Charge Clusters, Low Energy Nuclear Reactions and Electron Structure

Giorgio Vassallo
University of Palermo

J. Condensed Matter Nucl. Sci. 39 (2024) 1–21

Research Article

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Giorgio Vassallo
Università degli Studi di Palermo, Dipartimento di Ingegneria, Viale delle Scienze, Edificio 6

Abstract

This paper proposes the possibility that the formation of coherent charge clusters in nanometric gaps may have a role in the generation of Ultra Dense Hydrogen, Compton Scale Structures and in the catalysis of Low Energy Nuclear Reactions. This hypothesis is strictly related to a simple and intuitive theoretical framework that, in agreement with Occam's razor principle, proposes a common origin of fundamental physical properties as charge, mass, relativistic mass, spin and magnetic moment. This approach needs a particular Zitterbewegung electron model derived by a purely geometric/electromagnetic interpretation of Maxwell-Proca, Planck, De Broglie, Schrödinger, relativistic energy momentum and Aharonov-Bohm equations. Starting from this Zitterbewegung model a realistic hypothesis may be formulated on the structure of dense charge clusters seen by Shoulders and other researchers in their experiments.

Keywords: Aharonov-Bohm equations, aneutronic and many-body low energy nuclear reactions, compact structures, charge clusters, Darwin lagrangian, electromagnetic potentials, electron structure, Exotic Vacuum Objects, gaugeless Maxwell's equations, LENR, natural units, Nuclear Active Environments, Proca equation, relativistic energy-momentum relation, Schrödinger equation, Schwinger limits, Ultra Dense Hydrogen, Zitterbewegung.

1. Introduction

Maxwell's equations are generally considered a fully understood physical theory that has been confirmed by huge amount of experiments in the last 150 years. Consequently classic electrodynamics is commonly considered as an acquired knowledge that does not deserve further investigations. This perception endures despite some serious theoretical inconsistencies and several apparently inexplicable experimental results [1–5]. These inconsistencies are mainly originated from the violation of "Occam's razor", a rule that should be always used as a primary epistemological tool in scientific research [6]. As an example, an historical error that has not been widely revised, consists in not recognizing the electromagnetic potentials as fundamental real physical entities despite their reality has been experimentally demonstrated by the Aharonov-Bohm effect [7,8]. This mistake has prevented the identification of a realistic electron model that clearly defines the relationship between the concepts of mass and charge, spin and magnetic moment [6,9,10] and that might explain many unexpected experimental observations where electrons form dense clusters apparently defying the Coulomb repulsion [11,5,12,13,4].

Another important violation of Occam's razor rule often arises from the widespread use of gauges, as Lorenz and Coulomb gauges, a choice that denies the status of physical entity to a scalar field that is related to a generalization of Poynting vector (eq. 15) that suggests the possible existence of a previously unrecognized energy-mass transfer mechanism in low energy nuclear reactions.

Section 1 shows, in agreement with some previous works, some characteristic of a realistic electromagnetic electron-model, highlighting its relationship with gaugeless Maxwell's equations [14,6], Proca equation, von Klitzing constant and Schwinger limits. In this section is also proposed a simple electron Lagrangian that allows a derivation of Schrödinger equation and of the relativistic energy-momentum relation. Section 2 proposes a revised Darwin Lagrangian that, taking into account the effect of the rapid rotation (Zitterbewegung) of electron charges, suggests the possible existence of coherent charge clusters where the Coulomb repulsion is compensated by the magnetic Lorentz force. In section 3 we propose the possibility that the Nuclear Active Environments [15] are nanometric gaps where the interaction of protons or deuterons with coherent charge clusters form Ultra Dense Hydrogen or Compton scale structures that catalyze Low Energy Nuclear Reactions. In this section an hypothesis for the formation of the "heavy electrons" of the Widom-Larsen theory is also presented.

In section 4 are shortly described some experimental results presented by various authors that indicate the existence of very exotic and interesting charge aggregates. In section 5 the conclusions are presented with an enumeration of key concepts. Section 6 is an appendix with some propaedeutical information related to spacetime Clifford algebra rules, symbol definitions and natural units.

2. Electron Model

2.1. Proca-Maxwell Equation, Aharonov-Bohm Relations and Von Klitzing Constant

In Maxwell's equations does not appear the concept of mass, despite the experimental evidence shows that the electromagnetic sources are always associated with the presence of massive charged particles. This observation suggests the possibility that Maxwell's equations emerge naturally from a more fundamental equation, related to a Zitterbewegung electron model, that includes the concept of inertial mass and charge quantization. We believe that this point of view can be well explained by a particular interpretation of Proca equation (1):

$$\partial\left(\partial \wedge A_{\square}\right) + m^2 A_{\square} = 0 \tag{1}$$

In this equation the operator ∂ is the vector of the partial derivatives along the four directions of spacetime (see Appendix), while $A_{\square}$ is the electromagnetic four potential associated to the motion at speed of light of the elementary charge along a circular or helicoidal trajectory:

$$A_{\square} = \overrightarrow{A} + \gamma_t V$$

The symbol $\wedge$ is the spacetime algebra $Cl_{3,1}(\mathbb{R})$ wedge (external) product.

It is important to note that in this model the mass is no more an *intrinsic* property of the particle but is a direct consequence of the electromagnetic inertia of the current generated by the motion at speed of light of the elementary charge. In particular the charge has no intrinsic (i.e. unexplained) mass but has a mechanical momentum $e\overrightarrow{A}$ of pure electromagnetic nature:

$$\mathrm{e}\overrightarrow{A} = m\overrightarrow{c}$$

The electron momentum is simply the component of this momentum parallel to electron velocity $\overrightarrow{v}$:

$$e\overrightarrow{A}_{\parallel} = m\overrightarrow{v}$$

Consequently in agreement with Newton equation the acceleration of the electron is associated to a force f generated by the time derivative of this component [16]:

$$f = e\frac{d\overrightarrow{A}_{\parallel}}{dt} = m\frac{d\overrightarrow{v}}{dt}$$

The charge motion at speed of light is consistent with the gaugeless Maxwell's equations proposed in [10,6], where the D'Alembert equation can be applied to the charge density ρ:

$$\partial^2\rho = \nabla^2\rho - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\rho = 0$$

In agreement with both Planck and Einstein equations the mass value m is exactly equal in natural units, where $\hbar = c = 1$, to the charge angular speed ω and to the inverse of its trajectory radius r:

$$mc^2 = \hbar\omega$$
$$m = \omega = \frac{c}{r} = \frac{1}{r}$$

The time component of the charge electromagnetic four potential is the Coulomb potential V:

$$V = A_t = \frac{e}{r_c}$$

where r_c is the charge radius. The value of r_c and V can be easily computed by applying the electric Aharonov-Bohm equation:

$$d\varphi = eVdt$$
$$m = \omega = \frac{d\varphi}{dt} = eV$$
$$r_c = \frac{e}{V} = \frac{e^2}{m} = \frac{\alpha}{m} = \alpha r$$

the angle $d\varphi$ in agreement with the magnetic Aharonov-Bohm equation is also related to the charge vector potential $\overrightarrow{A}$:

$$d\varphi = e\overrightarrow{A}\cdot\overrightarrow{dl} = e\overrightarrow{A}\cdot\overrightarrow{c}dt = eAcdt = eAdt$$

This means that, in natural units, the vector potential module A is equal to the charge potential V and that the charge electromagnetic four potential is a nilpotent vector:

$$A = V$$
$$A_{\square}^2 = 0$$

It's important to remember that the product $e\overrightarrow{A}$ is exactly equal to the charge momentum $m\overrightarrow{c}$ and that consequently the electron charge is associated to a quantized angular momentum $\hbar$:

$$\begin{aligned} e\overrightarrow{A} &= m\overrightarrow{c} \\ eA &= eV = m \\ eAr &= mcr = mr = \hbar = 1 \end{aligned} \tag{2}$$

The angular speed ω is associated to the Zitterbewegung period T

$$T = \frac{2\pi}{\omega}$$

and to a Zitterbewegung current I that is equal to the charge potential multiplied by the inverse of Von Klitzing constant R_K:

$$I = \frac{e}{T} = \frac{e}{2\pi r} = \frac{e^2}{2\pi} A = \frac{\alpha}{2\pi} A = R_K^{-1} V$$

$$R_K = \frac{2\pi}{\alpha} \simeq 861.0226 \ (25812.8 \ \Omega)$$

We can define now a four current $I_\square$ that is equal to the charge electromagnetic four potential $A_\square$ multiplied by the constant R_K^{-1}:

$$I_\square = \frac{e\overrightarrow{\boldsymbol{c}}}{2\pi r} + \gamma_t \frac{e}{2\pi r} = \frac{\alpha}{2\pi} \left(A\overrightarrow{\boldsymbol{c}} + \gamma_t V \right) = \frac{\alpha}{2\pi} A_\square = R_K^{-1} A_\square$$

In a time dt the charge spans an angle $d\varphi$ that defines a cylindrical sector volume that has a vertical section area $\mathcal{A}$ that is equal to the product of the charge diameter $2r_c$ and the Zitterbewegung radius r:

$$\mathcal{A} = 2r_c r = 2\alpha r^2$$

Dividing the four current $I_\square$ by the area $\mathcal{A}$ we get a four current density $J_\square$ that is proportional to the square of the mass multiplied by the charge four potential. Substituting this four-current density value in Maxwell's equation 3, we get a non-linear Proca/Maxwell equation (5):

$$J_\square = \frac{I_\square}{\mathcal{A}} = \frac{1}{\mathcal{A} R_K} A_\square = \frac{1}{4\pi r^2} A_\square = \frac{m^2}{4\pi} A_\square$$

$$\partial F = -4\pi J_\square \tag{3}$$

$$\partial F = \partial \left(\partial \wedge A_\square \right) = -4\pi J_\square = -m^2 A_\square$$

$$\partial \left(\partial \wedge A_\square \right) + m^2 A_\square = 0 \tag{4}$$

Remembering that $eA = m$ (see eq. 2) and that $e^2 = \alpha$, equation 4 can be written in the following form 5:

$$\partial \left(\partial \wedge A_\square \right) + \alpha A^2 A_\square = 0 \tag{5}$$

In ordinary Maxwell equations, at time scales much larger than Zitterbewegung period $\left(T \simeq 0.81 \cdot 10^{-20} s \right)$, the currents generated internally by the Zitterbewegung motion of electron charges can be safely ignored and only the averaged macroscopic currents generated by the motion of many particles are usually considered.

This Zitterbewegung electron model follows an old research stream that started from the first decades of the XX century [17–27].

2.2. The Pure Electromagnetic Origin of Electron Mass

The electron magnetic flux can be computed integrating the charge vector potential A along the length $2\pi r$ of the Zitterbewegung orbit:

$$eA = m = \frac{1}{r}$$

$$\Phi_M = \oint \overrightarrow{A} \cdot \overrightarrow{dl} = 2\pi r A = \frac{2\pi}{e}$$

This means that the electron is an *indissoluble* interaction between the charge quantum e and the magnetic flux quantum $\Phi_M = {}^{2\pi}/_{e}$. The ratio between the electric flux $\Phi_E = 4\pi e$ and the magnetic flux Φ_M is the double of fine structure constant α:

$$\frac{\Phi_E}{\Phi_M} = 2e^2 = 2\alpha$$

Now, it is possible to calculate the magnetic energy W_m stored in the magnetic field produced by the spinning charge:

$$W_m = \frac{1}{2}\Phi_M I = \frac{1}{2}\frac{2\pi}{e}\frac{e}{T} = \frac{1}{2r} = \frac{1}{2}m$$

which is equal to half the electron rest mass-energy. The other half part can be attributed to the electric field energy:

$$W_e = \frac{1}{2}\epsilon_0 \iiint_{\mathcal{V}} E^2 \, d\mathcal{V} = \frac{1}{8\pi}\iiint_{\mathcal{V}} \frac{e^2}{r^4}\, d\mathcal{V} = \frac{e^2}{8\pi}\int_{r_c}^{\infty} \frac{1}{r^4} 4\pi r^2 dr$$
$$W_e = \frac{e^2}{2}\int_{r_c}^{\infty}\frac{1}{r^2}dr = -\frac{\alpha}{2r}\Big|_{r_c}^{\infty} = \frac{\alpha}{2r_c} = \frac{1}{2r} = \frac{1}{2}m$$
$$W = W_m + W_e = \frac{1}{r} = m$$

In these equation $r_c = \alpha r$ is the charge radius. For an electron at rest $r = r_0$ and $m_0 = {}^1/_{r_0} \simeq 511 \cdot 10^3 eV$ in natural units.

2.3. Electron Spin and Paramagnetic Resonance

The spin is an electron parameter that has the dimension of an angular momentum (it's dimensionless in natural units) and has only two possible values, $s = \pm {}^1/_2\hbar$.

Now, these two possible values are associated with two different energy levels, namely E_L and E_H in presence of a magnetic field $\overrightarrow{B}_E$, as demonstrated by the Electron Spin Resonance (ESR) experiments:

$$E_L = -B_E\mu_B = -\omega_p$$
$$E_H = B_E\mu_B = \omega_p$$

The angular frequency ω_p can be interpreted as the Larmor precession frequency, i. e. the gyroscopic precession of an object *that has a constant angular momentum* $\overrightarrow{\hbar}$ and is subjected to a mechanical torque $\overrightarrow{\tau} = \overrightarrow{\mu}_B \times \overrightarrow{B}_E$. The spin resonance frequency is obtained considering the difference of the two energy levels:

$$\omega_{ESR} = E_H - E_L = 2\omega_p$$

Consequently the spin is simply the component of the electron angular momentum $\overrightarrow{\hbar}$ along an external magnetic field. *The only difference from a classical gyroscope is the quantization of the component of the angular momentum vector* $\overrightarrow{\hbar}$ along the external flux density field $\overrightarrow{B}_E$. This component can take only two possible spin values, namely $\hbar_{\parallel} = \pm\frac{1}{2}\hbar$. 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: $\theta \in \left\{\frac{\pi}{3}, \frac{2\pi}{3}\right\}$.

$$\omega_p = B_E\mu_B$$

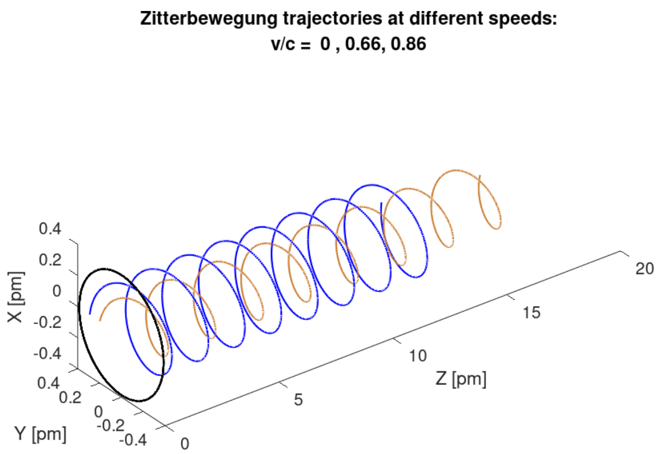

Figure 1.

2.4. Zitterbewegung and the Relativistic Energy-Momentum Relation

Calling $\overrightarrow{v}_z$ the velocity of an electron that moves along the z axis, $\overrightarrow{p}_z = e\overrightarrow{A}_z$ the electron mechanical momentum, $\overrightarrow{v}_\perp$ and $\overrightarrow{A}_\perp$ respectively the component of the charge velocity $\overrightarrow{c}$ and of the vector potential $\overrightarrow{A}$ orthogonal to $\overrightarrow{v}_z$ we can find the relativistic energy-momentum equation 6:

$$\left(e\overrightarrow{A}_\perp\right)^2 = \left(e\overrightarrow{A}_x\right)^2 + \left(e\overrightarrow{A}_y\right)^2$$

$$\left(e\overrightarrow{A}\right)^2 = \left(e\overrightarrow{A}_\perp\right)^2 + \left(e\overrightarrow{A}_z\right)^2 = m^2$$

$$m^2 = m^2 v_\perp^2 + m^2 v_z^2$$

As consequence of Pythagorean theorem the term $v_\perp^2$ can be written as $\left(1 - v_z^2\right)$:

$$m^2 = m^2\left(1 - v_z^2\right) + m^2 v_z^2$$

The term $m^2\left(1 - v_z^2\right)$ is exactly equal to the square of rest mass m_0

$$m^2 = m_0^2 + m^2 v_z^2$$

and consequently the square of total electron energy $\mathscr{E}$ is equal to the square of its relativistic mass:

$$\mathscr{E}^2 = m^2 = m_0^2 + p_z^2 \tag{6}$$

2.5. Zitterbewegung and Schwinger Limits

The Schwinger limits are values above which the electromagnetic fields become nonlinear:

$$E_c = \frac{m_0^2 c^3}{e\hbar} \simeq 1.32 \cdot 10^{18}\ V/m \qquad B_c = \frac{m_0^2 c^2}{e\hbar} \simeq 4.41 \cdot 10^{9}\ T$$

or, in natural units:

$$E_c = B_c = \frac{m_0^2}{e} \simeq 3.0567 \cdot 10^{12}\, eV^2$$

These values are exactly equal, to the value of the electric and magnetic fields generated/seen by the Zitterbewegung rotation of the charge of the electron at rest:

$$\begin{aligned} eA &= \omega_0 = m_0 \\ E_c &= \left| \frac{d\overrightarrow{A}}{dt} \right| = \frac{Ad\varphi}{dt} = A\omega_0 = \frac{m_0^2}{e} \\ ecB_c &= e \left| \frac{d\overrightarrow{A}}{dt} \right| = m_0^2 = \frac{m_0 c^2}{r_0} \\ B_c &= \frac{m_0^2}{e} \end{aligned}$$

This perfect matching can be considered another important point in favor of this electron model based on the non-linear Maxwell-Proca equation 5. The importance of Schwinger limits in electron modeling has been first suggested by dos Santos [28].

2.6. Electron Lagrangian

Calling $c_\square$ the electron charge four velocity,

$$\begin{aligned} c_\square &= \gamma_x c_x + \gamma_y c_y + \gamma_z c_z + \gamma_t c = \overrightarrow{c} + \gamma_t \\ \overrightarrow{c}^2 &= c = 1 \end{aligned}$$

we can define a Lagrangian $\mathscr{L}$ that is the dot product of $c_\square$ and the charge energy-momentum vector $eA_\square$:

$$\begin{aligned} eA_\square &= \gamma_x eA_x + \gamma_y eA_y + \gamma_z eA_z + \gamma_t eV \\ \mathscr{L} &= eA_\square \cdot c_\square \\ \mathscr{L} &= e\overrightarrow{A} \cdot \overrightarrow{\boldsymbol{c}} - eV \end{aligned}$$

The electron Action Ξ is the time integral of the Lagrangian $\mathscr{L}$:

$$\Xi = \int \mathscr{L} dt$$

The differential $\mathscr{L}dt$ is equal to the dot product of the energy-momentum vector $eA_\square$ and the differential of the charge four displacement in spacetime $dl_\square$

$$\begin{aligned} dl_\square &= c_\square dt = \gamma_x dx + \gamma_y dy + \gamma_z dz + \gamma_t dt \\ \mathscr{L}dt &= eA_\square \cdot c_\square dt = e\overrightarrow{A} \cdot \overrightarrow{\boldsymbol{c}} dt - eV dt \\ \mathscr{L}dt &= eA_\square \cdot dl_\square \\ \Xi &= e\int A_x dx + e\int A_y dy + e\int A_z dz - e\int V dt \end{aligned}$$

The gradient $\boldsymbol{\nabla}\Xi$ is equal to the charge momentum $e\overrightarrow{A}$

$$\boldsymbol{\partial}\Xi = \gamma_x eA_x + \gamma_y eA_y + \gamma_z eA_z - \gamma_t eV = \nabla\Xi + \gamma_t \frac{\partial\Xi}{\partial t}$$
$$\boldsymbol{\nabla}\Xi = e\overrightarrow{A}$$

while the module of the time derivative of the action Ξ is equal to the electron mass

$$\frac{\partial\Xi}{\partial t} = -eV = -m$$

2.7. Electron Lagrangian for Non Relativistic Speeds

We can now write a Lagrangian for an electron that moves in one dimension along the z direction, in presence of a potential $U(z)$, at non relativistic speeds.

Calling m_0 the electron rest mass, V_0 the electron charge potential at rest, $\overrightarrow{A}_\perp$the component of the charge vector potential orthogonal to electron velocity and A_z the parallel component, we can write:

$$\begin{aligned}
m_0 &= eV_0 \\
V &= V_0 + eU \\
\mathscr{L} &= e\overrightarrow{A} \cdot \overrightarrow{\boldsymbol{c}} - eV \\
e\overrightarrow{A} \cdot \overrightarrow{\boldsymbol{c}} &= e\overrightarrow{A}_\perp \cdot \overrightarrow{v}_\perp + eA_z v_z \\
\mathscr{L} &= e\overrightarrow{A}_\perp \cdot \overrightarrow{v}_\perp + eA_z v_z - m_0 - eU \\
m &= eA \\
\overrightarrow{v}_\perp + v_z^2 &= c^2 = 1 \\
e\overrightarrow{A}_\perp \cdot \overrightarrow{v}_\perp &= eA\overrightarrow{v}_\perp \cdot \overrightarrow{v}_\perp = m\left(1 - v_z^2\right) = m_0\sqrt{1 - v_z^2} \simeq m_0 - \frac{1}{2}m_0 v_z^2 \\
\mathscr{L} &\simeq \cancel{m_0} - \frac{1}{2}m_0 v_z^2 + eA_z v_z \cancel{- m_0} - eU \\
\mathit{\Xi} &\simeq \int eA_z v_z dt - \int \left(\frac{1}{2}m_0 v_z^2 + eU\right) dt \\
\mathit{\Xi} &\simeq \int eA_z dz - \int \left(\frac{1}{2}m_0 v_z^2 + eU\right) dt
\end{aligned}$$

2.8. Derivation of Schrödinger Equation

The charge action Ξ is the difference of two integrals:

$$\mathit{\Xi} \simeq \int eA_z dz - \int \left(\frac{1}{2}m_0 v_z^2 + eU\right) dt = \int eA_z dz - \int E_{tot} dt = \Xi_z - \Xi_t$$

so that we can define now a "wave function" ψ that encodes one particular quantum path for non relativistic speeds:

$$\psi = \exp i\Xi = \exp i\left(\Xi_z - \Xi_t\right) = \exp\left(i\Xi_z\right)\exp\left(-i\Xi_t\right) = \phi\left(z\right)\xi\left(t\right)$$
$$\frac{\partial\psi}{\partial z} = i\frac{\partial\Xi}{\partial z}\exp i\Xi = ieA_z\psi = ip_z\psi = im_0 v_z\psi$$

$$\begin{aligned}
\frac{\partial^2\psi}{\partial z^2} &= -\left(eA_z\right)^2 = -p_z^2 \\
-\frac{1}{2m_0}\frac{\partial^2\psi}{\partial z^2} &= \frac{1}{2}m_0 v_z^2\psi = E_k\psi \\
\frac{\partial\psi}{\partial t} &= -i\left(E_k + eU\right)\psi \\
i\frac{\partial\psi}{\partial t} &= -\frac{1}{2m_0}\frac{\partial^2\psi}{\partial z^2} + eU\psi
\end{aligned}$$

Remembering that ψ can be written as the product of the functions $\phi\left(z\right)$ and $\xi\left(t\right)$

$$\psi\left(z,t\right) = \phi\left(z\right)\xi\left(t\right)$$

we can rewrite Schrödinger equation in this form:

$$i\frac{\partial\psi}{\partial t} = i\phi\frac{d\xi}{dt} = -\frac{\xi}{2m_0}\frac{\partial^2\phi}{\partial z^2} + eU\phi\xi = E\phi\xi$$

Dividing this equation for ξ we can write an equation for the function $\phi\left(z\right)$ that is time independent:

$$-\frac{1}{2m_0}\frac{\partial^2\phi}{\partial z^2} + eU\phi = E\phi$$

2.9. London Equations

In our model the momentum of an electron is equal to the charge multiplied by the component of the vector potential parallel to the electron velocity v_z:

$$mv_z = eA_z \tag{7}$$

hypothesizing a unique collective velocity v_z and calling n_s the density of charge carriers, the coherent superconductive [29] current density j_s can be written as

$$j_s = n_s e v_z \tag{8}$$

$$v_z = \frac{eA_z}{m} \tag{9}$$

substituting eq. 3 in 2 we have the London equations ($\lambda_L = \sqrt{m/(4\pi n_s\alpha)}$ is the London penetration depth):

$$j_s = \frac{n_s e^2}{m}A_z = n_s\alpha r A_z = n_s r_c A_z = \frac{A_z}{4\pi\lambda_L^2} \Longrightarrow \lambda_L^{-2} = 4\pi n_s r_c \tag{10}$$

$$\nabla\times j_s = \frac{n_s e^2}{m}\nabla\times A_z = \frac{n_s e^2}{m}B$$

$$\frac{\partial j_s}{\partial t} = \frac{n_s e^2}{m}\frac{\partial A_z}{\partial t} = \frac{n_s e^2}{m}E_z$$

In this case the electrons behave as coherent bosons with integer spin ($\hbar = 1$)

3. Charge Clusters

3.1. "Massless" Darwin Lagrangian

Darwin Lagrangian can be used for modeling the interaction of a large number of massive charged particles:

$$\mathscr{L}_D = \sum_{a=1}^{N} \left[\frac{1}{2} m_a v_a^2 + \frac{1}{2} e_a \vec{A}_{ia} \left(\vec{r}_a \right) \cdot \vec{v}_a - \frac{1}{2} e_a V_{ia} \left(\vec{r}_a \right) \right] \tag{11}$$

In this equation $\vec{r}_a$ is the vector position of the generic particle, e_a its charge value, $\vec{v}_a$ its velocity, m_a its mass, $\vec{A}_{ia}\left(\vec{r}_a\right)$ and $V_{ia}\left(\vec{r}_a\right)$ are respectively the vector and the Coulomb potential at $\vec{r}_a$ due to the interaction with the other particles and N is the total number of the interacting particles.

Calling A_{sa} the charge vector potential generated by the Zitterbewegung motion of the generic particle (the self interaction vector potential) and A_{sza} its component along the electron velocity v_a the kinetic energy of the particle can be written as:

$$\frac{1}{2} m_a v_a^2 = \frac{1}{2} e_a A_{sa} v_a^2 = \frac{1}{2} e_a A_{sza} v_a = \frac{1}{2} e_a \vec{A}_{sa} \cdot \vec{v}_a$$

The Darwin Lagrangian can be written using only the electromagnetic potentials:

$$\vec{A}_a = \vec{A}_{ia} + \vec{A}_{sa}$$

$$\mathscr{L}_D = \sum_{a=1}^{N} \left[\frac{1}{2} e_a \vec{A}_a \left(\vec{r}_a \right) \cdot \vec{v}_a - \frac{1}{2} e_a V_{ia} \left(\vec{r}_a \right) \right]$$

3.2. Zitterbewegung Lagrangian and Charge Clusters

The Darwin Lagrangian takes into account only the component of the charge vector potential that is parallel to the electron velocity, ignoring the much larger value, for non relativistic speed, of the orthogonal component. This normally does not compromise the validity of the Darwin Lagrangian, considering that the orthogonal component rotates always at a frequency that, in natural units is equal to the electron rest mass and consequently its averaged value vanishes at time scales far greater than the Zitterbewegung period of the electron rest mass $\left(T \simeq 0.81 \cdot 10^{-20} s\right)$.

Calling V_{sa} the "self interaction" charge potential and r_{ca} the charge radius,

$$V_{sa} = \frac{e_a}{r_{ca}}$$

$$\vec{A}_a = \vec{A}_{ia} + \vec{A}_{sa}$$

$$V_a = V_{ia} + V_{sa}$$

the Lagrangian that takes into account the full charge vector potential has this simple form:

$$\mathscr{L}_Z = \sum_{a=1}^{N} e_a \vec{A}_a \cdot \vec{c}_a - e_a V_a$$

where $\vec{c}_a$ is the electron charge velocity vector $\left(\vec{c}_a^{\,2} = 1\right)$.

Calling $\vec{r}_{ab}$ the distance vector between the charges a and b, $\vec{r}_{uab}$ a unit vector that has the same direction of the vector distance $\vec{r}_{ab}$ and $\vec{c}_a$ the charge velocity vector we can write the value of the vector potential $\vec{A}_a$:

$$\vec{A}_a = \frac{e_a \vec{c}_a}{r_{ca}} + \frac{1}{2} \sum_{a \neq b} \frac{e_b \left[\vec{c}_b - \left(\vec{c}_b \cdot \vec{r}_{uab} \right) \vec{r}_{uab} \right]}{r_{ab}}$$

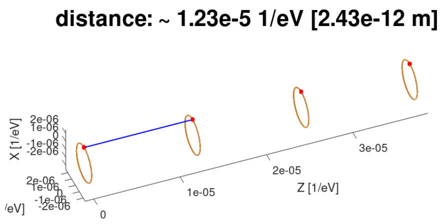

Figure 2.

and for Coulomb potential V_a

$$V_a = \frac{e_a}{r_{ca}} + \frac{1}{2}\sum_{a\neq b}\frac{e_b}{r_{ab}}$$

The Zitterbewegung Darwin Lagrangian has this final form:

$$e_a^2 = e_a e_b = \alpha$$

$$\mathscr{L}_Z = \sum_{a=1}^{N}\left[\frac{\alpha}{\cancel{r_c}}\cancel{\boldsymbol{c}_a^2} - \frac{\cancel{\alpha}}{\cancel{r_c}} + \frac{1}{2}\sum_{a\neq b}\frac{\alpha\left[\boldsymbol{c}_a\cdot\boldsymbol{c}_b - \left(\boldsymbol{c}_a\cdot\boldsymbol{r}_{uab}\right)\left(\boldsymbol{c}_b\cdot\boldsymbol{r}_{uab}\right) - 1\right]}{r_{ab}}\right]$$

and has extreme values when the velocity vectors of the charges are parallel or anti parallel.

The Coulomb repulsion F_C between charges that, moving in parallel, are in the same light cone and have velocity vectors orthogonal to their distance vectors, is fully compensated by the Lorentz force F_L:

$$\left|F_L\left(r_{ab}\right)\right| = \left|e_a\vec{c}_a \times \overrightarrow{B}_{ab}\left(r_{ab}\right)\right| = e_a c_a B_{ab} = \frac{e_a e_b}{r_{ab}^2} = \frac{\alpha}{r_{ab}^2} = \left|F_C\left(r_{ab}\right)\right| \tag{12}$$

$$\left|\overrightarrow{B}_{ab}\left(r_{ab}\right)\right| = \frac{e_b c_b}{r_{ab}^2}$$

A possible structure where the charges are in the same light cone and with parallel velocity vectors is a chain of coherent electrons with parallel Zitterbewegung orbit planes where the distance between the charges is equal to an integer multiple of the electron Compton wavelength λ_c

$$\lambda_c \simeq 1.23\cdot 10^{-5} eV^{-1}\left(2.43\cdot 10^{-12} m\right)$$

4. Zitterbewegung and LENR

4.1. Ultra Dense Hydrogen

Ultra Dense Hydrogen (UDH) is an hypothesized phase of hydrogen that exhibits extraordinary properties due to its high density, where the picometric internuclear distances are much shorter than in ordinary hydrogen. Discovered by Leif Holmlid, UDH may create the conditions where nuclear interactions could potentially occur at much lower energies than conventional nuclear reactions. Holmlid's research on UDH spans nearly 20 years, reflecting a sustained and dedicated effort to explore this novel phase of hydrogen and its implications [30–34].

He has authored or co-authored more than 50 papers related to UDH, covering various aspects such as its properties, the potential applications in nuclear reactions, and the experimental methods to study it. His work has been replicated by S. Zeiner-Gundersen and S. Olafsson [35].

Figure 3.

According to prof. Holmlid, UDH states may be explained by a Zitterbewegung [19] interpretation of quantum mechanics [30]:

"*Thus, the electrons which give the ultra-dense matter structure have no orbital motion, but only a spin motion. This electron spin motion may be interpreted as a motion of the charge with orbit radius* $r_q = \hbar/2m_e c \approx 0.192$ *pm and with the velocity of light c ('zitterbewegung')*".

In our model the orbit radius of the electron at rest is two times this value $(r_0 \simeq 0.38\, pm)$ in agreement with the "Larmor precession" interpretation of the electron spin.

If, as proposed by L. Holmlid, in Ultra Dense Hydrogen the electron has a proton at the center of its Zitterbewegung orbit, in agreement with Aharonov-Bohm equations, the electron Zitterbewegung angular speed (and consequently its mass m_u) should increase as a consequence of the potential reduction, while the orbit radius decreases:

$$
\begin{aligned}
d\varphi &= eV_0 dt - eU dt \\
d\varphi &= e\left(V_0 + \frac{e}{r_u}\right) dt \\
m_u &= \frac{d\varphi}{dt} = m_0 + \frac{\alpha}{r_u} \\
m_u &= m_0 + \alpha m_u \\
m_u &= \frac{m_0}{1-\alpha}
\end{aligned}
$$

This structure should be viewed as a *neutron-like particle* not as a particular form of the Hydrogen atom.

Is it possible to hypothesize that dense coherent electron charge clusters, in presence of protons or deuterons may form chains of Ultra Dense Hydrogen where these positive particles are in the center of the Zitterebewegung orbits. In a hypothetical UDH chain where the electron charges are in the same light cone, and their velocity vectors are parallel or anti parallel, the distance d between nuclei is approximately 2.3 pm:

$$
\begin{aligned}
\lambda_u &= \lambda_c (1-\alpha) \\
d &= \sqrt{\lambda_u^2 - \left(\frac{\lambda_u}{\pi}\right)^2} \approx 2.3 \cdot 10^{-12}\ \mathrm{m}
\end{aligned}
$$

It is important however to highlight the possibility that dense charge clusters may explain the formation of other exotic Compton scale structures, capable of catalyzing nuclear reactions, as the ones suggested by Frederick and Reitz [36] or by Storms [37,15,38], Shoulders [39] and Chicea [40].

4.2. UDH and LENR

By using the Holmlid notation "$H\,(0)$" to indicate ultra dense hydrogen particles, it is possible to hypothesize, as an example, a LENR reaction involving the ${}^7_3Li$, an isotope that constitutes more than 92% of the natural Lithium:

$$
{}^7_3Li + H\,(0) \to 2\,{}^4_2He + e. \tag{13}
$$

The three "miracles" required by the low-energy nuclear reactions could therefore find a possible explanation:

(1) Overcoming the Coulomb barrier: the ultra dense hydrogen particles are electrically neutral;
(2) No neutrons are emitted: the reactions products of (13) consist exclusively of helium nuclei and an electron;
(3) Absence of penetrating gamma radiation: the energy produced is mainly manifested as kinetic energy of the *electrons* and the reaction products and as X-ray emission from bremsstrahlung. Another possibility is the emission of *electro-scalar waves/pulses*, in agreement with the generalized Poynting vector (eq. 15) of the gaugeless Maxwell equations.

Many-body nuclear transmutation seen in Iwamura experiments [41] can be explained by the role of neutral particles formed by a chain/aggregate of four or six ultra dense deuterium particles:

$$
\begin{aligned}
{}^{133}_{55}Cs + 4D(0) &\rightarrow {}^{141}_{59}Pr + 4e \\
{}^{88}_{38}Sr + 4D(0) &\rightarrow {}^{96}_{42}Mo + 4e \\
{}^{138}_{56}Ba + 6D(0) &\rightarrow {}^{150}_{62}Sm + 6e.
\end{aligned}
$$

The picometric distance between deuterons in such hypothetical structures may favor these otherwise difficult to explain many-body nuclear transmutation

4.3. Nuclear Active Environments

In a recent paper [15] Edmund Storms suggests the possibility that Low Energy Nuclear Reactions are generate in very peculiar environments, i.e. nanometric gaps containing an "*assembly of electrons*" or "*a new kind of matter having a large negative charge and unusual magnetic properties*". Charge Clusters or EVO (Exotic Vacuum Objects) in nanogaps could efficiently catalyze LENR screening Coulomb barrier at pico-metric distance. Momentum conservation suggests that electrons, as a consequence of their lighter mass, take a large part of the energy produced in the reaction, indicating a possible answer to the old questions related to the lack of penetrating radiation in LENR and to the concomitant preference for the He_4 production channel. It's possible that the formation of these charge clusters in nanogaps is favored by doping the metal lattice with low work function elements (K, Ca, Sr, Cs) and by fast high voltage and current pulses [42,43]. Fast variations of the electromagnetic potentials imply, as a consequence of Aharonov-Bohm effect, a collective and rapid variation of the electron Zitterbewegung phase, possibly increasing the probability of formation of coherent electron aggregates, ultra dense hydrogen and compact structures [36] in Nuclear Active Environments [44,9].

It's important to note however that charge clusters may be formed also in other environments as demonstrated by the experiments of Shoulders and other researchers (see par. 4 "Experimental evidence of charge clusters"), suggesting consequently the possibility to explain also LENR reactions in systems where nanogaps are absent.

4.4. Widom–Larsen Theory and the Generalized Poynting Vector

In agreement with gaugeless Maxwell's equations the Poynting vector $\overrightarrow{\mathfrak{S}}$ contains, in presence of the Scalar field S, an extra term (see eq. 15) [6]:

$$
\overrightarrow{\mathfrak{S}} = \frac{1}{4\pi}\left(\overrightarrow{E} \times \overrightarrow{B} - S\overrightarrow{E}\right)
$$

Combining the Gauss law (eq. 14) with the component $S\overrightarrow{E}/4\pi$ of the generalized Poynting vector $\overrightarrow{\mathfrak{S}}$, emerges a non-null divergence of an energy flux density that implies the presence of a power source or a power sink (depending on the sign of the product ρS) where both charge density ρ and scalar field S are not vanishing [45]:

$$4\pi\rho = \nabla \cdot \overrightarrow{E} \tag{14}$$
$$\rho S = \frac{1}{4\pi}\nabla \cdot \overrightarrow{E}S$$

This also implies a possible mass-energy transfer mechanism between charges with different sign in presence of the scalar field S:

$$\frac{dm}{dt} = \iiint_{\mathcal{V}} \rho S d\mathcal{V}$$

This mechanism could be at the origin of the formation of the "heavy electrons" that, according to the Widom-Larsen theory, are captured by protons forming ultra low momentum neutrons.

The scalar field $S = \partial \cdot A_{\square}$ is the four divergence of the electromagnetic four potential and could be generated by very high derivatives of the electric potential and/or by divergent currents. This alternative hypothesis on heavy electrons formation is supported also by the mechanism used in the Brillouin Energy reactors:

"*Hydrogen is adsorbed into this nickel layer and a very short duration, high power electromagnetic pulse is repetitively applied to the rod. When the pulse is applied to the rod, the hydrogen nuclei (which are protons) undergo a sequence of nuclear reactions. The net result is that four hydrogen nuclei end up yielding one helium nucleus plus energy, which can be extracted from the core in the form of heat for useful purposes*" (Source: Brillouin Energy FAQ).

5. Experimental evidence of charge clusters

In this section some experiments are presented that show the existence of exotic charge clusters that cannot be easily explained by mainstream electron model.

5.1. Prins Experiment

Johan F. Prins has observed the formation of a stable superconductive electron structure in vacuum $\left(10^{-6} mbar\right)$ in a micrometric gap between an Oxygen doped diamond cathode with negative electron affinity and a gold plated steel anode. Surprisingly this highly conductive phase persists after removing or inverting the potential between the electrodes.

Prins raises the following important questions in his paper [4,46]:

"Why, and how, do electrons accumulate within the gap to form this highly conducting phase?

Why does this gap phase, once established, allow current to flow in either direction?

Why does this gap phase remain stable when the potential is switched off?

Electrons are charged, and should repel each other. One would have expected that they should 'explode' out of the gap."

A possible answer to these questions can be derived by eq. 12 that shows the possibility that in coherent electron structures the Coulomb repulsion can be balanced by magnetic Lorentz force generated by the Zitterbewegung motion at speed of light of the electron charge.

5.2. Shoulders experiment

Kenneth Shoulders has reported the observation of high density charged plasma clusters of $\sim 10^{10} - 10^{14}$ electrons with a ion content ratio $< 10^{-5}$ in special spark gap devices (Air Force report AFRL-PR-ED-TR-2002-0039, [5,47,39]). The Coulomb repulsion, as in Prins experiment, should clearly prevent the formation of these dense aggregates.

Moreover, the sudden explosion of a charge cluster (EV or Electrum Validum or EVO Exotic Vacuum Objects) leads to copious emission of X-rays, suggesting that probably the mean distance between the charges is in the order of few picometer.

Black (optically invisible) EVs, have been generated in low pressure ($10^{-2} - 10^{-3}$ Torr) hydrogen gas suggesting the possibility of a common mechanism at origin of Shoulders EVs and Prins electron bonds.

5.3. FreelTech experiment

Another really impressive experiment has been presented by FreelTech team. In this experiment vacuum tubes (high voltage diodes or Kenotrons) have been used as vacuum capacitors adding a supplemental external well isolated electrode anode. The charge accumulated by these special capacitors is much larger than that calculated considering only the normal interelectrode capacitance (J.P. Biberian ICCF24 poster: "Vacuum Capacitors for Energy Storage"). Once again this experiment shows the possible existence of exotic dense charge clusters where the Coulomb repulsion is apparently compensated by a previously unrecognized attractive force.

5.4. Lockheed Martin patent

In the US9502202B2 patent "Systems and methods for generating coherent matterwave beams" the authors suggest the possibility of generating coherent electron beams using special arrays of microscopic resonant cavities. The formation of these coherent beams however should be prevented, according to mainstream theories, by the fermionic nature of the electrons and by Coulomb repulsion. In our proposed Zitterbewegung model however the "Larmor precession" interpretation of $\pm{}^1\!/\!_2\hbar$ spin (see par. 1.2) does not exclude the possibility that the free electron angular momentum may be aligned, in particular conditions, to an external magnetic field, so that spin $\hbar$ electrons may form bosonic coherent clusters where the Coulomb repulsion is compensated by the Lorentz force (see eq. 12). The possibility that a collective coherent wavefunction phase can be obtained exploiting the Aharonov-Bohm effect has been recognized by the authors:

"*the Aharonov-Bohm (AB) effect may be used to change the phase of massive particles and produce coherent matterwave beams.*"

"*the AB effect is a phase-shifting process that does not change the energy of the particles, coherence can be achieved while keeping the wavelength the same for all particles.*"

"*using the AB effect for coherence induction and using coherence growth in microcavities that combine resonance with coherence may pave the road for the production of an energetic intense beam of coherent matterwaves.*"

6. Conclusions

An electron model has been proposed that could explain the structure of the exotic charge clusters seen by Shoulders and other researchers. In agreement with Storms hypothesis the Nuclear Active Environments that catalyze LENR could consist of nanogaps containing these clusters. The proposed electron model is consistent with Planck, Schrödinger, Maxwell-Proca, relativistic energy-momentum, Aharonov-Bohm and Schwinger limits equations.

The main key points of the presented hypotheses can be summarized in a few points:

(1) Occam's razor is a fundamental epistemological tool
(2) Electromagnetic potentials are real fundamental physical entities that allow a simple conceptual connection between mechanics and electromagnetism
(3) The four-divergence of the four potential is a real scalar field that is not always zero (i.e. Lorenz/Coulomb gauges are not always applicable)

(4) Gaugeless Maxwell equations reveal the nature of the electromagnetic sources as the four partial derivatives of the scalar field
(5) D'Alembert wave equation can be applied to both charge density and scalar field
(6) The electron can be modeled as a current ring generated by an electric charge without intrinsic mass (massless) that rotates at speed of light
(7) The charge quantum e is always coupled to a magnetic flux quantum h/e
(8) The charge orbit radius is equal to the reduced Compton wavelength
(9) The fine structure constant is equal to the ratio of charge radius and charge Zitterbewegung orbit radius
(10) The electron charge has a mechanical momentum equal to the charge value multiplied by the local value of the vector potential
(11) Using natural units the electron's charge momentum is equal to its relativistic mass
(12) The electron momentum is equal to the product of charge for the component of local vector potential along the electron velocity vector
(13) The electron rest mass, in natural units, is equal to the module of the component of charge mechanical momentum orthogonal to electron velocity vector
(14) The value of electron relativistic mass is consistent with both special relativity and electromagnetism
(15) The spin is the component of free electron angular momentum $\hbar$ along an external magnetic field
(16) Most physical values that in natural units are dimensionless (pure numbers) are quantized
(17) The electron model is consistent with Maxwell, Proca, Planck, De Broglie, Schrödinger, relativistic energy-momentum and Aharonov-Bohm equations
(18) Schwinger Limits for electric and magnetic fields are exactly equal to the values generated by the Zitterbewegung rotation of an electron at rest
(19) Is it possible to write a Lagrangian that may explain the exotic dense charge clusters seen/studied by some researchers
(20) Dense charge clusters in "Nuclear Active Environments" could favor the formation of neutral Compton scale composites or UDH and consequently the catalysis of unusual fusion or fusion-fission nuclear reactions
(21) A mechanism, based on the generalized Poynting vector of the gaugeless Maxwell's equations, that might explain the formation of the "heavy electrons" of the Widom-Larsen theory has been proposed.

7. Appendix

7.1. Spacetime $[Cl_{3,1}(\mathbb{R})]$ Clifford algebra rules

Vectors $\{\gamma_x, \gamma_y, \gamma_z, \gamma_t\}$ are the basis vectors of Minkowski spacetime:

$$\gamma_x^2 = \gamma_y^2 = \gamma_z^2 = -\gamma_t^2 = 1 \quad (Minkowski\, signature\ +++-)$$
$$\gamma_i\gamma_j = -\gamma_j\gamma_i \ \ with \ \ i \neq j \ and \ i,j \in \{x,y,z,t\}$$

Four vectors are indicated by a square subscript (ex. $A_\square$), 3D vectors by an arrow on top (ex. $\overrightarrow{A}$)

The symbol ∂ represent the vector of the four space-time partial derivatives:

$$\partial = \gamma_x \frac{\partial}{\partial x} + \gamma_y \frac{\partial}{\partial y} + \gamma_z \frac{\partial}{\partial z} + \gamma_t \frac{1}{c}\frac{\partial}{\partial t}$$

There are 2^4 subsets of the spacetime basis vectors.

Table 1. Blades of space-time algebra $[Cl_{3,1}(\mathbb{R})]$

blade	bit mask	grade	hex.
1	0000	0 (scalar)	0
γ_x	0001	1 (vector)	1
γ_y	0010	1 (vector)	2
$\gamma_x\gamma_y = \gamma_{xy}$	0011	2 (bivector)	3
γ_z	0100	1 (vector)	4
$\gamma_x\gamma_z = \gamma_{xz}$	0101	2 (bivector)	5
$\gamma_y\gamma_z = \gamma_{yz}$	0110	2 (bivector)	6
$\gamma_x\gamma_y\gamma_z = \gamma_{xyz} = I_\triangle$	0111	3 (pseudovector)	7
γ_t	1000	1 (vector)	8
$\gamma_x\gamma_t = \gamma_{xt}$	1001	2 (bivector)	9
$\gamma_y\gamma_t = \gamma_{yt}$	1010	2 (bivector)	A
$\gamma_x\gamma_y\gamma_t = \gamma_{xyt}$	1011	3 (pseudovector)	B
$\gamma_z\gamma_t = \gamma_{zt}$	1100	2 (bivector)	C
$\gamma_x\gamma_z\gamma_t = \gamma_{xzt}$	1101	3 (pseudovector)	D
$\gamma_y\gamma_z\gamma_t = \gamma_{yzt}$	1110	3 (pseudovector)	E
$\gamma_x\gamma_y\gamma_z\gamma_t = \gamma_{xyzt} = I$	1111	4 (pseudoscalar)	F

Table 2. The spinor field $\boldsymbol{\partial} A_\square$.

$\partial A_\square$	$\gamma_x A_x$	$\gamma_y A_y$	$\gamma_z A_z$	$\gamma_t A_t$
$\gamma_x \frac{\partial}{\partial x}$	$\frac{\partial A_x}{\partial x}$	$\gamma_x\gamma_y \frac{\partial A_y}{\partial x}$	$\gamma_x\gamma_z \frac{\partial A_z}{\partial x}$	$\gamma_x\gamma_t \frac{\partial A_t}{\partial x}$
$\gamma_y \frac{\partial}{\partial y}$	$-\gamma_x\gamma_y \frac{\partial A_x}{\partial y}$	$\frac{\partial A_y}{\partial y}$	$\gamma_y\gamma_z \frac{\partial A_z}{\partial y}$	$\gamma_y\gamma_t \frac{\partial A_t}{\partial y}$
$\gamma_z \frac{\partial}{\partial z}$	$-\gamma_x\gamma_z \frac{\partial A_x}{\partial z}$	$-\gamma_y\gamma_z \frac{\partial A_y}{\partial z}$	$\frac{\partial A_z}{\partial z}$	$\gamma_z\gamma_t \frac{\partial A_t}{\partial z}$
$\gamma_t \frac{\partial}{\partial t}$	$-\gamma_x\gamma_t \frac{\partial A_x}{\partial t}$	$-\gamma_y\gamma_t \frac{\partial A_y}{\partial t}$	$-\gamma_z\gamma_t \frac{\partial A_z}{\partial t}$	$-\frac{\partial A_t}{\partial t}$

7.2. Gaugeless Maxwell's equations

7.2.1. *The spinor field $\partial A_\square$*

Applying the operator ∂ to the four potential vector field $A_\square(x, y, z, t)$ defined as

$$A_\square = \gamma_x A_x + \gamma_y A_y + \gamma_z A_z + \gamma_t A_t \qquad \{with\ A_i \in \mathbb{R}\},$$

we get a spinor field G that is a composition of a scalar field S and a bivector field $\boldsymbol{F}$:

$$\boldsymbol{\partial} A_\square = \boldsymbol{\partial} \cdot A_\square + \boldsymbol{\partial} \wedge A_\square = S + F = G$$

7.2.2. *The electromagnetic bivector F*

There is a simple relation between the electric field $\overrightarrow{E}$, the magnetic field $\overrightarrow{B}$ and the electromagnetic bivector F

$$\overrightarrow{E} = \gamma_x E_x + \gamma_y E_y + \gamma_z E_z$$
$$\overrightarrow{B} = \gamma_x B_x + \gamma_y B_y + \gamma_z B_z$$
$$F = \partial \wedge A_\square = \left(\overrightarrow{E} + I\overrightarrow{B}\right)\gamma_t$$
$$S = \partial \cdot A_\square$$

Table 3. Products $\boldsymbol{\partial} G$.

$\boldsymbol{\partial} G$	S	$\gamma_{xt} E_x$	$\gamma_{yt} E_y$	$\gamma_{zt} E_z$	$\gamma_{yz} B_x$	$-\gamma_{xz} B_y$	$\gamma_{xy} B_z$
$\gamma_x \frac{\partial}{\partial x}$	$\gamma_x \frac{\partial S}{\partial x}$	$\gamma_t \frac{\partial E_x}{\partial x}$	$\gamma_{xyt} \frac{\partial E_y}{\partial x}$	$\gamma_{xzt} \frac{\partial E_z}{\partial x}$	$\gamma_{xyz} \frac{\partial B_x}{\partial x}$	$-\gamma_z \frac{\partial B_y}{\partial x}$	$\gamma_y \frac{\partial B_z}{\partial x}$
$\gamma_y \frac{\partial}{\partial y}$	$\gamma_y \frac{\partial S}{\partial y}$	$-\gamma_{xyt} \frac{\partial E_x}{\partial y}$	$\gamma_t \frac{\partial E_y}{\partial y}$	$\gamma_{yzt} \frac{\partial E_z}{\partial y}$	$\gamma_z \frac{\partial B_x}{\partial y}$	$\gamma_{xyz} \frac{\partial B_y}{\partial y}$	$-\gamma_x \frac{\partial B_z}{\partial y}$
$\gamma_z \frac{\partial}{\partial z}$	$\gamma_z \frac{\partial S}{\partial z}$	$-\gamma_{xzt} \frac{\partial E_x}{\partial z}$	$-\gamma_{yzt} \frac{\partial E_y}{\partial z}$	$\gamma_t \frac{\partial E_z}{\partial z}$	$-\gamma_y \frac{\partial B_x}{\partial z}$	$\gamma_x \frac{\partial B_y}{\partial z}$	$\gamma_{xyz} \frac{\partial B_z}{\partial z}$
$\gamma_t \frac{\partial}{\partial t}$	$\gamma_t \frac{\partial S}{\partial t}$	$\gamma_x \frac{\partial E_x}{\partial t}$	$\gamma_y \frac{\partial E_y}{\partial t}$	$\gamma_z \frac{\partial E_z}{\partial t}$	$\gamma_{yzt} \frac{\partial B_x}{\partial t}$	$-\gamma_{xzt} \frac{\partial B_y}{\partial t}$	$\gamma_{xyt} \frac{\partial B_z}{\partial t}$

7.2.3. *Maxwell's equations*

The four Maxwell's equations in vacuum, using natural units where $\hbar = c = 1,\ \varepsilon_0 = {}^1\!/_{4\pi}, \mu_0 = 4\pi$, can be encoded in a very compact form using spacetime algebra:

$$\partial^2 A_{\square} = 0$$

or remembering that $G = \partial A_{\square} = S + F$

$$\partial G = 0$$
$$\partial S + \partial F = 0$$

or calling $4\pi J_{\square}$ the vector field $\boldsymbol{\partial} S$:

$$\begin{aligned}
\partial F &= -\partial S = -4\pi J_{\square} \\
J_{\square} &= \gamma_x J_x + \gamma_y J_y + \gamma_z J_z + \gamma_t J_t = \overrightarrow{J} - \gamma_t \rho \\
\partial G &= \partial S + \partial \left(\overrightarrow{E} + I\overrightarrow{B}\right) \gamma_t = 0 \\
\partial S &= 4\pi J_{\square} \\
\partial F &= \partial \left(\partial \wedge A_{\square}\right) \\
\partial \left(\partial \wedge A_{\square}\right) &= -4\pi J_{\square}
\end{aligned}$$

7.2.4. *Energy density of the Electromagnetic Field*

The energy-momentum density vector $w_{\square}$ of the field $\boldsymbol{G}$ can be represented by a rotation of the base vector γ_t :

$$\begin{aligned}
w_{\square} &= \frac{1}{8\pi} \left(G \gamma_t \widetilde{G}\right) \\
\widetilde{G} &= S - F = S - \left(\overrightarrow{E} + I\overrightarrow{B}\right) \gamma_t \\
w_{\square} &= \frac{1}{4\pi} \left[\frac{1}{2} \left(S^2 + E^2 + B^2\right) \gamma_t - \left(\overrightarrow{E} \times \overrightarrow{B} - S\overrightarrow{E}\right)\right] \\
w_{\square} &= \left(w_s + w_E + w_M\right) \gamma_t - \overrightarrow{\mathfrak{S}},
\end{aligned}$$

where $w_s = \frac{S^2}{8\pi} = J_{\square} \cdot A_{\square}$, $w_E = \frac{\boldsymbol{E}^2}{8\pi}$ and $w_M = \frac{B^2}{8\pi}$ are the specific energies of the scalar, electric and the magnetic flux density fields, and where $\overrightarrow{\mathfrak{S}}$ is the generalized Poynting vector

$$\overrightarrow{\mathfrak{S}} = \frac{1}{4\pi} \left(\overrightarrow{E} \times \overrightarrow{B} - S\overrightarrow{E}\right) \tag{15}$$

7.3. Natural units

Symbol name [SI units], [natural units]

$A_\square$ electromagnetic four-potential $[V \cdot s \cdot m^{-1}]$, $[eV]$;
$\overrightarrow{A}$ electromagnetic vector potential $[V \cdot s \cdot m^{-1}]$, $[eV]$;
A electromagnetic vector potential module $[V \cdot s \cdot m^{-1}]$, $[eV]$;
m mass $[kg]$, $[eV]$;
F electromagnetic field bivector $[V \cdot s \cdot m^{-2}]$, $[eV^2]$;
$\overrightarrow{B}$ magnetic flux density field $[V \cdot s \cdot m^{-2}] = [T]$, $[eV^2]$;
$\overrightarrow{E}$ 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 $[A \cdot m^{-2}]$, $[eV^3]$;
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 $[7.2973525664 \cdot 10^{-3}]$, $[7.2973525664 \cdot 10^{-3}]$; $\alpha = e^2$
m_0 electron rest mass $[9.10938356 \cdot 10^{-31} kg]$, $[0.5109989461 \cdot 10^6 eV]$;
λ_c Compton wavelength $[2.426\,310 \cdot 10^{-12}\ m]$, $[1.229\,588 \cdot 10^{-5}\ eV^{-1}]$;
r_0 reduced Compton electron wavelength (Compton radius) $r_0 = \lambda_c/2\pi$;

Acknowledgments

Thanks to Ugo Abundo, Francesco Celani, Andras Kovacs, Guido Parchi, Jacques Ruer and other members of the CleanHMe project for their support and to Fabrizio Righes for many interesting exchange of information on the topics covered by this paper.

References

[1] D. Reed and L. Hively. Implications of gauge-free extended electrodynamics. *Symmetry*, 12, 12 2020.
[2] D. A. Woodside. Three-vector and scalar field identities and uniqueness theorems in Euclidean and Minkowski spaces. *American Journal of Physics*, 77(5):438–446, 2009.
[3] D. Reed. Unravelling the potentials puzzle and corresponding case for the scalar longitudinal electrodynamic wave. *Journal of Physics: Conference Series*, 1251, jun 2019.
[4] J. F. Prins. The diamond-vacuum interface: Electron extraction from n-type diamond: evidence for superconduction at room temperature. *Semiconductor Science and Technology*, 18(3):S131, feb 2003.
[5] K. Shoulders. *EV, A Tale of Discovery*. Austin, TX, 1987.
[6] A. Kovacs, G. Vassallo, P. O'Hara, F. Celani, and A.O. Di Tommaso. *Unified Field Theory and Occam's Razor*. World Scientific, 04 2022.
[7] Y. Aharonov and D. Bohm. Significance of electromagnetic potentials in the quantum theory. *Physical Review*, 115:485–491, 8 1959.
[8] A. Tonomura, N. Osakabe, T. Matsuda, T. Kawasaki, J. Endo, S. Yano, and H. Yamada. Evidence for Aharonov-Bohm effect with magnetic field completely shielded from electron wave. *Phys. Rev. Lett.*, 56:792–795, Feb 1986.

[9] A.O. Di Tommaso and G. Vassallo. Electron structure, Ultra-Dense Hydrogen and Low Energy Nuclear Reactions. *Journal of Condensed Matter Nuclear Science*, 29:525–547, Aug 2019.
[10] F. Celani, A.O. Di Tommaso, and G. Vassallo. Maxwell's equations and Occam's razor. *Journal of Condensed Matter Nuclear Science*, 25:100–128, Nov 2017.
[11] K. Shoulders and J. Sarfatti. Energy conversion from the exotic vacuum, 2004.
[12] K. Shoulders. Permittivity transitions, 2000.
[13] M.J. Arman and C. Chase. System and methods for generating coherent matterwave beams, Nov 2016. US Patent US9502202.
[14] G. Bettini. Clifford algebra, 3 and 4-dimensional analytic functions with applications. manuscripts of the last century. *viXra.org*, Quantum Physics, 2011.
[15] E. Storms. A New Understanding of Cold Fusion. *researchgate preprint*, 06 2023.
[16] F. Celani, A.O. Di Tommaso, and G. Vassallo. The electron and Occam's razor. *Journal of Condensed matter nuclear science*, 25:76–99, Nov 2017.
[17] A. L. Parson and Smithsonian Institution. *A magneton theory of the structure of the atom (with two plates)*. Number v. 65 in Publication (Smithsonian Institution). Smithsonian Institution, 1915.
[18] H. S. Allen. The case for a ring electron. *Proceedings of the Physical Society of London*, 31(1):49, dec 1918.
[19] D. Hestenes. The zitterbewegung interpretation of quantum mechanics. *Foundations of Physics*, 20(10):1213–1232, 1990.
[20] D. Hestenes. Zitterbewegung Modeling. *Foundations of Physics*, 23(3):365–387, 1993.
[21] D. Hestenes. Zitterbewegung in quantum mechanics. *Foundations of Physics*, 40(1):1–54, 2010.
[22] J. Paul Wesley David L. Bergman. Spinning charged ring model of electron yielding anomalous magnetic moment. *Galilean Electrodynamics*, 1:63–67, Sep/Oct 1990.
[23] David L. Bergman and J. Paul Wesley. Spinning Charged Ring Model of Electron Yielding Anomalous Magnetic Moment. *Galilean Electrodynamics*, 1(5):63–67, 1990.
[24] O. Consa. Helical Model of the Electron. *The General Science Journal*, pages 1–14, June 2014.
[25] G. Bettini. The Moebius Strip: a Biology of Elementary Particles . *viXra.org*, Quantum Physics, 2010.
[26] Richard Gauthier. The electron is a charged photon. volume 60 of *APS April Meeting 2015*, 2015.
[27] R. L. Mills, J. J. Farrell, and W. R. Good. *Unification of Spacetime, the Forces, Matter, and Energy*. Science Press, Ephrata, PA 17522, 1992.
[28] C. dos Santos. The Structure of the Electron Revealed by Schwinger Limits. *researchgate preprint*, 06 2023.
[29] A. Kovacs and G. Vassallo. *High-temperature superconductivity is the catalyzed Bose-Einstein condensation of electrons: a rigorous understanding of spin correlations, Bose-Einstein condensation, and Thomas-Fermi screening reveals how superconductors really work*. 12 2023.
[30] L. Holmlid and S. Olafsson. Spontaneous Ejection of High-energy Particles from Ultra-dense Deuterium D(0). *International Journal of Hydrogen Energy*, 40(33):10559–10567, 2015.
[31] L. Holmlid and S. Olafsson. Muon detection studied by pulse-height energy analysis: Novel converter arrangements. *Review of Scientific Instruments*, 88(1):013306, 2017.
[32] L. Holmlid. Heat generation above break-even from laser-induced fusion in ultra-dense deuterium. *AIP Advances*, 5(8), 08 2015.
[33] S. Badiei, P. Andersson, and L. Holmlid. High-energy coulomb explosions in ultra-dense deuterium: Time-of-flight-mass spectrometry with variable energy and flight length. *International Journal of Mass Spectrometry*, 282:70–76, 04 2009.
[34] L. Holmlid. Charge asymmetry of muons generated in a muon generator from ultra-dense hydrogen d(0) and p(0). *Particles*, 6:188–197, 01 2023.
[35] S. Zeiner-Gundersen and S. Olafsson. Hydrogen reactor for Rydberg Matter and Ultra Dense Hydrogen, a replication of Leif Holmlid. International Conference on Condensed Matter Nuclear Science, ICCF-21, Fort Collins, USA, 2018.
[36] J.M. Frederick and J.R. Reitz. Electromagnetic Composites at the Compton Scale. *International Journal of Theoretical Physics*, 51(1):322–330, 2012.
[37] E. Storms and B. Scanlan. Role of cluster formation in the lenr process. *15th International Conference on Condensed Matter Nuclear Science*, 10 2009.
[38] E. Storms. *The Explanation of Low Energy Nuclear Reaction: An Examination of the Relationship Between Observation and Explanation*. Infinite Energy Press, Concord, NH, 2014.

[39] K. Shoulders and S. L. Shoulders. Observations on the role of charge clusters in nuclear cluster reactions. 2003.
[40] D. Chicea. Electron clusters - possible deuterium fusion catalysers. *Journal of New Energy*, 2, 3 1997.
[41] Iwamura, Y. and Itoh,T. and Yamazaki,N. and Yonemura,H. and Fukutani, K. and Sekiba, D. Recent Advances in Deuterium Permeation Transmutation Experiments. *Journal of Condensed Matter Nuclear Science*, 10:76–99, Jan 2013.
[42] F. Celani, C. Lorenzetti, E. Purchi, S. Fiorilla, S. Cupellini, M. Nakamura, P. Cerreoni, P. Boccanera, R. Burri, E.F. Marano, A. Spallone, and G. Vassallo. Electromagnetic Excitation of Coaxially-Coiled Constantan Wires by High-Power, High-Voltage, Microsecond Pulses. *Journal of Condensed Matter Nuclear Science*, 36:408–435, 2022.
[43] F. Celani, C. Lorenzetti, G. Vassallo, E. Purchi, S. Fiorilla, S. Cupellini, M. Nakamura, P. Boccanera, R. Burri, B. Ortenzi, L. Notargiacomo, and A. Spallone. Steps to identify main parameters for AHE generation in sub-micrometric materials: measurements by isoperibolic and air-flow calorimetry. *Journal of Condensed Matter Nuclear Science*, 29:52–74, 08 2018.
[44] F. Righes, G. Vassallo, and G. Parchi. Conduction state transition induced by solitons in a graphene junction at room temperature. *Journal of Physics Communications*, 6(8):085005, aug 2022.
[45] K. J. van Vlaenderen. A generalisation of classical electrodynamics for the prediction of scalar field effects. *arXiv.physics/0305098*, 2003.
[46] J. F. Prins. *The Physics Delusion*. Sage Wise 66 (pty) Ltd, 07 2011.
[47] H.E. Puthoff and M.A. Piestrup. Charge confinement by Casimir forces, 2004.