Electron Structure, Ultra-dense Hydrogen and Low Energy Nuclear Reactions

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Abstract

In this paper, a simple Zitterbewegung electron model, proposed in a previous work, is presented from a different perspective that does not require advanced mathematical concepts. A geometric-electromagnetic interpretation of mass, relativistic mass, De Broglie wavelength, Proca, Klein-Gordon and Aharonov-Bohm equations in agreement with the model is proposed. Starting from the key concept of mass-frequency equivalence a non-relativistic interpretation of the 3.7 keV deep hydrogen level found by J. Naudts is presented.

According to this perspective, ultra-dense hydrogen can be conceived as a coherent chain of bosonic electrons with protons or deuterons at center of their Zitterbewegung orbits. The paper ends with some examples of the possible role of ultra-dense hydrogen in some aneutronic low energy nuclear reactions.

Index Terms

Aharonov-Bohm equations, aneutronic reactions, compact structures, De Broglie wavelength, electron structure, ESR, Heisenberg's uncertainty principle, Klein-Gordon equation, LENR, natural units, Proca equation, relativistic mass, ultra-dense Hydrogen, Zitterbewegung.

Nomenclature

Symbol, name, SI units, natural units (NU).

$\boldsymbol{A}_{\square}$ electromagnetic four potential $[V \cdot s \cdot m^{-1}]$, $[eV]$;

$\boldsymbol{A}_{\triangle}$ electromagnetic vector potential $[V \cdot s \cdot m^{-1}]$, $[eV]$;

A electromagnetic vector potential module $[V \cdot s \cdot m^{-1}]$, $[eV]$;

m mass $[kg]$, $[eV]$;

$\boldsymbol{F}$ electromagnetic field bivector $[V \cdot s \cdot m^{-2}]$, $[eV^2]$;

$\boldsymbol{B}$ flux density field $[V \cdot s \cdot m^{-2}] = [T]$, $[eV^2]$;

$\boldsymbol{E}$ electric field $[V \cdot m^{-1}]$, $[eV^2]$;

V potential energy $[J = kg \cdot m^2 \cdot s^{-2}]$, $[eV]$;

$J_{\square}$ four current density field, $[A \cdot m^{-2}]$, $[eV^3]$;

J_Δ current density field, $[A \cdot m^{-2}]$, $[eV^3]$;

ρ charge density $[A \cdot s \cdot m^{-3} = C \cdot m^{-3}]$, $[eV^3]$;

x, y, z space coordinates $[m]$, $[eV^{-1}]$, $[1.9732705 \cdot 10^{-7}\ m \simeq 1\ eV^{-1}]$;

t time variable $[s]$, $[eV^{-1}]$, $[6.5821220 \cdot 10^{-16}\ s \simeq 1\ eV^{-1}]$;

c light speed in vacuum $[2.997\,924\,58 \cdot 10^8\ m \cdot s^{-1}]$, $[1]$;

$\hbar$ reduced Planck constant ($\hbar = h/2\pi$) $[1.054\,571\,726 \cdot 10^{-34}\ J \cdot s]$, $[1]$;

μ_0 permeability of vacuum $[4\pi \cdot 10^{-7}\ V \cdot s \cdot A^{-1} \cdot m^{-1}]$, $[4\pi]$;

ϵ_0 dielectric constant of vacuum $[8.854\,187\,817 \cdot 10^{-12}\ A \cdot s \cdot V^{-1} \cdot m^{-1}]$, $[\frac{1}{4\pi}]$;

e electron charge $[1.602\,176\,565 \cdot 10^{-19}\ A \cdot s]$, $[0.085\,424\,546]$;

α fine structure constant $[7.2973525664 \cdot 10^{-3}]$, $[7.2973525664 \cdot 10^{-3}]$;

m_e electron rest mass $[9.10938356 \cdot 10^{-31} kg]$, $[0.5109989461 \cdot 10^6 eV]$;

λ_c electron Compton wavelength $[2.426\,310\,2389 \cdot 10^{-12}\ m]$, $[1.229\,588\,259 \cdot 10^{-5}\ eV^{-1}]$;

r_e reduced Compton electron wavelength (Compton radius) $r_e = \lambda_c/2\pi$;

r_c electron charge radius $r_c = \alpha r_e$;

1 Introduction

According to Carver Mead mainstream physics literature has a long history of hindering fundamental conceptual reasoning, often *"involving assumptions that are not clearly stated"* [17]. One of these is the unrealistic assumption of point-like shaped elementary particles with *intrinsic* properties as mass, charge, angular momentum and spin. In agreement with the laws of mechanics and electromagnetism, a point-like particle cannot have an "intrinsic angular momentum". Moreover, a magnetic moment must necessarily be generated by a current loop, that cannot exist in a point-like particle. Furthermore, the electric field generated by a point-like charged particle should have an infinite energy. An alternative, realistic approach that fully addresses these *very basic* problems is therefore indispensable. A possibility is given by a *Zitterbewegung* interpretation of quantum mechanics, according to which charged elementary particles can be modeled by a current ring generated by a massless charge distribution rotating at light speed along a circumference whose length is equal to the particle Compton wavelength [10, 6]. As a consequence, every elementary charge is always associated with a magnetic flux quantum and every charge is coupled to all other charges on its light cone by time-symmetric interactions [17]. The aim of this paper is to present a gentle introduction to an electron Zitterbewegung model together with some observations that reinforce its plausibility. In Section 2 the deep connection between some basic concept as energy, mass, frequency, and information is exposed. In Section 3 an introduction to a Zitterbewegung electron model is presented, together with a geometric-electromagnetic interpretation of Proca, Klein-Gordon and Aharonov-Bohm equations. In section 4 a simple geometric interpretation of relativistic mass and De Broglie wavelength is proposed. In section 5 the relation of Electronic Spin Resonance ESR frequency with Larmor precession frequency of the Zitterbewegung orbit is presented. In Section 6 some hypotheses on the structure of ultra-dense hydrogen are formulated, whereas Section 7 deals with the possible role of ultra-dense hydrogen in low energy nuclear reactions.

N.B. In this paper all equations enclosed in square brackets with subscript "NU" have dimensions expressed in natural units.

2 Energy, Mass, Frequency and Information

The concept of measurement is fundamental to all scientific disciplines based on experimental evidence. The most used measurement units (such as the international system, SI) are based mainly on human conventions not directly related to fundamental constants. To simplify the conceptual understanding of certain physical quantities it's convenient to adopt in some cases a measurement system based on universal constants such as the speed of light c and the Planck's quantum $\hbar$.

Considering that a measure is an event localized in space and time, the quantum of action can be seen, in some cases, as an objective entity in some respects analogous to a bit of information located in the space-time continuum. In accordance with Heisenberg's uncertainty principle, the result of the measurement of some values (such as angular momentum) cannot have an accuracy less than half a single Planck's quantum. Therefore, to simplify the interpretation of physical quantities, it may be useful to adopt a system in which both the speed of light and the quantum of action are dimensionless quantities (pure numbers) having a unitary value, *i.e.*: $c = 1$ and $\hbar = 1$. In this system, the constancy of light speed makes it possible to use a single measurement unit for space and time, simplifying, in some cases, the conceptual interpretation of physical quantities. The energy of a photon, a "particle of light", is equal to Planck's quantum multiplied for the photon angular frequency. By using the symbol T to indicate the period of a single complete oscillation and λ the relative wavelength, it is, therefore, possible to write

$$E = \hbar\omega = \frac{2\pi\hbar}{T} = \frac{2\pi\hbar c}{\lambda}. \tag{1}$$

By using natural units, period and wavelength coincide and the above expression is simplified:

$$\left[E = \omega = \frac{2\pi}{T} = \frac{2\pi}{\lambda}\right]_{NU}. \tag{2}$$

The NU subscript highlights the use of natural units for expressions contained within square brackets. This equation indissolubly links some fundamental entities of physics, such as space, time and energy, giving the possibility to express an energy value simply as a frequency or as the inverse of a time, or even as the inverse of a length. *Vice versa*, it allows to use as a measurement unit of both space and time a value equal to the inverse of a particular energy value as the electron-volt. Therefore to compute photon wavelength in vacuum with natural units it is sufficient to divide the constant 2π by its energy. This value will correspond exactly to the period of a complete oscillation. Therefore, in natural units the inverse of an eV can be used as a measurement unit for space and time:

$$L_{(1eV)} = 1\ \text{eV}^{-1} \simeq 1.9732705 \cdot 10^{-7}\ \text{m} \simeq 0.2\ \mu\text{m},$$

$$T_{(1eV)} = 1\ \text{eV}^{-1} \simeq 6.582122 \cdot 10^{-16}\ \text{s} \simeq 0.66\ \text{fs}.$$

Consequently, an angular frequency can be measured in electron volts:

$$1\ \text{eV} \simeq 1.519268 \cdot 10^{15}\ \text{rad}\,\text{s}^{-1}.$$

Following these concepts, it is possible to define and link together the fundamental concepts of information, space, time, frequency and energy. A "quantum of information" carried by a single photon will have a "necessary reading time" and a "spatial dimension" inversely proportional to its energy. A simple example is given by radio antennas (dipoles), whose length is proportional to received (or transmitted) "radio photons" wavelength and inversely proportional to their frequency and to the number of bits that can be received in a time unit. In this perspective, the concept of energy is therefore closely linked to "density" of information in space and time.

3 Electron Structure

The famous Einstein's formula $E = mc^2$ becomes particularly explanatory if expressed in natural units:

$$[E = m]_{NU}.$$

Mass is energy and it is, therefore, possible to associate a precise amount of energy to a particle having a given mass. Taking up the considerations made on the deep bond existing between the concepts of space, time, frequency and energy, it is interesting trying to associate electron rest mass m_e to an angular frequency ω_e, a length r_e and a time T_e. In fact Einstein's formula can be expressed as

$$E_e = m_e c^2 = \hbar\omega_e = \frac{\hbar c}{r_e} = \frac{\hbar}{T_e}, \tag{3}$$

or adopting natural units

$$\left[E_e = m_e = \omega_e = \frac{1}{r_e} = \frac{1}{T_e}\right]_{NU}. \tag{4}$$

These constants have a simple and clear interpretation if one accepts a particular electron model consisting of a current ring generated by a massless charge rotating at light speed along a circumference whose radius is equal to the electron reduced Compton wavelength, defined as $r_e = \lambda_c/2\pi \simeq 0.38616 \cdot 10^{-12}$ m [10, 7, 8, 6]. According to this model the charge is not a point-like entity, but it is distributed on a spherical surface whose radius is equal to electron classical radius: $r_c \simeq 2.8179 \cdot 10^{-15}$ m [6]. In equation (4) ω_e is the rotating charge angular frequency, r_e is the orbit radius and $2\pi T_e$ its period. The current loop is associated with a quantized magnetic flux Φ_M equal to Planck's constant ($h = 2\pi\hbar$) divided by the elementary charge e:

$$\Phi_M = h/e,$$

or in natural units

$$\left[\Phi_M = 2\pi/e\right]_{NU},$$

The rotation is caused by a centripetal Lorentz force due to the magnetic field associated with the current loop generated by the elementary rotating charge. The value of this elementary charge, in natural units, is a pure number and is equal to the square root of the ratio between the charge radius r_c and the the orbit radius r_e:

$$\left[e = \sqrt{\frac{r_c}{r_e}} = \sqrt{\alpha} \simeq 0.0854245\right]_{NU}. \tag{5}$$

Similar models, based on the concept of "current loop", have been proposed by many authors but have often been ignored for their incompatibility with the most widespread interpretations of Quantum Mechanics . It is interesting to remember how, already in his "Nobel lecture" of 1933, P.A.M. Dirac referred to an internal high-frequency oscillation of the electron: "*It is found that an electron which seems to us to be moving slowly, must actually have a very high frequency oscillatory motion of small amplitude superposed on the regular motion which appears to us. As a result of this oscillatory motion, the velocity of the electron at any time equals the velocity of light. This is a prediction which cannot be directly verified by experiment, since the frequency of the oscillatory motion is so high and its amplitude is so small*". In the scientific literature, the German word *Zitterbewegung* (ZBW) is often used to indicate this rapid oscillation/rotation of the electron charge. The rotating charge is characterized by a momentum p_c of purely electromagnetic nature:

$$p_c = eA = e\frac{\Phi_M}{2\pi r_e} = \frac{\hbar\omega_e}{c} = \frac{\hbar}{r_e} = m_e c.$$

In this formula the variable $A = \hbar/er_e$ indicates the vector potential seen by the rotating charge [6]. Multiplying the charge momentum p_c by the radius r_e we obtain the "intrinsic" angular momentum $\hbar$ of the electron:

$$p_c r_e = \hbar. \tag{6}$$

Using natural units the momentum p_c has the dimensions of an energy and it is exactly equal to the electron mass-energy at rest m_e:

$$\left[p_c = eA = E_e = \frac{1}{r_e} = m_e = \omega_e\right]_{NU}.$$

3.1 Aharonov-Bohm Equations and Zitterbewegung Model

The magnetic Aharonov-Bohm effect is described by a quantum law that gives the phase variation φ of the "electron wave function" starting from the integral of the vector potential $\boldsymbol{A}_\vartriangle$ along a path [1], *i.e.*

$$\varphi = \frac{e}{\hbar}\int \boldsymbol{A}_\vartriangle \cdot d\boldsymbol{l}. \tag{7}$$

In the proposed Zitterbewegung model, the "wave function phase" of the electron has a precise geometric meaning and indicates the charge rotation phase. A possible counter-test consists in verifying, using (7), that the phase shift φ along the circumference of the Zitterbewegung orbit is equal exactly to 2π radians:

$$\varphi = \frac{e}{\hbar}\oint \boldsymbol{A}_{\triangle} \cdot d\boldsymbol{l} = \frac{e}{\hbar}\int_0^{2\pi r_e} A dl = \frac{e}{\hbar}\int_0^{2\pi r_e} \frac{\hbar}{e r_e} dl = 2\pi$$

The result is also consistent with the prediction of the *electric* Aharonov-Bohm effect, a quantum phenomenon that establishes the variation of phase φ as a function of the integral of electric potential V in a time interval T:

$$\varphi = \frac{e}{\hbar}\int_T V dt. \tag{8}$$

Applying the electric Aharonov-Bohm effect formula to compute the phase shift φ within a time interval $T_e = {}^{2\pi}/_{\omega_e}$ equal to a Zitterbewegung period we obtain the expected result, *i.e.* $\varphi = 2\pi$. The electric potential of the electron rotating charge can be expressed as

$$V = \frac{e}{4\pi\varepsilon_0 r_c} = \left[\frac{e}{r_c}\right]_{NU}$$

and its period as

$$T_e = \frac{2\pi r_e}{c} = [2\pi r_e]_{NU}.$$

A simple calculation, applying (8) and (5), yields the same results:

$$\varphi = \frac{e}{\hbar}\int_0^{T_e} V dt = \frac{e}{\hbar} V T_e = \left[\frac{e^2}{r_c} 2\pi r_e\right]_{NU} = 2\pi.$$

and therefore:

$$V = A = |A_{\triangle}|$$

$$d\varphi = \frac{e}{\hbar} V dt$$

$$\left[\frac{d\varphi}{dt} = \omega_e = m_e = eV = eA\right]_{NU}$$

3.2 Proca equation and Zitterbewegung electron model

A deep connection of Maxwell's equations

$$\boldsymbol{\partial}\left(\boldsymbol{\partial} \wedge \boldsymbol{A}_{\square}\right) + \mu_0 \boldsymbol{J}_{\square} = 0$$

with Proca equation for a particle of mass m

$$\boldsymbol{\partial}\left(\boldsymbol{\partial} \wedge \boldsymbol{A}_{\square}\right) + \left(\frac{mc}{\hbar}\right)^2 \boldsymbol{A}_{\square} = 0$$

$$\left[\boldsymbol{\partial}\left(\boldsymbol{\partial} \wedge \boldsymbol{A}_{\square}\right) + m^2 \boldsymbol{A}_{\square} = 0\right]_{NU}$$

emerges if we prove that equation $\left[\mu_0 \boldsymbol{J}_{\square} = m^2 \boldsymbol{A}_{\square}\right]_{NU}$ can be applied to the electron Zitterbewegung model introduced in [6]. In this model the electron's charge orbit delimits a disc shaped volume with radius r_e and height $2r_c$. Inside this volume the *average* Zitterbewegung current density$\bar{\boldsymbol{J}}_e$ can be computed dividing the Zitterbewegung current by one half the disc vertical section $\mathscr{A}$:

$$\bar{\boldsymbol{J}}_e = \frac{\boldsymbol{I_e}}{\mathscr{A}}$$

$$\mathscr{A} = 2 r_e r_c = 2\alpha r_e^2$$

$$\bar{\boldsymbol{J}}_e = \frac{\boldsymbol{I}_e}{\mathscr{A}} = \frac{\boldsymbol{I}_e}{2\alpha r_e^2}$$

from [6] (p. 82) we have

$$\left[\boldsymbol{I_e} = \frac{\alpha \boldsymbol{A}_\triangle}{2\pi}\right]_{NU}$$

and substituting

$$\left[\bar{\boldsymbol{J}}_{\boldsymbol{e}} = \frac{\boldsymbol{A}_\triangle}{4\pi r_e^2}\right]_{NU}$$

$$\left[\mu_0 \bar{\boldsymbol{J}}_{\boldsymbol{e}} = 4\pi \bar{\boldsymbol{J}}_{\boldsymbol{e}} = \frac{\boldsymbol{A}_\triangle}{r_e^2} = \omega_e^2 \boldsymbol{A}_\triangle = m_e^2 \boldsymbol{A}_\triangle\right]_{NU}$$

Remembering that the electron's electromagnetic four potential seen by the rotating charge is a light-like vector [6] (p.91)

$$\boldsymbol{A}_\square = \boldsymbol{A}_\triangle + \gamma_t A_t$$

$$\boldsymbol{A}_\square^2 = 0 \qquad \Longrightarrow \qquad |\boldsymbol{A}_\triangle| = A_t$$

we can write:

$$\left[\mu_0 J_{et} = \frac{A_t}{r_e^2} = \omega_e^2 A_t = m_e^2 A_t\right]_{NU}$$

$$\left[\mu_0 \bar{\boldsymbol{J}}_{\boldsymbol{e}\square} = \mu_0 \left(\bar{\boldsymbol{J}}_{\boldsymbol{e}} + \gamma_t J_{et}\right) = m_e^2 \left(\boldsymbol{A}_\triangle + \gamma_t A_t\right) = m_e^2 \boldsymbol{A}_\square\right]_{NU}$$

and consequently *(QED)*:

$$\left[\mu_0 \bar{\boldsymbol{J}}_{\square \boldsymbol{e}} = m_e^2 \boldsymbol{A}_\square\right]_{NU}$$

3.3 Proca and electromagnetic Klein-Gordon equations

In this paragraph we will use only natural units, omitting the subscript NU. The aim is to show the connection of Proca equation and an "electromagnetic version" of Klein-Gordon equation. Applying the operator $\boldsymbol{\partial}\wedge$ to Proca equation

$$\boldsymbol{\partial} \left(\boldsymbol{\partial} \wedge \boldsymbol{A}_\square\right) + m^2 \boldsymbol{A}_\square = 0 \tag{9}$$

$$\boldsymbol{\partial F} + m^2 \boldsymbol{A}_\square = 0$$

we get

$$\boldsymbol{\partial} \wedge \boldsymbol{\partial F} + m^2 \boldsymbol{\partial} \wedge \boldsymbol{A}_\square = 0$$

$$\boldsymbol{\partial} \wedge \boldsymbol{\partial F} + m^2 \boldsymbol{F} = 0.$$

Writing now Maxwell's equations with an averaged four current vector density

$$\boldsymbol{\partial F} = -4\pi \bar{\boldsymbol{J}}_\square \tag{10}$$

and applying to both member the operator $\boldsymbol{\partial}\cdot$ we obtain an expression

$$\boldsymbol{\partial} \cdot \boldsymbol{\partial F} = -4\pi\, \boldsymbol{\partial} \cdot \bar{\boldsymbol{J}}_\square = 0$$

that is equal to zero as a consequence of charge-current conservation law. For this reason, the term $\boldsymbol{\partial} \wedge \boldsymbol{\partial F}$ can be safely substituted by the term $\boldsymbol{\partial}^2 \boldsymbol{F}$:

$$\boldsymbol{\partial} \wedge \boldsymbol{\partial F} = \boldsymbol{\partial}^2 \boldsymbol{F} - \boldsymbol{\partial} \cdot \boldsymbol{\partial F} = \boldsymbol{\partial}^2 \boldsymbol{F}$$

As a result we obtain a Klein-Gordon-like equation where the electromagnetic bivector $\boldsymbol{F}$ substitutes the "wave-function" ψ:

$$\boldsymbol{\partial}^2 \boldsymbol{F} + m^2 \boldsymbol{F} = 0 \tag{11}$$

A similar equation for electromagnetic four potential can be obtained simply applying the Lorenz gauge condition $\boldsymbol{\partial A}_\square = \boldsymbol{\partial} \wedge \boldsymbol{A}_\square$ to Proca equation:

$$\boldsymbol{\partial}^2 \boldsymbol{A}_\square + m^2 \boldsymbol{A}_\square = 0$$

or

$$\boldsymbol{\partial}^2 \boldsymbol{A}_\square + \alpha A^2 \boldsymbol{A}_\square = 0$$

It's important to note that the Lorenz gauge condition can been applied to Maxwell's equations 10 only when *an averaged* value of four current density vector is used. In this case also the electromagnetic four potential is an averaged value, and a no more harmonic function of space-time.

4 Geometric interpretation of relativistic electron mass and De Broglie wavelength

If an electron moves along an axis z orthogonal to the charge rotation plane, the latter will describe a helical trajectory whose length is $L = c\Delta t$ and whose axis length is $l = v_z \Delta t$. The electron mass is exactly equal to the inverse of the helix radius r if expressed in NU, i.e. $m = r^{-1}$. An acceleration along z, implies a smaller radius and hence a mass increase. Using the Pythagorean theorem it is possible to write the value of the radius r as a function of v_z [7, 6]:

$$r = r_e \sqrt{1 - \frac{v_z^2}{c^2}}$$

and the related mass variation

$$m = \frac{\hbar\omega}{c^2} = \frac{m_e}{\sqrt{1 - \frac{v_z^2}{c^2}}}.$$

The charge momentum is proportional to the angular frequency and it has a direction tangent to the helical path. The relativistic momentum of charge is, then,

$$p_c = \frac{\hbar\omega}{c} = \frac{\hbar}{r} \tag{12}$$

or, using natural units

$$\left[p_c = \omega = \frac{1}{r} = m\right]_{NU}.$$

Equation (12) suggests a particular interpretation of the Heisenberg uncertainty principle: an electron, whose charge has a momentum p_c, cannot be confined within a spherical space of radius R less than r. This means that it must be

$$R > r = \frac{\hbar}{p_c}.$$

Now, the charge momentum vector can be decomposed into two components: $\vec{p_\perp}$, which is orthogonal to rotation plane (xy) and another one, $\vec{p_\parallel}$, parallel to the electron direction of motion, i.e. in the z direction. Therefore the relativistic momentum can be expressed as

$$\vec{p_c} = \vec{p_\perp} + \vec{p_\parallel}.$$

The magnitude of component $\vec{p_\perp}$ is a constant, independent from velocity v_z, and is proportional to the charge angular speed ω_e in the xy plane. Therefore,

$$p_\perp = \frac{\hbar\omega_e}{c} = m_e c,$$

or in natural units

$$[p_\perp = \omega_e = m_e]_{NU} \,,$$

whereas the component $p_\parallel$ is the momentum of the electron and is proportional to the *instantaneous* angular frequency $\omega_z = {}^{v_z}/_{r}$

$$p_\parallel = \frac{\hbar\omega_z}{c} = \frac{\hbar v_z}{cr} = \frac{\hbar\omega}{c^2} v_z = m v_z$$

or in natural units

$$\left[p_\parallel = \omega_z = \frac{v_z}{r} = m v_z\right]_{NU} .$$

Using again the Pythagorean theorem it is possible to write the following equations

$$\omega_e = \frac{v_\perp}{r} = \frac{\sqrt{c^2 - v_z^2}}{r} = \frac{\sqrt{c^2 - v_z^2}}{r_e\sqrt{1 - {}^{v_z^2}/_{c^2}}} = \frac{c}{r_e}. \tag{13}$$

and, as a consequence of (13), also

$$\omega = \frac{c}{r}.$$

But

$$\omega_z = \frac{v_z}{r}$$

and therefore the sum of squares of the angular frequencies yields the following relations

$$\omega^2 = \omega_e^2 + \omega_z^2,$$

$$p_c^2 = p_\perp^2 + p_\parallel^2,$$

and, finally,

$$m^2 c^2 = m_e^2 c^2 + m^2 v_z^2. \tag{14}$$

For the sake of simplicity we will use the symbol p to indicate the electron momentum $p_\parallel$

$$p = p_\parallel = m v_z.$$

According to De Broglie hypothesis, ω_z is the instantaneous angular frequency associated to a particle with rest mass m_e, relativistic mass m and velocity $v_z = \omega_z r$ and therefore

$$p = m v_z = \frac{\hbar\omega}{c^2} v_z = \frac{\hbar}{cr} v_z = \frac{\hbar\omega_z}{c} = \hbar\frac{2\pi}{\lambda} = \hbar k, \tag{15}$$

or

$$\left[p = m v_z = \omega v_z = \frac{v_z}{r} = \omega_z = \frac{2\pi}{\lambda} = k\right]_{NU} .$$

Equation (15) yields

$$\frac{p}{k} = p\frac{\lambda}{2\pi} = \hbar. \tag{16}$$

where the term $k = {}^{2\pi}/_{\lambda}$ is the wave number of the electron and λ the related De Broglie wavelength.

Of course, if we observe the electron at a spatial scale much larger than its Compton wavelength and at a time scale much higher than the very short period $T \simeq 8.1 \cdot 10^{-21}$ s of the Zitterbewegung rotation, for a constant speed v_z the electron can be approximated to a point particle, equipped with "mass" and charge, which moves with a uniform motion along the z-axis of the helix. Particularly, Fig. 1 represents the helical trajectories of electrons moving at different speeds.

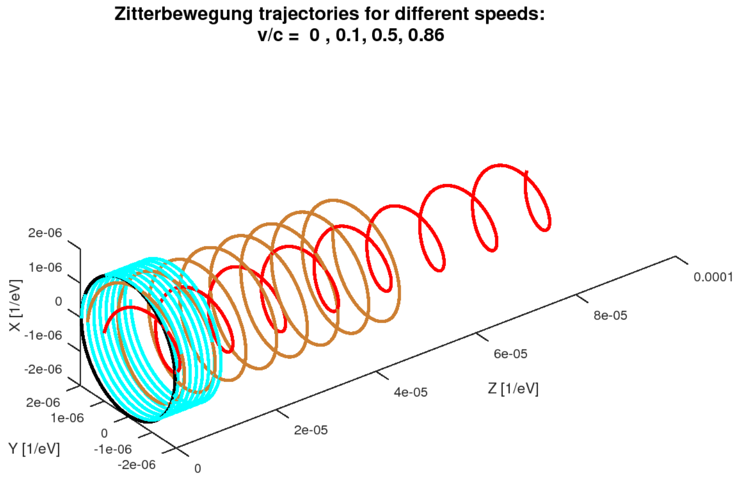

Figure 1: Zitterbewegung trajectories for different speeds.

5 ESR, NMR, Spin and *Intrinsic* angular momentum

As shown in the previous paragraph, in the proposed model, the electron has an angular momentum $\vec{\hbar}$ and a magnetic moment $\vec{\mu_B}$, equal to Bohr magneton. It is, therefore, reasonable to assume that, in presence of an external magnetic field, the electron is subjected, as a small gyroscope, to a torque τ and to a Larmor precession with frequency ω_p. The only difference with a classical gyroscope is the quantization of the $\hbar_{\parallel}$ component of the angular momentum $\vec{\hbar}$ along the external flux density field $\overrightarrow{B}_E$. This component can take only two possible spin values, namely $\hbar_{\parallel} = \pm\frac{1}{2}\hbar$ (see [6], p. 83). The two spin values will correspond to two possible values for the angle θ formed between the angular momentum vector and the external magnetic field vector: $\theta \in \left\{\frac{\pi}{3}, \frac{2\pi}{3}\right\}$:

$$\hbar_{\parallel}^2 + \hbar_{\perp}^2 = \hbar^2,$$

$$\hbar_{\parallel} = \pm\frac{1}{2}\hbar.$$

The torque exerted by the external flux density field $\overrightarrow{B}_E$ is

$$\tau = |\boldsymbol{\mu}_B \times \boldsymbol{B}_E| = B_E \mu_B \sin(\theta)$$

and the related Larmor precession angular frequency is

$$\omega_p = \frac{B_E \mu_B}{\hbar}. \tag{17}$$

The precession angular frequency will correspond to two possible energy levels:

$$E_H = \hbar\omega_p \qquad \text{if } \theta = \frac{2\pi}{3}$$

$$E_L = -\hbar\omega_p \qquad \text{if } \theta = \frac{\pi}{3}$$

The energy levels difference corresponds to the Spin Electronic Resonance (ESR) frequency ν_{ESR}:

$$\Delta E = E_H - E_L = 2\hbar\omega_p = \hbar\omega_{ESR} = h\nu_{ESR}. \tag{18}$$

From (18) and (17) it is possible to determine the ESR frequency as

$$\nu_{ESR} = 2\frac{B_E \mu_B}{h}. \tag{19}$$

For instance, an external magnetic flux density field equal to $B_E = 1.5\,\mathrm{T}$ yields a frequency $\nu_{ESR} \simeq 42$ GHz. By calling s the spin value and μ the nuclear magnetic moment we can also generalize (19) for particles other than the electron. In this case the term used is Nuclear Magnetic Resonance (NMR) frequency, which is equal to

$$\nu_{NMR} \simeq \frac{B_E \mu}{hs}. \tag{20}$$

For instance, for isotope ${}^{7}_{3}Li$, with $s = {}^{3}/_{2}$, $\mu \simeq 1.645 \cdot 10^{-26}$ and $B_E = 1.5$ T, the NMR frequency is $\nu_{NMR} \simeq 24.8$ MHz, whereas for isotope ${}^{11}_{5}B$ we have $s = {}^{3}/_{2}$, $\mu \simeq 1.36 \cdot 10^{-26}\ \mathrm{J \cdot T^{-1}}$ and NMR frequency is $\nu_{NMR} \simeq 20.5$ MHz. Another example deals with isotope ${}^{87}_{38}Sr$ with $s = {}^{9}/_{2}$ and $\mu \simeq 5.52 \cdot 10^{-27}\ \mathrm{J \cdot T^{-1}}$. In this case NMR frequency is $\simeq 278$ kHz for $B_E = 0.15$ T with a Larmor frequency ${}^{\omega_p}/_{2\pi} = {}^{1}/_{2}\nu_{NMR} \simeq 139$ kHz.

5.1 Electron spin and coherent systems

In the proposed model, the electron, in presence of an external magnetic field, is subjected to Larmor precession and its spin value $\pm{}^{\hbar}/_{2}$ is interpreted as the intrinsic angular momentum component parallel to the magnetic field. It is interesting to note that a hypothetical technology, able to align the intrinsic angular momentum of a sufficient number of electrons, could favor the formation of a coherent superconducting and super-fluid condensate state. In this state, the electrons would behave as particles with whole spin $\hbar$ and would no longer be subject to the Fermi-Dirac statistic. The compression effect (pinch) of an electrical discharge, accurately localized in a very small "capillary" volume, inside which a very rapid and uniform variation of the electric potential occurs, could favor the formation of a superconducting plasma. The conjecture is based on the possibility that, as a consequence of Aharonov-Bohm effect, a rapid, collective and simultaneous variation of the Zitterbewegung phase catalyzes the creation of coherent systems like those described by K. Shoulders and H. Puthoff [21]: *"Laboratory observation of high-density filamentation or clustering of electronic charge suggests that under certain conditions strong coulomb repulsion can be overcome by cohesive forces as yet imprecisely defined"*.

6 Hypotheses on the structure of ultra-dense Hydrogen

In relativistic quantum mechanics, the Klein-Gordon equation describes a charge density distribution in space and time. In this equation appears a term ${}^{m^2c^2}/_{\hbar^2}$, whose interpretation becomes simple and intuitive if one uses natural units and the principle of mass-energy-frequency equivalence. In particular, it is possible to recognize this term as the square of the Zitterbewegung angular frequency ω:

$$\left[\frac{m^2c^2}{\hbar^2} = m^2 = \omega^2\right]_{NU}$$

In the paper "*On the hydrino state of the relativistic hydrogen atom*" [19], the author, by applying the Klein-Gordon equation to the hydrogen atom, finds a possible deep energetic level of $E_0 \approx 3.7\,\mathrm{keV}$ (see page 3 equations (16) and (17)) at a distance r_0 from the nucleus. In particular Naudts demonstrates that

$$E_0 \simeq m_e c^2 \alpha \simeq 3.7\,\mathrm{keV}$$

at a distance from nucleus equal to

$$r_0 \simeq \frac{\hbar}{m_e c} \simeq 0.39 \cdot 10^{-12}\ \mathrm{m}.$$

According to the author, the E_0 level corresponds to the hypothetical state of a relativistic electron: "*The other set of solutions contains one eigenstate which describes a very relativistic particle with a binding energy which is a large fraction of the rest mass energy*". It is possible to formulate an alternative hypothesis according to which the radius r_0 is simply the radius r_e of the Zitterbewegung orbit, in the center of which the proton is located. Consequently the energy $-E_0$ can be interpreted as the electrostatic potential energy between the electron charge and the proton:

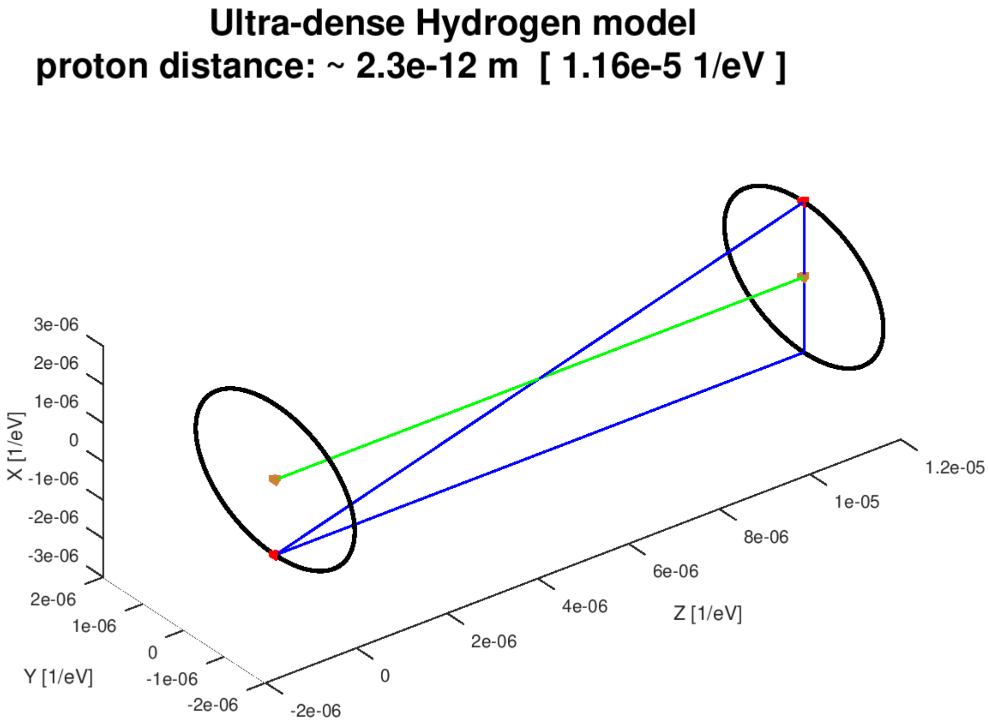

Figure 2: Ultra-dense Hydrogen Model.

$$E_0 = \frac{1}{4\pi\epsilon_0}\frac{e^2}{r_e} = \frac{\hbar}{r_e}\alpha c = m_e c^2 \alpha,$$

$$\left[E_0 = \frac{e^2}{r_e} = \frac{\alpha}{r_e} = \omega_e e^2 = m_e \alpha\right]_{NU}.$$

A series of numerous experiments conducted by Professor Leif Holmlid of the University of Gothenburg, recently replicated by Sindre Zeiner-Gundersen [24], seem to demonstrate the existence of a very compact form of deuterium [22, 12, 13]. Starting from the kinetic energy (about 630 eV) of the nuclei emitted in some experiments, achieved by irradiating this particular form of ultra-dense deuterium with a small laser, a distance between deuterium nuclei of about $2.3 \cdot 10^{-12}$ m has been computed, a value much smaller than the distance of about $74 \cdot 10^{-12}$ m that separates the nuclei of a normal deuterium molecule. Therefore, it is possible to advance an hypothesis on the structure of ultra-dense hydrogen (UDH) starting from the electron Zitterbewegung model. The proton is considerably smaller than Zitterbewegung orbit radius r_e, consequently an hypothetical structure formed by an electron with a proton (or a deuterium nucleus) in its center would have a potential energy of $\left[-e^2/r_e \simeq -3.7\,\text{keV}\right]_{NU}$, a value corresponding to the energy in the X-ray range with a wavelength of about $3.3 \cdot 10^{-10}$ m. The distance between the deuterium nuclei in the Holmlid experiment could be explained by an ordered linear sequence of ultra-dense particles in which the rotation planes of the electron charges are parallel and equidistant. In these hypothetical aggregates, the Zitterbewegung phases of two neighboring electrons differ by π radians and the distance d_c between the charges of the two electrons is equal to the distance traveled by light in a time equal to a rotation period T. This distance amounts to $d_c = cT = \lambda_c \simeq 2.42 \cdot 10^{-12}$ m. In this case, the distance between the nuclei d_i can be obtained by applying the Pythagorean theorem, as shown in Fig. 2, yielding the value

$$d_i = \sqrt{\lambda_c^2 - \left(\frac{\lambda_c}{\pi}\right)^2} \simeq 2.3 \cdot 10^{-12}\ \text{m}.$$

This UDH model follows by the third assumption of Carver Mead "Alternate World View": *"every element of matter is coupled to all other charges on its light cone by time-symmetric interactions"* [17].

6.1 Ultra-dense Hydrogen and Anomalous Heat Generation in Metal-hydrogen Systems

The combustion of a mole of hydrogen (about two grams) generates an energy of 286kJ, a value that corresponds to an energy of 1.48 eV per atom. The formation of an ultra-dense hydrogen atom would release an energy of 3.7 keV per atom, a value 2500 times higher. The conversion of only two grams of hydrogen into ultra-dense hydrogen would then be able to generate an energy of 715 MJ $\simeq$ 198 kWh. Consequently, the hypothesis, according to which in some experiments the development of anomalous heat is partially or totally due to the formation of ultra-dense hydrogen, cannot be excluded. Following *an alternative* hypothesis, the $\alpha m_e c^2 \simeq$ 3.7 keV energy is not emitted as an X-ray photon but is stored in the electron mass-frequency-energy, with a consequent small Zitterbewegung orbit radius reduction. By defining m_{eu} and r_{eu} the mass and the radius, respectively, in this new state we have:

$$m_{eu}c^2 = m_e c^2 + \alpha m_e c^2 \simeq 514.728\,\text{keV}. \tag{21}$$

The mass increase implies a Zitterbewegung radius reduction. In fact

$$m_e c^2 = \hbar\omega_e = \frac{\hbar c}{r_e},$$

$$m_{eu}c^2 = m_e\left(1+\alpha\right)c^2 = \hbar\omega_{eu} = \frac{\hbar c}{r_{eu}},$$

and therefore

$$r_{eu} = \frac{\hbar}{m_e\left(1+\alpha\right)c} = \frac{r_e}{1+\alpha}.$$

This radius reduction generates a potential energy decrease:

$$\triangle E_p = \frac{e^2}{4\pi\varepsilon_0}\left(\frac{1}{r_e} - \frac{1}{r_{eu}}\right) = \frac{e^2\alpha}{4\pi\varepsilon_0 r_e} = \left[\frac{\alpha^2}{r_e}\right]_{NU} \simeq 27.2\,\text{eV}.$$

Following the Carver Mead "transactional" interpretation of photons, the eventual (or necessary?) emission of the ultraviolet 27.2 eV photon may be favored by a "Mills catalyst" [18, 17].

Another Zitterbewegung model for deep electron states has been recently presented by A. Kovacs et al., aimed at explaining their impressive experimental results [16].

7 Ultra-dense Hydrogen and Low-energy Nuclear Reactions

In the proposed model the particles of hydrogen or ultra-deuterium deuterium are electrically neutral but have a magnetic moment almost equal to electron's one. This is a value 960 times higher than neutron magnetic moment. A particle with magnetic moment $\boldsymbol{\mu}$ is subjected in presence of a magnetic field $\boldsymbol{B}$ to a force $\boldsymbol{f}$ proportional to $\boldsymbol{B}$ gradient

$$\boldsymbol{f} = \nabla\left(\boldsymbol{B}\cdot\boldsymbol{\mu}\right)$$

The magnetic field $\boldsymbol{B}$ generated by a nucleus could therefore exert a considerable "remote action" on the particles of ultra-dense hydrogen. This force could be the source of the "long range potential" mentioned in a theoretical work of Gullström and Rossi, "Nucleon polarizability and long range strong force from $\sigma I = 2$ meson exchange potential" [9]:

"A less probable alternative to the long range potential is if the e-N coupling in the special EM field environment would create a strong enough binding to compare an electron with a full nuclide. In this hypothesis, no constraints on the target nuclide are set, and nucleon transition to excited states in the target nuclide should be possible. In other words these two views deals with the electrons role, one is as a carrier of the nucleon and the other is as a trigger for a long range potential of the nucleon".

Therefore, it is possible that, according to this scenario, electrons would have a fundamental dual role as catalysts of low-energy nuclear reactions (or LENR, Low Energy Nuclear Reactions): the first as neutralization-masking effect of the positive charge of hydrogen or deuterium nuclei, a necessary condition to overcome the Coulomb barrier, the second as the source of a relatively long-range magnetic force.

By using the Holmlid notation "H(0)" to indicate ultra-heavy hydrogen particles, it is possible to hypothesize a LENR reaction involving the $^{7}_{3}Li$, an isotope that constitutes more than 92% of the natural Lithium

$$^{7}_{3}Li + H\,(0) \rightarrow 2^{4}_{2}He + e. \tag{22}$$

This reaction would produce an energy of about 17.34 MeV mainly in the form of kinetic energy of helium nuclei, without emission of neutrons or penetrating gamma rays. A similar reaction, able to release about 8.67 MeV, could be hypothesized for the isotope $^{11}_{5}B$

$$^{11}_{5}B + H\,(0) \rightarrow 3^{4}_{2}He + e. \tag{23}$$

Emissions in the X-ray range would still be present in the form of braking radiation (*Bremsstrahlung*) generated by the deceleration caused by impacts of helium nuclei with other atomic nuclei.

The three "miracles" required by the low-energy nuclear reactions could therefore find, for example, in the reaction (22) a possible explanation:

1. Overcoming the Coulomb barrier: the ultra-heavy hydrogen particles are electrically neutral;
2. No neutrons are emitted: the reactions products of (22) and (23) consist exclusively of helium nuclei and an electron;
3. Absence of penetrating gamma radiation: the energy produced is manifested as kinetic energy of the reaction products and as X-ray emission from *bremsstrahlung*.

The mechanical energy of the alpha particles produced by the reactions could be converted with a reasonable yield directly into electrical energy or into usable mechanical energy [23], avoiding the need for an intermediate conversion into thermal energy. None of the three miracles is required to justify the production of abnormal heat due to ultra-dense hydrogen formation.

In the Iwamura experiment the low-energy nuclear transmutation of elements deposited on a system formed by alternating thin layers of palladium (Pd) and calcium oxide (CaO) was observed. The transmutation occurs when the system is crossed by a flow of deuterium. The CaO layer, essential for the transmutation, is hundreds of atomic layers far from the surface where the atoms to transmute are deposited or implanted. It is, therefore, necessary to find a mechanism that explains the remote action, the role of the CaO and the overcoming of the Coulombian barrier by deuterium nuclei. An interesting hypothesis could derive from considering the formation of ultra-dense deuterium (UDD) at the interface between calcium oxide and palladium, an area in which the high difference in the work function between Pd and CaO favors the formation of a layer with high electron density (SEL, Swimming Electron Layer) [14]. The ultra-dense deuterium could subsequently migrate to the area where the atoms to transmute are present. Therefore, aggregates of neutral charged ultra-dense deuterium would be, according to this hypothesis, the probable responsible for the transmutation of Cs into Pr and Sr into Mo. By using again the Holmlid notation "D(0)" to indicate "atoms" of ultra-dense deuterium, the hypothesized reactions in Iwamura experiments [15] would be very simple:

$$^{133}_{55}Cs + 4D(0) \;\rightarrow\; ^{141}_{59}Pr + 4e$$

$$^{88}_{38}Sr + 4D(0) \;\rightarrow\; ^{96}_{42}Mo + 4e$$

$$^{138}_{56}Ba + 6D(0) \;\rightarrow\; ^{150}_{62}Sm + 6e.$$

In this context, the electrons would have the precise role of deuterium nucleus vectors within the nucleus to be transmuted. It is possible that strontium oxide, with its very low work function, substitutes the calcium oxide role in Celani's experiments [5].

8 Conclusions

In this paper a simple electron model has been introduced, where the concepts of mass-energy, momentum, magnetic momentum and spin naturally emerge from its geometric and electromagnetic parameters, thus avoiding the obscure concept of "intrinsic value". An intuitive geometric interpretation of relativistic mass and De Broglie wavelength has been presented. A Zitterbewegung interpretation of Proca, Klein-Gordon and Aharonov-Bohm equations has been proposed. Electronic Spin Resonance (ESR) frequency has been related to the Larmor precession frequency of the Zitterbewegung rotation plane. Then the proposed model has been applied to ultra-dense hydrogen, highlighting its possible role in low energy nuclear reactions.

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