}$  energy level defined by the equation (37), is given by the condition of coherence of the electromagnetic circulating wave, i.e., the effective length of the circumference of the orbit on which the wave propagates stably must be equal to a multiple of the de Broglie wavelength of the atomic system, because the electron cannot have a de Broglie wavelength different to the capture one defined by the equation (32):  $2\pi r_n n = \lambda \lambda_{no}$ . By equation (38), we obtain the radius of the pseudo-orbit which characterizes the  $n^{th}$  quantum state of the atom

$$r_n = \tilde{\lambda}_o = \tilde{\lambda}_{el} n \sqrt{\frac{n^2 \sigma^2}{Z^2} - 1} < \lambda_o \tag{40}$$

The pseudo-orbit is a circle of radius (40) on which the electron is described by a circulating electromagnetic wave. For atoms with  $Z \ll n\sigma$  equation (40) can be approximated in the form  $r_n \cong \frac{n^2}{Z} a_0$  with  $a_0 \cong \tilde{\lambda}_{el} \sigma$  Bohr radius of the hydrogen. Because the energy localized by the capture was completely transmitted to the system, equation (37) can be rewritten using the reduced mass energy at rest of the electron-nucleus system rather than that of the electron, that is, one replaces at  $\epsilon$  the reduced mass energy

$$\epsilon_\mu \equiv \frac{\epsilon_{nuc} \epsilon_e}{\epsilon_{nuc} + \epsilon_e} \tag{41}$$

Therefore, following the founding principles of BT, to calculate the kinetic energy of the orbiting system is enough to subtract to the capture energy in equation (37) relative to the orbiting system its energy at rest in equation (41), therefore, in accordance with special relativity for the kinetic energy one obtains

$$K_n = \epsilon_\mu (\gamma_n - 1) \tag{42}$$

It is very important to consider than each electron captured by a nucleus on the  $n^{th}$  pseudo-orbit must have a different fine structure constant defined by the constraints condition on which is subject, therefore, for each energetic level one will consider the characteristic fine structure constant  $\alpha_n$  which is only a bit different from the value defined for a free interaction.

## Effective energy at rest of a nucleus

In equation (41), it is necessary to estimate the value at rest of the mass energy  $\varepsilon_{nuc}$  of the nucleus; therefore, for a fixed atomic number  $Z \geq 1$  with a number  $N$  of neutrons, one can define  $i=1,2,\dots,N$  the isotopic number. Considering that only the DEMS formed by electron-proton interactions contribute to the total energy of the atom, the presence of neutrons in the nucleus partially shields the positive charge by affecting the amount of energy available for the interaction. In fact, for a fixed value of  $Z$ , when the number of neutrons increase, neutrons and protons are arranged in such a way to maximize the stability of the nucleus. Therefore, the energy of the resting mass of the nucleus participating in the formation of the DEMS during the interaction with the orbital electrons cannot be higher than that of the protons forming the nucleus, therefore, it can be assumed that the mass of the nucleus participating in the reduced mass of the system is a fraction is lower than that of the nucleus and can be supposed to be proportional to the nucleus mass by a fraction of the effective mass energy of the nucleus.

$$\zeta = Z/(Z + N) \quad (43)$$

Considering an element  $X$  with its isotopes family, each with relative atomic mass  $A_r(X)$  with  $i=1,2,\dots,N$ , and abundance  $w(X)$ , the average atomic mass of the mixing of the isotopes of the element gives

$$\bar{A}(X) = \sum_{i=1}^n w(iX) A_r(iX) \quad (44)$$

The equation (44) is effectively equal to the sum of the atomic number  $Z$ , of the mean number of neutrons weighted as a function of their isotope abundance in equation given by equation (45), of the atomic electrons expressed in AMU in equation (46), of the excess or defect of mass characteristic  $\Delta$  of the considered nucleus.

Let to be

$$\bar{N} = \sum_{i=1}^n w(iX) N_i \quad (45)$$

$$z_e = Z \varepsilon_e / \varepsilon_u \quad (46)$$

Equations (44) is coinciding with

$$\bar{A}(X) = Z + \bar{N} + z_e + \Delta \quad (47)$$

Considering that for an element  $X$ , the resting mass energy associated with the effective nucleus, that is, the fraction of the average nuclear mass electrically active of a natural isotopic mix of the same element can be defined by considering the charge fraction in equation (43) of the effective mass energy:

$$M(X) = \bar{A}(X) - z_e = Z + \bar{N} + \Delta \quad (48)$$

By using the fraction (43) with the effective mass (48) one obtains

$$\varepsilon_{nuc}(X) = \zeta M(X) \varepsilon_u \quad (49)$$

For an isotopic mix of the element  $X$ , equation (49) becomes

$$\varepsilon_{nuc}(X) = \frac{Z}{Z + \bar{N}} \left( \bar{A}(X) - Z \frac{\varepsilon_e}{\varepsilon_u} \right) \varepsilon_u \quad (50)$$

Considering the natural mix of atoms formed by the fundamental isotopes of hydrogen  $^1\text{H}$ ,  $^2\text{H}$  and  $^3\text{H}$  is neglectable, the resting mass energy in equation (50) gives  $\varepsilon_{nuc}(H) = 1.50327737 \cdot 10^{-10} \text{ J}$  instead of pure  $^1\text{H}$  and  $\varepsilon_{nuc}(^1\text{H}) = 1.50327759 \cdot 10^{-10} \text{ J}$ . In both cases, the

evaluations are lower than that of the remaining energy of the proton because of the use of the energy of an atomic mass unit:  $\varepsilon_u = 1.49241808 \cdot 10^{-10} \text{ J}$  estimated for an atom of  $^{12}\text{C}$ , but in the case of the natural mix of hydrogen, the value is even lower because of the shielding effect due to the presence of neutrons in the nucleus of deuterium. In all cases, the differences in the model results were minimal, and equation (50) is suitable for hydrogen and deuterium atoms and can be extended to more heavy atoms as helium and lithium.

## Quantum numbers

Equation (33) is the energy acquired by the atomic system once after electron capture, stability is achieved. This value includes the mass energy at rest of the electron and the rotational kinetic energy provided during electron capture. The integer value  $n$  can be thought to consist of two components: A number  $n_r$  that defines the multiplicity of the action associated with the radial momentum and a number  $n_\phi$  that defines the multiplicity of the action associated with the angular momentum supplied to the nucleus during the electron capture in such a way that  $n = n_r + n_\phi$  with degenerate energy states associated with all their combinations without the orbit to be elliptical, as predicted by the Sommerfeld model, because this shape would produce a radial emission in the DEMS. To simplify, in accordance with the Bohr-Sommerfeld model, the principal quantum number  $n_r \equiv n = 1, 2, 3, \dots$  and secondary quantum number  $n_\phi \equiv l = 0, 1, 2, \dots, n-1$  in such a way that  $n = n + l$ .

Because the spin of an atom in the fundamental state is always zero because the two particles forming each single DEMS have opposite spins, for excited atoms subject to external fields, the spatial orientation of the photon emission can be defined by a new number obtained as the product  $m = lL$  with values  $m = -(l, \dots, 0, \dots, +l)$ . This number is consistent with the role of the magnetic quantum number, and is in fact different from zero only if the atom is plunged in an external electromagnetic field, assuming a precise orientation up or down with rotational kinetic energy defined by the secondary quantum number. Therefore, it is possible to define the complete state of the electron and its atomic system using the spin  $s = (-1/2, +1/2)$  of the electron and the set of quantum numbers  $(n, l, m)$  defining the state of the atomic system in the environment.

## The wave behavior of an interacting electron: Orbital eigenvalues

As discussed in [11] and in the estimation of the Sommerfeld constant during the formation of a hydrogen atom by the electron-proton capture [10], an electron during its interaction with a nucleus gives up all of its energy at the DEMS, and its propagation is described by a wave described by the linear differential equation:

$$\hbar \left( \frac{1}{c} \frac{\partial}{\partial t} - \cos \theta \frac{\partial}{\partial x} + iK \right) \psi = 0 \quad (51a)$$

The solutions of the equation (51a) are:

$$\psi = \varphi \Xi = \begin{cases} e^{\left( \frac{E_r + P_r}{\hbar} - Kct \right)} & t < 0^- \\ e^{-iKct} & 0^- \leq t \leq 0^+ \\ e^{\left( \frac{E_r - P_r}{\hbar} - Kct \right)} & t > 0^+ \end{cases} \quad (51b)$$

The first part of equation (51b), defined as the wave function  $\varphi = e^{-ikc t}$  it is associated with the corpuscular characteristics of the captured electron, which carries the residual momentum of the electron corresponding to the momentum not yet transferred in time in other interactions, that is, the residual momentum  $\hbar K_n = \gamma_n(1 - \beta_n \cos \theta)\varepsilon/c$ , whose value is always less than or equal to the Galilean momentum  $m_e c$  of the electron [8], and represents the total momentum transferred to the system during the capture process at time  $t=0$ . The second part of equation (51b) is a wave function  $\Xi = e^{i(\frac{E_n}{\hbar}t - \frac{p_n}{\hbar}x)}$  describing the system before and after the interaction by carrying information regarding the energy and momentum of the moving electron.

For an atom, the interaction between electron and nucleus is stable and is described over time as a DEMS formed in the time interval  $0^- \leq t \leq 0^+$  with action  $\hbar$ . In this case, we can consider the system electron nucleus, as described by the full wave function part  $\psi = e^{-ikc t}$  of equation (51b), which describes the momentum exchange. In this case, the wave equation (51a) can be rewritten in the reduced form as  $(\mathcal{H} + ichK_n)\psi = 0$ , with  $\mathcal{H} = \hbar \frac{\partial}{\partial t}$ , which can be considered the Hamiltonian operator of the stable system, variable only on time, with  $c\hbar K_n$  eigenvalues of the energy exchanged, corresponding to  $E_n^* = \gamma_n(1 - \beta_n \cos \theta)\varepsilon$  that after electron capture with  $\cos \theta = 0$  becomes the capture energy in equation (33), that is,  $E_n^* \equiv E_n$ .

**Electron bond and orbital energy**

The captured electron rotates with the nucleus around the common center of mass with a rotational kinetic energy equal to equation (42), which balances the attractive force, such that the sum of the orbital relativistic kinetic energy with the binding energy is zero:  $K_n + B_n = 0$ . This condition implies that the energy that characterizes the capture of electrons in the  $n$ th orbit of the ion must be opposed to the relativistic kinetic energy of the electron, using equation (42) and using the values of the modified fine structure constants  $\alpha_n$  expressed as a function of the first quantum number associated with the  $n$ th capture level, computed using the recursive correction method examined [10] and revised for atoms with  $Z$  protons in appendix A the binding energy of the  $n$ th orbit is given by:

$$B_n = -K_n = \varepsilon \left( 1 - \frac{1}{\sqrt{1 - \beta_n^2}} \right) \tag{52}$$

where,  $\beta_n = Z\alpha_n/n$ .

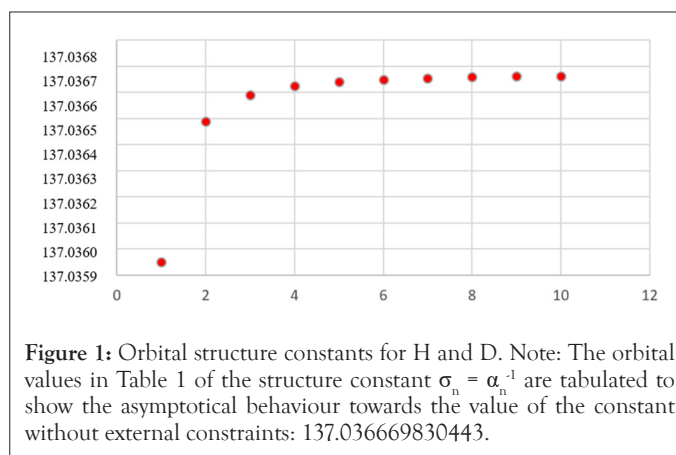
The values of  $\sigma_n$  and  $\alpha_n$  calculated for the atoms of hydrogen and deuterium and also the values of  $\sigma_n$  and  $\alpha_n$  calculated for helium and lithium atoms are listed in Table 1. Figure 1 shows the orbital values of the orbital electromagnetic structure constant, that is,  $\sigma_n$ .

**Table 1:** Sommerfeld orbital constants for Z=1 (hydrogen); Sommerfeld orbital constants for Z=2 (helium) and Sommerfeld orbital constants for Z=3 (lithium).

| n | $\sigma_n$       | $\alpha_n^{(*)}$    |
|---|------------------|---------------------|
|   |                  |                     |
| 1 | 137.035950244954 | 0.00729735517003008 |
| 2 | 137.036489933615 | 0.00729732643097056 |
| 3 | 137.036589876262 | 0.00729732110893124 |
| 4 | 137.036624856212 | 0.00729731924621806 |

|            |                  |                     |
|------------|------------------|---------------------|
| 5          | 137.036641046931 | 0.00729731838404832 |
| 6          | 137.036649841891 | 0.00729731791570920 |
| 7          | 137.036655144977 | 0.00729731763331538 |
| 8          | 137.036658586883 | 0.00729731745003099 |
| 9          | 137.036660946637 | 0.00729731732437210 |
| 10         | 137.036662634565 | 0.00729731723448852 |
| <b>Z=2</b> |                  |                     |
| 1          | 137.034935840356 | 0.00729740918888733 |
| 2          | 137.036316427785 | 0.00729733567033653 |
| 3          | 137.036350014072 | 0.00729733388182998 |
| 4          | 137.036489934089 | 0.00729732643094532 |
| 5          | 137.036554696630 | 0.00729732298227863 |
| 6          | 137.036589876262 | 0.00729732110893124 |
| 7          | 137.036611088587 | 0.00729731997935612 |
| 8          | 137.036624856240 | 0.00729731924621657 |
| 9          | 137.036634295241 | 0.00729731874358161 |
| 10         | 137.036641046943 | 0.00729731838404768 |
| <b>Z=3</b> |                  |                     |
| 1          | 137.030194061221 | 0.00729766170770531 |
| 2          | 137.035050769958 | 0.00729740306864051 |
| 3          | 137.035950244954 | 0.00729735517003008 |
| 4          | 137.036265063006 | 0.00729733840556895 |
| 5          | 137.036410779106 | 0.00729733064602762 |
| 6          | 137.036489933615 | 0.00729732643097056 |
| 7          | 137.036537661315 | 0.00729732388942498 |
| 8          | 137.036568638438 | 0.00729732223986456 |
| 9          | 137.036589876262 | 0.00729732110893124 |
| 10         | 137.036605067546 | 0.00729732029998186 |

**Note:** (\*) Values of the Sommerfeld constant for levels 1-10 were calculated for hydrogen, helium, lithium using the recursive numerical method for electron capture using the recursive numerical method for electron capture and presented by Auci [10].



**Figure 1:** Orbital structure constants for H and D. Note: The orbital values in Table 1 of the structure constant  $\sigma_n = \alpha_n^{-1}$  are tabulated to show the asymptotical behaviour towards the value of the constant without external constraints: 137.036669830443.

**Atomic energy levels**

To define the energy levels of the DEMS model of an atom, it is necessary to consider the difference in the binding energy in equation (52) between the fundamental level with  $n=1$  and another level  $n>1$ , which is equivalent to the difference between the capture energy  $E_1$  for an electron bound to the bare atomic nucleus and the capture energy  $E_n$  at a level other than the



principal quantum number. Using equation (52), we can write:

$$\frac{1}{\lambda_n} = \frac{B_n - B_1}{hc} = \frac{E_1 - E_n}{hc} \quad (53)$$

The action  $h$  in the equation (53) is the standard value of the Planck constant obtained for an electron-proton free interaction during the transition between levels.

### Hydrogen and deuterium

The estimations of the energy levels for hydrogen in Table 2. Using equations (41), (52) and (53) and the orbital fine structure constant  $\alpha_1$  shown in Table 1, the fundamental level of hydrogen, corresponding to the quantum number ( $n=1, l=0$ ), has a binding energy  $B_1^H = -2.17877438 \cdot 10^{-18} \text{ J}$  equivalent to  $|B_1^H| = 13.5988401 \text{ eV}$ . This value is only slightly lower than the Rydberg energy  $E_H = 13.6057028 \text{ eV}$  of the atom, thus, of the kinetic energy of the electron  $K_e = 13.6062462 \text{ eV}$  measured immediately before the capture process begins. In fact, both values are greater than  $|B_1^H|$  because the effective resting energy of nucleus  ${}_1^1\text{H}^+$  is defined by equation (49) with  $\bar{A}(H) \equiv A_r({}^1\text{H}) = 1.00782503223$  being only slightly lower than the energy of proton  $\varepsilon_{\text{mc}}({}^1\text{H}^+) = 1.50327759464 \cdot 10^{-10} \text{ J} \approx \varepsilon_p$ ; therefore, equation (41) gives a reduced mass energy of the system  $\varepsilon_\mu < \varepsilon_e$  only after the electron capture occurs, whereas before electron capture, the kinetic energy is that of the impinging electron, and the mass energy involved is independent of the mass of the proton because of the delay in the propagation of the electromagnetic field during the DEMS production. The proton can be considered not involved, that is, the proton is perceived as having an infinite mass by giving  $\varepsilon_\mu \rightarrow \varepsilon_e$ . In this case, the relativistic kinetic energy of the electron was greater than that of  $|B_1^H|$ . In addition, in the case of Rydberg energy, the experimental value is measured during the process of ionization of the atom, that is, during a non-relativistic ejection of the electron in which the total energy is that of the resting mass energy  $\varepsilon_e$ .

**Table 2:** H I energy levels. ( $Z=1, N=0, A_r({}^1\text{H})=1.00782503223$ ).

| n  | Theoretical (cm <sup>-1</sup> ) | Experimental <sup>(1)</sup> (cm <sup>-1</sup> ) | Th/Ex      |
|----|---------------------------------|---|------------|
| 1  | 0.0000                          | 0.0000  | -          |
| 2  | 82262.1663                      | 82258.9544                                      | 1.00003905 |
| 3  | 97495.2178                      | 97492.3040                                      | 1.00002989 |
| 4  | 102826.7354                     | 102823.9040                                     | 1.00002754 |
| 5  | 105294.45765                    | 105291.6570                                     | 1.00002660 |
| 6  | 106634.9462                     | 106632.1681                                     | 1.00002605 |
| 7  | 107443.2178                     | 107440.4508                                     | 1.00002575 |
| 8  | 107967.8168                     | 107965.0568                                     | 1.00002556 |
| 9  | 108327.4801                     | 108324.7253                                     | 1.00002543 |
| 10 | 108584.7450                     | 108581.9945                                     | 1.00002533 |

**Note:** (1): National Institute of Standards and Technology (NIST) Atomic Spectra Database (ASD) energy levels for hydrogen.

The calculation for deuterium is similar to that performed for hydrogen, considering the effective resting energy of the deuterium nucleus defined by equation (49) using  $\bar{A}(H) \equiv A_r({}^2\text{H}) = 2.01410177812$  one obtains  $\varepsilon({}^2\text{H}^+) = 1.50253160466 \cdot 10^{-10} \text{ J} < \varepsilon_p$ . In this case, the

fundamental energy level for Deuterium (D) calculated using equation (52) is given by  $|B_1^D| = 13.5988364 \text{ eV}$ , with energy lower than that of hydrogen.

It is important to emphasize that the theoretical values calculated are exact values, that is, they refer to the atoms that are formed during the electron capture process according to the BT model. The energy level values in Table 1 were calculated using equation (53).

### Helium and lithium

To extend the model to atoms with  $Z > 1$ , it is interesting to consider helium with  $Z=2$  and lithium with  $Z=3$ . These two atoms are interesting because they are the heaviest elements produced during the non-stellar synthesis of primordial nuclei. The procedure for calculating the energy levels was the same as that for hydrogen. The energy levels for helium and lithium are listed in Table 3.

**Table 3:** D I energy levels. ( $Z=1, N=1, A_r({}^2\text{H}) = 2.01410177812$ ), He II energy levels. ( $Z=2, \bar{A}(\text{He}) = 4.00260165$ ) and Li III energy levels. ( $Z=3, \bar{A}(\text{Li}) = 6.94093785$ ).

| n  | Theoretical (cm <sup>-1</sup> ) | Estimated <sup>(1)</sup> (cm <sup>-1</sup> ) | Th/Es      |
|--|---------------------------------|--|------------|
| <b>D I energy levels. (<math>Z=1, A_r({}^2\text{H})=2.01410177812</math>)</b>  |                                 |  |            |
| 1  | 0.0000                          | 0.0000                                       | -          |
| 2  | 82262.14406                     | 82281.493                                    | 0.99976484 |
| 3  | 97495.19143                     | 97518.836                                    | 0.99975754 |
| 4  | 102826.7076                     | 102851.878                                   | 0.99975527 |
| 5  | 105294.4291                     | 105320.308                                   | 0.99975428 |
| 6  | 106634.9174                     | 106661.1812                                  | 0.99975376 |
| 7  | 107443.1888                     | 107469.6848                                  | 0.99975346 |
| 8  | 107967.8169                     | 107994.4344                                  | 0.99975326 |
| 9  | 108327.4800                     | 108354.2009                                  | 0.99975312 |
| 10   | 108584.7156                     | 108611.5396                                  | 0.99975308 |
| <b>He II energy levels. (<math>Z=2, \bar{A}(\text{He})=4.00260165</math>)</b>  |                                 |  |            |
| 1  | 0.0000                          | 0.0000                                       | -          |
| 2  | 329193.15040                    | 329179.76231                                 | 1.000041   |
| 3  | 390144.57400                    | 390140.82497                                 | 1.000010   |
| 4  | 411476.97043                    | 411477.18175                                 | 1.000000   |
| 5  | 421350.68083                    | 421352.70920                                 | 0.999995   |
| 6  | 426714.14026                    | 426717.15366                                 | 0.999993   |
| 7  | 429948.12435                    | 429951.72607                                 | 0.999992   |
| 8  | 432047.09926                    | 432051.07855                                 | 0.999991   |
| 9  | 433486.14721                    | 433490.38252                                 | 0.999990   |
| 10   | 434515.48857                    | 434519.90514                                 | 0.999990   |
| <b>Li III energy levels. (<math>Z=3, \bar{A}(\text{Li})=6.94093785</math>)</b> |                                 |  |            |
| 1  | 0.0000                          | 0.0000                                       | -          |
| 2  | 741001.31102                    | 740736.43390                                 | 1.000358   |
| 3  | 878168.40029                    | 877919.74441                                 | 1.000283   |

|    |              |              |          |
|----|--------------|--------------|----------|
| 4  | 926172.79499 | 925932.85143 | 1.000259 |
| 5  | 948391.25468 | 948155.58428 | 1.000249 |
| 6  | 960460.35118 | 960226.99032 | 1.000243 |
| 7  | 967737.57099 | 967505.57339 | 1.000240 |
| 8  | 972460.74048 | 972229.60574 | 1.000238 |
| 9  | 975698.91808 | 975468.36035 | 1.000236 |
| 10 | 978015.16155 | 977785.00701 | 1.000235 |

**Note:** (1): National Institute of Standards and Technology (NIST) Atomic Spectra Database (ASD) energy levels for deuterium, He II with relative abundance of  $^3\text{He}$  and  $^4\text{He}$  and Li III with relative abundance of  $^6\text{Li}$  and  $^7\text{Li}$ .

### Spectral lines

To calculate the emission spectrum wavelengths for excited atoms, it is necessary to consider the change in energy of an atom or ion when the electron-nucleus system receives sufficient energy to change the energy state of one or more DEMS. If the energy received is sufficient to change the state of the system, the electron moves on the spherical shell, which corresponds to the energy absorbed at a wavelength  $\lambda_j < \lambda_i$  with  $j > i$  at a distance  $r_j > r_i$  from the nucleus, and then after a time  $\tau_{ji} = h/(E_i - E_j)$  returns to the original orbital emitting the surplus energy by means of a photon [12]. Using the binding energy as per equation (52), since the excited final state  $j$  has a lower binding energy than the initial ground state  $i$ ,  $|B_j| > |B_i|$  with  $B_j - B_i = E_i - E_j$ , for the return energy jump  $j \rightarrow i$  the use of the first part of equation (37) yields the emission wavelength as a function of the wavelength of the atomic system:

$$\lambda_{j \rightarrow i} = \tau_{ji} c = \frac{hc}{E_i - E_j} \frac{l_0}{\gamma_i - \gamma_j} \quad (54)$$

$$l_0 = \frac{hc}{\varepsilon_\mu} = \left(1 + \frac{\varepsilon_e}{\varepsilon_{nuc}}\right) \frac{hc}{\varepsilon_e} = \lambda_e + \lambda_{nuc} \quad (55)$$

And  $\gamma_i$ ,  $\gamma_j$  Lorentz gamma factors are associated with the initial and final energy levels between which electron transitions occur.

From a phenomenological point of view, atoms emit only when they acquire enough energy to modify the pseudo-orbital of one or more electrons by transforming into emitting DEMS. This process, called atomic excitation, consists of distributing a random amount of energy to the electrons of the atom starting from the outermost electrons that have a distance of interaction with the nucleus and an energy of greater bonding than the innermost electrons. In this way, in a power process, in which all the electrons of the atom acquire sufficient energy over time to move to higher energy levels, the atom behaves as a multi-dipole source (DEMS) by emitting chromatic photons associated with the excess energy acquired by the electron-nucleus system. The consequent effect is the return of the electrons to their original configuration. The process described involves each electron undergoing slippage during the level jump that involves the exit from the condition of atomic stability, inducing the transformation of the atom into a multi-dipole source with consequent chromatic emission of energy forming the characteristic spectrum. The orbital slippage causes the electron to move for a limited time on a noncircular trajectory, not necessarily elliptical, with respect to

which the fine-structure constant differs from the exact value of the corresponding layer; therefore, a correction  $\chi_{ij}$  that takes into account the shift is necessary. Table 4, shows the correction ratios obtained empirically, considering the positive and negative orbital slippage of electrons during jumps between the energy levels. The corrections proposed are obtained by modifying the value of the fine structure constant of the outer layer such that the emitted spectral line corresponds to the experimental observation, which corresponds to a model that agrees exactly with the measured emission spectrum. In Table 5, the estimations of the principal transition lines of the Lyman, Balmer and Paschen series for hydrogen and Tables 6 shows the Hydrogen atomic constants. In Table 7 the helium and lithium Lyman series are tabulated. The correct values for the orbital slip are displayed in the third column.

$$\lambda_{j \rightarrow i} = \frac{l_0}{\sqrt{1 - \left(\frac{Z}{i}\alpha_i\right)^2} \sqrt{1 - \left(\frac{Z}{j}\chi_{ij}\alpha_j\right)^2}} \quad (56)$$

**Table 4:** H I correction ratio.

|      | Lyman       |      | Balmer     |      | Paschen    |
|------|-------------|------|------------|------|------------|
| 1-2  | 1.000054838 | -    | -          | -    | -          |
| 1-3  | 1.000143000 | 2-3  | 0.99982067 | -    | -          |
| 1-4  | 1.000056150 | 2-4  | 0.99957331 | 3-4  | 0.99989454 |
| 1-5  | 1.000308300 | 2-5  | 0.99923863 | 3-5  | 0.99974404 |
| 1-6  | 1.000655400 | 2-6  | 0.99882536 | 3-6  | 0.99957835 |
| 1-7  | 1.000691800 | 2-7  | 0.99834800 | 3-7  | 0.99945350 |
| 1-8  | 1.001600000 | 2-8  | 0.99781600 | 3-8  | 0.99919060 |
| 1-9  | 1.000918500 | 2-9  | 0.99718730 | 3-9  | 0.99914100 |
| 1-10 | 1.000394000 | 2-10 | 0.99648380 | 3-10 | 0.99875600 |

**Table 5:** H I Emission lines-Lyman series, H I Emission lines-Balmer series and H I Emission lines-Paschen series. ( $Z=1, N=0, A_r(^1\text{H})=1.00782503223$ ).

| $j \rightarrow i$  | Theoretical exact (nm) | Theoretical with slippage | Experimental <sup>(1)</sup> |
|--|------------------------|---------------------------|-----------------------------|
| <b>H I Emission lines-Lyman series.</b><br>( $Z=1, N=0, A_r(^1\text{H})=1.00782503223$ ) |                        |                           |                             |
| 10-1   | 92.09396771            | 92.0947                   | 92.0947                     |
| 9-1  | 92.31267996            | 92.3148                   | 92.3148                     |
| 8-1  | 92.62019267            | 92.6249                   | 92.6249                     |
| 7-1  | 93.07241725            | 93.0751                   | 93.0751                     |
| 6-1  | 93.77788760            | 93.7814                   | 93.7814                     |
| 5-1  | 94.97176049            | 94.9742                   | 94.9742                     |
| 4-1  | 97.25097237            | 97.2517                   | 97.2517                     |
| 3-1  | 102.56913342           | 102.5728                  | 102.5728                    |

|  |               |           |           |
|--|---------------|-----------|-----------|
| 2-1  | 121.56256576  | 121.5670  | 121.5670  |
| <b>H I Emission lines-Balmer series.</b><br>(Z=1, N=0, $A_r$ (H)=1.00782503223)  |               |           |           |
| 10-2   | 379.901988789 | 379.7909  | 379.7909  |
| 9-2  | 383.651625364 | 383.5397  | 383.5397  |
| 8-2  | 389.019526145 | 388.9064  | 388.9064  |
| 7-2  | 397.124003794 | 397.0075  | 397.0075  |
| 6-2  | 410.293779975 | 410.1734  | 410.1734  |
| 5-2  | 433.173044477 | 434.0472  | 434.0472  |
| 4-2  | 486.273257938 | 486.1350  | 486.1350  |
| 3-2  | 656.46728858  | 656.2790  | 656.2790  |
| <b>H I Emission lines-Paschen series.</b><br>(Z=1, N=0, $A_r$ (H)=1.00782503223) |               |           |           |
| 10-3   | 901.75169733  | 901.5300  | 901.5300  |
| 9-3  | 923.16819091  | 922.9700  | 922.9700  |
| 8-3  | 954.87279912  | 954.6200  | 954.6200  |
| 7-3  | 1005.22717686 | 1004.9800 | 1004.9800 |
| 6-3  | 1094.12441164 | 1093.8170 | 1093.8170 |
| 5-3  | 1282.17625443 | 1281.8072 | 1281.8072 |
| 4-3  | 1875.63856352 | 1875.1300 | 1875.1300 |

**Note:** (1): National Institute of Standards and Technology (NIST) Atomic Spectra Database (ASD) spectral lines for hydrogen-Lyman series, hydrogen-Balmer series and hydrogen-Paschen series.

**Table 6:** Hydrogen atomic constants.

| Atomic Constants<br>Electron Capture<br>Model (ECD) | Symbol-Equation  | Theoretical<br>estimation (S.I.)         |
|---|--|--|
| Mean square length                                  | $\rho^*$   | 1.27555662                               |
| Structure constant                                  | $\sigma$   | 137.035950                               |
| Bohr radius (+)                                     | $a_0 = \lambda_{el} \sqrt{\sigma^2 - 1} \cong \lambda_{el} \sigma$ | $5.29162744 \times 10^{11}$ m            |
| Orbital radius                                      | $r_n = n^2 a_0$  | -  |
| Rydberg constant (#)                                | $R_H = \frac{m_e c}{2h\sigma^2}$                                   | $1.09737433 \times 10^7$ m <sup>-1</sup> |
| Rydberg energy (#)                                  | $E_H = \frac{m_e c^2}{2\sigma^2}$                                  | 13.6057028 eV                            |

**Note:** (+) Theoretical values calculated during capture process; (#) Refers to the electrons captured in the hydrogen atom being stabilized.

**Table 7:** He II-emission lines-Lyman series. (Z=2,  $\bar{A}$  (He)=4.00260165), Li III-Emission lines-Lyman series. (Z=3,  $\bar{A}$  (Li)=6.94093785).

| $j \rightarrow i$   | Theoretical exact<br>(nm) | $\chi_{1,j}$  | Theoretical<br>with<br>slippage | Ritz <sup>(1)</sup> |
|---|---------------------------|---------------|---------------------------------|---------------------|
| <b>He II-emission lines-Lyman series.</b> (Z=2, $\bar{A}$ (He)=4.00260165)  |                           |               |                                 |                     |
| 6-1   | 23.4348924878197          | 0.99987710544 | 23.43472796                     | 23.43472796         |
| 5-1   | 23.7332000516591          | 0.99994308262 | 23.73308751                     | 23.73308751         |
| 4-1   | 24.3026966721836          | 0.99999722314 | 24.30268767                     | 24.30268767         |
| 3-1   | 25.6315239693052          | 1.0000384430  | 25.63177027                     | 25.63177027         |
| 2-1   | 30.3773027712290          | 1.0000631456  | 30.37858147                     | 30.37858147         |
| <b>Li III-Emission lines-Lyman series.</b> (Z=3, $\bar{A}$ (Li)=6.94093785) |                           |               |                                 |                     |
| 8-1   | 10.2831914788377          | 1.02300       | 10.29                           | 10.29               |
| 7-1   | 10.3333799366446          | 1.01600       | 10.34                           | 10.34               |
| 6-1   | 10.4116739308196          | 0.99800       | 10.41                           | 10.41               |
| 5-1   | 10.5441714594132          | 1.00800       | 10.55                           | 10.55               |
| 4-1   | 10.7971212866958          | 1.00200       | 10.80                           | 10.80               |
| 3-1   | 11.3873375502246          | 1.00100       | 11.39                           | 11.39               |
| 2-1   | 13.4952527765271          | 1.00055       | 13.50                           | 13.50               |

**Note:** (1): National Institute of Standards and Technology (NIST) Atomic Spectra Database (ASD) spectral lines for He II-Lyman series and lithium Li III-Lyman series.

### The Bohr model as first order approximation of the DEMS atomic model

One considers the McLaurin's development of the orbital gamma factor in equation (37)

$$\gamma_n = \frac{1}{\sqrt{1-\beta_n^2}} = 1 + \frac{1}{2}\beta_n^2 + \frac{3}{8}\beta_n^4 + \dots \quad (57)$$

Equation (52) makes

$$B_n = -\varepsilon \left( \frac{1}{2} \frac{Z^2}{n^2} \alpha_n^2 + \frac{3}{8} \frac{Z^4}{n^4} \alpha_n^4 + \dots \right) \quad (58)$$

Using equation (58), the difference in capture energy in the two levels  $j \rightarrow i$  given by  $\Delta E_{j \rightarrow i}$  can be considered to be formed by a change in rotational energy and a change in the vibrational energy of the atom plus other terms that are negligible because they are not experimentally significant.

$$\Delta E_{j \rightarrow i} \cong \delta E_{rot} + \delta E_{vib} + \dots \quad (59)$$

Whereas the vibrational term is less than  $10^4$  times the rotational term and because the shell-to-shell electron jumps change, the rotational energy of the system, but not significantly the Zitterbewegung of the nucleus, to simplify equation (59). It is possible to assess the intensity of the energy transition spectral line by considering only the contribution to the rotational energy change in equation (59). Thus, using equations (59), (52) and (55), the reciprocal of the wavelength of the photon emitted by the atom during a transition is given by

$$\frac{1}{\lambda_{j \rightarrow i}} = \frac{\Delta E_{j \rightarrow i}}{hc} \cong \frac{Z^2}{2l_0} \left( \frac{\alpha_i^2}{i^2} - \frac{\alpha_j^2}{j^2} \right) \quad (60)$$

To simplify, considering that for orbits the values of the coupling

constants are  $\alpha_i \cong \alpha_j \cong \alpha$ , their value is replaced by that of the free value of the fine-structure constant  $\alpha$ . Therefore, the equation (60) becomes

$$\frac{1}{\lambda_{j \rightarrow i}} = \frac{Z^2 \alpha^2}{2l_0} \left( \frac{1}{i^2} - \frac{1}{j^2} \right) \quad (61)$$

Equation (61) describes the emission line in the transition  $j \rightarrow i$  associated with the electron-nucleus system and can be rewritten in the classical spectroscopic form:

$$\frac{1}{\lambda_{j \rightarrow i}} = R \left( \frac{1}{i^2} - \frac{1}{j^2} \right) \quad (62)$$

Using equation (55) in equation (61), Rydberg's constant in equation (62) in SI units is given by:

$$R = \frac{\epsilon_0 \epsilon_e}{e^2 \sigma^3} \frac{Z^2}{\left( 1 + \frac{\epsilon_e}{\epsilon_{mc}} \right)} \quad (63)$$

Equation (63) for an atom of hydrogen gives the value of the Rydberg's constant with  $Z=1$  is  $R_H = 1.09675973 \cdot 10^7 \text{ m}^{-1}$ ; therefore, equation (63) can be rewritten as  $R = Z^2 R_H$  in agreement with classical spectroscopy.

This paragraph aims to prove that the DEMS atomic model is consistent in the first approximation to the Bohr model.

### Effective nuclear mass

According to the Bridge Theory (BT) [8], any electromagnetic interaction between electric charges in motion generates an inertial mass. By contrast, each inertial mass corresponds to an electromagnetic interaction that produces it.

The existence of a pair of interacting charges for example, electron-proton leads to the creation of a DEMS of limited space-time extension that moves following a trajectory linked to the dynamic characteristics of the interacting particles. The overall energy and momentum of the DEMS correspond to the total energy and momentum of the observed system, in which the resting masses of a particles pre-exist the DEMS and represent the energy retained at the time of their formation starting from one or more events that generated them through a decay or assembly of other particles. At the present stage of BT development, it can be assumed that the phenomena that initiated the resting mass energies of particles are associated with the formation of space-time, but this topic is unrelated to this work.

During the direct interaction of the particles, all available energy is converted into electromagnetic energy of the DEMS, but only during the life of the source. In the case of a DEMS at zero-emission, that is, an atom, the duration is indefinite, therefore, the total electromagnetic energy of the atom must correspond to the total inertial mass of the observed system. In particular, considering an atom from the point of view of the electron, the sum of all quantum jumps between the possible energy states must correspond to the available energy equivalent to the rest mass energy of the atom.

Let's check it out. The energy relative to each possible orbit is considered. We define multiplicity as the number of times the reduced mass energy of the electron-nucleus system, very close in value to the resting energy of the orbiting electron, is contained

in the resting energy of the atom

$$F = \frac{\epsilon_{atom}}{\epsilon_\mu} \quad (64)$$

Equation (64) is equal to the maximum number of possible electron-nucleus orbital interactions, based on the available energy associated with the total resting mass of the nucleus. Using equation (37) each energy level corresponds to the capture of electrons whose energy is equivalent to a fraction of the total mass energy of the dipole system:

$$E_n = \frac{\epsilon_\mu}{\sqrt{1 - \left( \frac{\alpha_n}{n} \right)^2}} \quad (65)$$

Using the total capture energy (65) and summing the F possible quantum levels determined by the ratio (64), the total energy that can be engaged during all possible nucleus-electron interactions cannot exceed the total resting mass energy of the nucleus-electron system

$$E = \sum_{n=1}^F E_n = \sum_{n=1}^F \frac{\epsilon_\mu}{\sqrt{1 - \left( \frac{\alpha_n}{n} \right)^2}} \quad (66)$$

By developing in the McLaurin series, the gamma factor of the equation (66), one obtains

$$E \cong \epsilon_\mu \left( F + \frac{\alpha^2}{2} \sum_{n=1}^F \frac{1}{n^2} + \dots \right) \cong \epsilon_{atom} \left( 1 + \frac{\pi \alpha^2}{12F} + \dots \right) \cong \epsilon_{atom} \quad (67)$$

In the case of a hydrogen atom with  $F \cong 1837$ , equation (65) provides the rest mass energy of the atom  $\epsilon_{atom} = (m_p + m_e)c^2 \cong m_p c^2$ , showing that a fraction of its total mass energy is shared electromagnetically through the quantum levels that are formed during the interaction between the nucleus and the electron. In other words, the proton interacting with the electrons grants each quantum level a portion of its mass energy [13]. Consequently, generalizing, the sum of all capture energies associated with the quantum levels of an atom, is the effective rest mass energy of the nucleus-electrons system.

### DISCUSSION

In this work it has been proven that the atomic model based on the BT is able to provide a perfect description of the atomic phenomenology, with the advantage, compared to the Bohr-Sommerfeld-Schrodinger models, of introducing quantum principles and special relativity in a way self-consistent with the Maxwellian electromagnetic theory, as both quantum and relativistic phenomenologies derive from the particular way of interacting in pairs of moving charged particles. This approach is completely theoretical without require the use of experimental or measured data and in this sense, it could be asserted that the consistency of the results obtained cannot be considered a coincidence at all. The adequate use of the principles of BT could therefore lead to a formal and phenomenological revision of Quantum Electrodynamics (QED) in which the typical concepts of quantum indeterminism and wave-particle dualism disappear in favour of the principle of electromagnetic interaction in



dipoles, which from a phenomenological point of view allows to replace the concept of Coulombian interaction with that of direct electromagnetic interaction, which transforms through DEMS all the energy of the interacting system into electromagnetic energy localized in the form of exchange photons and the atoms into DEMS with zero radial emission, simplifying the phenomenology of the elementary electromagnetic interactions of matter.

Considering the atoms examined, the good agreement shown by the calculation of the radii and energies of the atomic levels and of the spectral lines of the atoms H, D, He, Li, suggests how the orbital capture may be the only way to produce a large amount of monatomic hydrogen in a cooling universe in which electrons and protons can have been produced in perfect symmetry.

Although the model shows that the orbital motion of atomic electrons around the nucleus is relativistic, from a spectrometric point of view, the first-order approximation of the model leads back to Bohr's model, thus demonstrating its substantial correctness in terms of first principles.

## CONCLUSION

The theoretical results of the spectra obtained were presented both in the exact form and in the modified form. The modify form is necessary to match the theoretical data with the observational one and it is produced by the corrections introduced based on the principle of the orbital slippage of electrons due to the absorption of an excess of external energy, which produces the continuous passage of an electron from the fundamental orbit to a more energetic one.

The proposed correction, although currently is obtained in a semi-empirical way, is based on the principle that the fine structure constant varies as a function of the orbit because the dipole moment of the electron-nucleus system changes in continuous for each orbital motion.

Finally, it is shown that the electron-nucleus interaction changes on the basis of the nuclear isotopy due to the different inertia of the atomic nucleus and that only the mass energy of the charged fraction of the atomic nucleus can contribute to the binding energy of the system. Therefore, the sum of the energies of all the orbital levels of the atom is equal to the mass energy of the active atomic nucleus and its captured electrons.

The atomic model developed in the present work is completely obtained using the BT, which means that not has required the introduction of external physical concepts, in fact, quantum and

relativistic formalisms appearing in the model are completely consistent with BT because developed inside the theory. In this sense, the atomic model is obtained using only the Maxwell's electromagnetic theory, further expanded by the introduction of the typical concepts of BT.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

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