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Origin of the Electric Charge and Its Two Signs

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Abstract

Here, we explore in depth the idea emerged in some of our studies on the origin of the signs (±) of the electric charge (e) of a particle, according to which these two signs ($\pm e$) are related to the two directions (clockwise (cl) and counterclockwise ($\underline{cl}$)) of rotation of the phase of the wave oscillation associated with the particle. We demonstrate that this is possible if one uses the IQuO-representation of a quantum oscillator of field structured by "sub-oscillators" with "semi-quanta". The consequences of this "new Physics" are multiple and allow us to represent the "internal" structure of the particles. Finally, the structure of the IQuO of a fermionic field and that of a bosonic field is shown, allowing us to represent the process of pair annihilation.

Keywords

Electric Charge, IQuO, Semi-Quantum, Sub-Oscillator, Phase Interaction, Fermion, Boson

1. Introduction

The phenomenology describing the electrical attraction and repulsion between certain particles is based on the conventional assignment of a tag ($\pm e$) to them as the origin of their dual behavior; this is equivalent to assigning a physical characteristic (e) called "*electric charge*" that originates (as acting characteristic) and "feels" a particular force carried by a mediating field, the Electromagnetic Field (EMF). In this article, we will delve into the origin of the two signs (±) of (e) and examine its physical nature. In the next article, currently under submission, we will explain why and how the photon determines attraction or repulsion between two charged particles, since the mechanism of these actions has not yet been covered in the literature. Our current investigation of the electromagnetic interaction process begins with an observation on the correlation existing in field theory between the phase (φ) of oscillations of the wave associated with a particle and its electric charge *e*. This correlation is already highlighted in the structure of the solutions to the wave equations Σ and its conjugate Σ_c, assigned to a particle. We highlight that the solution and its conjugate differ by a sign ± of the respective phases of the oscillations. Both the Klein-Gordon (K-G) equation Σ_{KG}, sect. 2.1, and the Dirac equation Σ_D, sect. 2.2, as is well known, present solutions with negative probability density and negative energy, which, as we will demonstrate, can be avoided if we consider "not separate" the system of the two equations (Σ, Σ_c). For the negative probability density (appearance devoid of physical meaning), the physics literature introduces a parameter (λ) with double-signed (±) that transforms the probability density into electric charge density if (λ) coincides with the electric charge ($\lambda = \pm e$). However, we note that the two equations, the K-G and Dirac equations, do not explicitly contain the electric charge ($\lambda = \pm e$). Treating negative energy solutions, the K-G equation, constructed by a two-component "spinor", section 2.1, and the Dirac equation with a four-component spinor, sect. 2.2, we highlight the presence of the double solution (positive $\Psi_{(+)}$ and negative $\Psi_{(-)}$) which however becomes a quadruple solution [($\Psi_{(+)}$, $\Psi_{(-)}$), (($\Psi_+)_c$, $(\Psi_-)_c$)] considering the conjugate functions and the physical system of the two equations (Σ, Σ_c); in this way, it is possible to assume that negative solutions in Σ-equation correspond to positive solutions in the conjugate equation (Σ_c), that is [$(\Psi_-)_c = (\Psi_+)_{(p\to -p)}$, $(\Psi_-) = (\Psi_+)_{c\,(p\to -p)}$]. Therefore, the negative solutions $\Psi_{(-)}$ disappear only if one considers as "complete" the system of the two equations [(Σ_{KG}, $(\Sigma_c)_{KG}$), (Σ_D, $(\Sigma_c)_D$)] and not one of the two single equations. Noting two different pairs of solutions, then it is possible to consider two different physical behaviors in particles described by wave equations: this pushes us to introduce, in sect. 3.1, a physical characteristic $\underline{\lambda}_\varepsilon$ which distinguishes these pairs. Showing that the conjugate solutions with positive energies (ε) differ from non-conjugate ones for the direction of the phase rotation $\boldsymbol{r}_\varphi$, we can correlate the physical characteristic $\underline{\lambda}_\varepsilon$ just with $\boldsymbol{r}_\varphi$. In this way, a particle at "*apparent*" negative energy is detected as a particle with positive energy but with the opposite sign (±) of the direction of the phase rotation $\boldsymbol{r}_\varphi$, or of the parameter $\underline{\lambda}_\varepsilon$, relative to particles with positive energies. The parameter $\underline{\lambda}_\varepsilon$ with double-signed (±) is identified by Dirac precisely as the electric charge ($\pm e$). Thanks to the double sign (±), Dirac hypothesizes the positron and therefore antimatter, however, He is unable to eliminate the concept of negative energy as solutions to the "motion" equations; then, He resorts to a background present in the universe, where negative energies are "gaps" of particles with positive energy, which in the literature is referred to as the "*Dirac Sea*", section 2.2. Instead, we show that it is possible to avoid resorting to the "*Dirac Sea*" if we establish a close correlation between the direction $\boldsymbol{r}_\varphi$ of phase rotation and the electric charge $\pm e$; indeed, we could establish that the two characteristics "coincide" if a photon can read the direction of phase rotation of a particle. In this case, we could talk about "*physical equivalence*" between the two directions of rotation [(clockwise (*cl*) – counterclockwise ($\underline{cl}$))] associated with the phase of an oscillation [($cl \Leftrightarrow -\varphi$), ($\underline{cl} \Leftrightarrow +\varphi$)], which can so be observed, and two signs ± of the electric charge *e*. This would appear to contradict experience and the classical and quantum theory of oscillations, in which phase rotation is not considered a physical observable at all. We point out, in this study (as, in fact, has also been noted in other previous studies [1] [2]) that if into an "*isolated*" oscillator (classical and quantum) it is not possible to observe the two directions of phase rotation, instead into a "*field*" quantum oscillator may be possible to detect the direction $\boldsymbol{r}_{\varphi}$. We recall the physical equivalence between a field and a system of coupled oscillators, in which case it is demonstrated that a single field oscillator can be considered as a forced oscillator and therefore no longer isolated, sect. 3.2, when it is crossed by a quantum of the field. From this new perspective derives an unpublished representation of the quantum oscillator indicated as **I**ntrinsic **Qu**antum **O**scillator of field (defined by the acronym **IQuO** [1] [2]) in which a structure composed of "***sub-oscillators***" crossed by "***semi-quanta***" (half-quanta) is highlighted, sect. 3.3. This unexpected aspect determines a 2-dimensional representation, sect. 3.2, of a quantum oscillator by creation and annihilation operators (a, a^{+}) at double-components in which it is possible to identify a degree of freedom "*internal*" (as Dirac hypothesized in its text "*The Principles of Quantum Mechanics*") given just by the direction of phase rotation ($\boldsymbol{r}$) in a field oscillator; this degree of freedom can allow a photon to distinguish into an IQuO (that of the field of an electron) these two directions and therefore detect the electric charge. What we show in this article (as also it has been shown in previous studies) identifies a new paradigm, the "***IQuO hypothesis***", for describing particles (the new physics?) and interactions with notable consequences on our physical knowledge: one of the first notable consequences is the distinction of the IQuO into two different representations that identify the oscillators of the Fermion and Boson fields, sect. 3.4 and 3.5. This representation allows us to describe the process of creation and annihilation of pairs at a fundamental level, section 3.6. In this last section, by the IQuO idea, we will see, in a new way, that the action of pair annihilation, realized by a coupling between two representative IQuO of two fermion fields, will take place in two phases: a first phase (not-dynamic) of reciprocal phase shifts between the two fields [3], implemented through exchanges of energy semi-quanta *sq* (half-quanta) between IQuO, which is followed by a second phase of exchanges of "whole" quanta of energy that determines the dynamic action of annihilation of two fermions. Therefore, the "*IQuO hypothesis*" can be seen as a new descriptive paradigm in physics because it can explain in depth the origin of electric charge and its two signs, and the fundamental aspects of electromagnetic interactions. The way in which a photon, after reading the rotation directions of the oscillation phase of the wave functions of two particles, determines and regulates the attractive or repulsive action between the particles is discussed in the second part of this study, which will undergo a submission process in JHEPGC.

2. Equations of Klein-Gordon and Dirac

2.1. Dual Wave Equation of the Klein Gordon

In Relativity and Quantum Mechanics (QM), one has for a free massive particle:

$$\left\{\left(E^2=p^2c^2+m^2c^4\right),\ \left[\left(E\to\tilde{H}_t=i\frac{\partial}{\partial t}\right),\left(p\to\tilde{p}=-i\frac{\partial}{\partial x}\right)\right]_{QM}\right\} \tag{1}$$

where E(energy) ≡ H and H is the Hamiltonian [4]. Applying to wave function Ψ, one obtains the Klein-Gordon equation (Σ_{KG}):

$$\left(\frac{\hbar^2}{c^2}\right)\frac{\partial^2\Psi(x_i)}{\partial t^2}=\left[\hbar^2\nabla^2-m^2c^2\right]\Psi(x_i) \tag{2}$$

The covariant form of Σ_{KG} is:

$$\begin{gathered}\left[\sum\nolimits_i\tilde{p}_i^2+m^2c^2\right]\Psi(x_i)=0\\ \varepsilon=\pm E=\pm c\sqrt{\boldsymbol{p}^2+m^2c^2}\end{gathered} \tag{3}$$

With ε the energy of a particle. Besides, it is:

$$\begin{gathered}\frac{\partial}{\partial x_\mu}\left(J_\mu\right)=\left(div\,\boldsymbol{J}+\frac{\partial}{\partial t}\rho\right)=0\\ \left\{\boldsymbol{J}=\left(\frac{\hbar}{i2m}\right)\left[\Psi^*\nabla\Psi-\Psi\nabla\Psi^*\right],\ \rho=\left(\frac{i\hbar}{2mc^2}\right)\left[\Psi^*\frac{\partial}{\partial t}\Psi-\Psi\frac{\partial}{\partial t}\Psi^*\right]\right\}\end{gathered} \tag{4}$$

In the QM theory [4], it is possible doubles the solution Ψ of Equation (2) in two components: Ψ ≡ (φ, χ). A wave function with two components is called *Spinor*. Exactly, one sets:

$$\begin{gathered}\Psi=(\phi+\chi)\\ i\hbar\left(\frac{\partial\Psi}{\partial t}\right)=mc^2(\phi-\chi)\end{gathered} \tag{5}$$

By Equation (5), the Σ_{KG} can be written as:

$$\left\{\begin{aligned}i\hbar\frac{\partial\phi}{\partial t}&=-\left(\frac{\hbar^2}{2m}\right)\nabla^2(\phi+\chi)+mc^2\phi\\ i\hbar\frac{\partial\chi}{\partial t}&=\left(\frac{\hbar^2}{2m}\right)\nabla^2(\phi+\chi)-mc^2\chi\end{aligned}\right\}\Leftrightarrow\left\{\left(i\hbar\frac{\partial}{\partial t}-H_f\right)\hat{\Psi}=0\right\} \tag{6}$$

The (2 × 2) matrices operating in Ψ-spinor are combinations of the Pauli matrices:

$$\Psi=\begin{pmatrix}\phi\\ \chi\end{pmatrix}\to\sigma_1=\begin{pmatrix}0&1\\1&0\end{pmatrix},\ \sigma_2=\begin{pmatrix}0&-i\\i&0\end{pmatrix},\ \sigma_3=\begin{pmatrix}1&0\\0&-1\end{pmatrix},\ \sigma_0=\begin{pmatrix}1&0\\0&1\end{pmatrix} \tag{7}$$

By making H_f explicit, Equation (6), we obtain the "***dual equation***" of Σ_{KG} by of Pauli matrices:

$$\left\{\left(\sigma_0\left(i\frac{\partial}{\partial t}\right)-(\sigma_3+i\sigma_2)\left(\frac{\tilde{p}^2}{2m}\right)+mc^2\sigma_3\right)\hat{\Psi}=0\right\} \tag{8}$$

With solution of plate wave given by:

$$\Psi=\left(\sqrt{V}\right)\begin{pmatrix}\phi_0\\ \chi_0\end{pmatrix}\exp\left[\frac{i}{\hbar}(\boldsymbol{p}\cdot\boldsymbol{x}-\varepsilon t)\right] \tag{9}$$

From continuity equation, Equation (4), derives the normalization of function:

$$\int \rho \mathrm{d}t = \int \Psi^{+}\sigma_3 \Psi \mathrm{d}t = \int \left(\varphi^{*}\varphi - \chi^{*}\chi\right)\mathrm{d}t = \pm 1 \tag{10}$$

Here, there is the first problem of Σ_{KG} given by ρ *density* with negative values; to avoid negative values, we can introduce a $\underline{\lambda}_\rho$ -parameter in ρ, which becomes $\rho_\lambda = \underline{\lambda}_\rho \rho$ such that is:

$$\left\{\left[\left(\underline{\lambda}_\rho = +1\right) \Leftrightarrow \left(\rho_\lambda\right)_{+} = \underline{\lambda}_\rho \left(\varphi^{*}\varphi - \chi^{*}\chi\right)_{>0} = +1\right]\right\} \tag{11a}$$

$$\left\{\left[\left(\underline{\lambda}_\rho = -1\right) \Leftrightarrow \left(\rho_\lambda\right)_{-} = \underline{\lambda}_\rho \left(\varphi^{*}\varphi - \chi^{*}\chi\right)_{<0} = +1\right]\right\} \tag{11b}$$

Note that the ρ_λ values are always positive. In literature, the $\underline{\lambda}_\rho$ parameter is given as electric charge e and $\rho_e = \underline{\lambda}_\rho \rho$ becomes the "*electric charge density*". This solution ($\underline{\lambda} \Leftrightarrow \pm e$) is only phenomenology because does not investigate the origin of the electric charge (e) and its signs (±). The second problem of Σ_{KG} is given by solutions of the Equation (8) with energy negative, see the matrix σ_3, which has eigenvalues (±1) and, thus, it is: [$\pm mc^2 \to \sigma_3(mc^2)$]. Replacing the solution (9) in Equation (8), we obtain a system of two equations:

$$\begin{Bmatrix} \left(\varepsilon - mc^2\right)\phi_0 = \left(\dfrac{p^2}{2m}\right)\left(\phi_0 + \chi_0\right) \\ \left(\varepsilon + mc^2\right)\chi_0 = -\left(\dfrac{p^2}{2m}\right)\left(\phi_0 + \chi_0\right) \end{Bmatrix}$$

where ($\varepsilon = \pm E_p$); the solutions are:

$$\phi_{0(+)} = \frac{E_p - mc^2}{2\sqrt{mc^2 E_p}} = \chi_{0(-)},\ \chi_{0(+)} = -\frac{E_p - mc^2}{2\sqrt{mc^2 E_p}} = \phi_{0(-)} \tag{12}$$

where the subscript (+) points out the solution with positive energies ($\varepsilon = +E_p$), while the subscript (−) points out the solution with negative energies ($\varepsilon = -E_p$). One obtains two conditions of normalization:

$$\left[\phi_{0(+)}\phi_{0(+)} - \chi_{0(+)}\chi_{0(+)} = 1\right]_{(\varepsilon = +E_p)},\ \left[\phi_{0(-)}\phi_{0(-)} - \chi_{0(-)}\chi_{0(-)} = -1\right]_{(\varepsilon = -E_p)} \tag{13}$$

Here, we find again the negative value of the ρ density. Therefore, the problems of the presence of negative energy and negative density are correlated. The solutions of the dual equation, Equation (8), are:

$$\Psi_{+} = \begin{pmatrix} \phi \\ \chi \end{pmatrix}_{(+)} = \left(\sqrt{V}\right)\begin{pmatrix} \phi_{0(+)} \exp\left[\dfrac{i}{\hbar}\left(\boldsymbol{p}\cdot\boldsymbol{x} - E_p t\right)\right] \\ \chi_{0(+)} \exp\left[\dfrac{i}{\hbar}\left(\boldsymbol{p}\cdot\boldsymbol{x} - E_p t\right)\right] \end{pmatrix} \tag{14a}$$

$$\Psi_{-} = \begin{pmatrix} \phi \\ \chi \end{pmatrix}_{(-)} = \left(\sqrt{V}\right)\begin{pmatrix} \phi_{0(-)} \exp\left[\dfrac{i}{\hbar}\left(\boldsymbol{p}\cdot\boldsymbol{x} + E_p t\right)\right] \\ \chi_{0(-)} \exp\left[\dfrac{i}{\hbar}\left(\boldsymbol{p}\cdot\boldsymbol{x} + E_p t\right)\right] \end{pmatrix} \tag{14b}$$

where (Ψ_{-}) are solutions of Σ_{KG} associated to the negative values of energy. If we point out by Σ_{KG}^{*} the conjugated equation of Σ_{KG}, to the conjugated solution Ψ^* of Σ_{KG}^{*}, one can associate the "conjugated" wave functions $\Psi_c = (\sigma_1\Psi^*)$, which could describe the "π_c *conjugated particles*" to those of Σ_{KG}. Recall the π-pion where π^- is the conjugated particle of π^+. We consider a solution π_c with positive energy; by Equation (7), Equation (12) and Equation (14) one obtains:

$$
\begin{aligned}
\left(\Psi_+\right)_c &= \sigma_1\Psi_+^* = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\begin{pmatrix} \phi_+^* \\ \chi_+^* \end{pmatrix} = \begin{pmatrix} \chi_+^* \\ \phi_+^* \end{pmatrix} = \begin{pmatrix} \chi_{0(+)}\exp\left[\frac{-i}{\hbar}\left(\boldsymbol{p}\cdot\boldsymbol{x}-E_p t\right)\right] \\ \phi_{0(+)}\exp\left[\frac{-i}{\hbar}\left(\boldsymbol{p}\cdot\boldsymbol{x}-E_p t\right)\right] \end{pmatrix} \\
&= \begin{pmatrix} \phi_{0(-)}\exp\left[\frac{-i}{\hbar}\left(\boldsymbol{p}\cdot\boldsymbol{x}-E_p t\right)\right] \\ \chi_{0(-)}\exp\left[\frac{-i}{\hbar}\left(\boldsymbol{p}\cdot\boldsymbol{x}-E_p t\right)\right] \end{pmatrix} = \begin{pmatrix} \phi_{0(-)}\exp\left[\frac{i}{\hbar}\left(-\boldsymbol{p}\cdot\boldsymbol{x}+E_p t\right)\right] \\ \chi_{0(-)}\exp\left[\frac{i}{\hbar}\left(-\boldsymbol{p}\cdot\boldsymbol{x}+E_p t\right)\right] \end{pmatrix} \\
&= \begin{pmatrix} \phi_{0(-)}\exp\left[\frac{i}{\hbar}\left(\boldsymbol{p}\cdot\boldsymbol{x}+E_p t\right)\right] \\ \chi_{0(-)}\exp\left[\frac{i}{\hbar}\left(\boldsymbol{p}\cdot\boldsymbol{x}+E_p t\right)\right] \end{pmatrix}_{(\boldsymbol{p}\to-\boldsymbol{p})} = \begin{pmatrix} \phi_- \\ \chi_- \end{pmatrix}_{(\boldsymbol{p}\to-\boldsymbol{p})} = \left(\Psi_-\right)_{(\boldsymbol{p}\to-\boldsymbol{p})}
\end{aligned} \tag{15}
$$

where we have omitted the normalization volume V and applied the transformation $(\boldsymbol{p}\to-\boldsymbol{p})$. Note the correlation $(\Psi_+)_c = (\Psi_-)_{(\boldsymbol{p}\to-\boldsymbol{p})}$. It follows that the negative solution (Ψ_-) of Σ_{KG} can describe a conjugate particle π_c with positive energy $(\Psi_+)_c$ and moment $\boldsymbol{p}$ (opposite to that $-\boldsymbol{p}$ of π particle of Σ_{KG}) only if we give physical meaning to the conjugate equation Σ_{KG}^{*}. Remember the existence of two pions (π^+, π^-) in which one is conjugate to the other. In this way, it is also: $(\Psi_-) = [(\Psi_+)_c]_{(\boldsymbol{p}\to-\boldsymbol{p})}$. In fact, we can have:

$$
\begin{aligned}
\left(\Psi_-\right)_{(\boldsymbol{p}\to-\boldsymbol{p})} &= \begin{pmatrix} \phi_- \\ \chi_- \end{pmatrix} = \begin{pmatrix} \phi_{0(-)}\exp\left[\frac{i}{\hbar}\left(\boldsymbol{p}\cdot\boldsymbol{x}+E_p t\right)\right] \\ \chi_{0(-)}\exp\left[\frac{i}{\hbar}\left(\boldsymbol{p}\cdot\boldsymbol{x}+E_p t\right)\right] \end{pmatrix}_{(\boldsymbol{p}\to-\boldsymbol{p})} \\
&= \begin{pmatrix} \chi_{0(+)}\exp\left[\frac{i}{\hbar}\left(-\boldsymbol{p}\cdot\boldsymbol{x}+E_p t\right)\right] \\ \phi_{0(+)}\exp\left[\frac{i}{\hbar}\left(-\boldsymbol{p}\cdot\boldsymbol{x}+E_p t\right)\right] \end{pmatrix} = \begin{pmatrix} \chi_{0(+)}\exp\left[\frac{-i}{\hbar}\left(\boldsymbol{p}\cdot\boldsymbol{x}-E_p t\right)\right] \\ \phi_{0(+)}\exp\left[\frac{-i}{\hbar}\left(\boldsymbol{p}\cdot\boldsymbol{x}-E_p t\right)\right] \end{pmatrix} \\
&= \begin{pmatrix} \chi_{0(+)}\exp\left[\frac{i}{\hbar}\left(\boldsymbol{p}\cdot\boldsymbol{x}-E_p t\right)\right] \\ \phi_{0(+)}\exp\left[\frac{i}{\hbar}\left(\boldsymbol{p}\cdot\boldsymbol{x}-E_p t\right)\right] \end{pmatrix}^* \\
&= \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}\begin{pmatrix} \phi_{0(+)}\exp\left[\frac{i}{\hbar}\left(\boldsymbol{p}\cdot\boldsymbol{x}-E_p t\right)\right] \\ \chi_{0(+)}\exp\left[\frac{i}{\hbar}\left(\boldsymbol{p}\cdot\boldsymbol{x}-E_p t\right)\right] \end{pmatrix}^* \\
&= \sigma_1\left(\Psi_+^*\right) = \left(\Psi_+\right)_c
\end{aligned} \tag{16}
$$

So, we highlight that the negative solution $\Psi_{(-)}$ with moment ($\boldsymbol{p}$) are coincident with $\Psi_{+(c)}$ (with positive energy) of $(\Sigma_c)_{KG}$ but with moment ($-\boldsymbol{p}$). We also have that: $(\Psi_-)_c = (\Psi_+)_{(p\to -p)}$. Therefore, the negative solutions $\Psi_{(-)}$ disappear only if one considers as "complete" the system of the two equations (Σ_{KG}, $(\Sigma_c)_{KG}$) and not one of the two single equations. We could expect that the two equations ($(\Sigma_c)_{KG}$, $(\Sigma)_{KG}$) describe two identical particles except for a "*physical aspect*" linked to the conjugation operation and transformation ($\boldsymbol{p} \to -\boldsymbol{p}$). This *physical aspect* must be a physical quantity or descriptive physical characteristic. Remember the operation of conjugation changes the sign (±) of the exponential part of a wave function, and thus of E_p in Equation (12), therefore, the conjugate particles are different from the particles "ordinary" (omitting the moving in direction opposed) in a particular physical characteristic $\underline{\lambda}_\varepsilon$ that changes of sign (±) in the conjugate solutions. Recall the parameter $\underline{\lambda}_\rho$ associated with density ρ, see the Equation (11), which has two "eigenvalues" $\left[\left(\underline{\lambda}'_\rho = \pm 1\right)\right]$: we suspect $\underline{\lambda}_\rho \equiv \underline{\lambda}_\varepsilon$ because the energy and density are correlated, see the Equation (13). We point out by $\left[\left(\underline{\lambda}'_\varepsilon = \pm 1\right)\right]$ the sign (±) of two values of $\underline{\lambda}_\varepsilon$; then, we admit the following correlations:

$$\left\{\left[\left(\underline{\lambda}'_\varepsilon = +1\right) \Leftrightarrow \left(\varepsilon_+ = +E_p\right)\right] \to \left[\left(\underline{\lambda}'_\varepsilon\right)\varepsilon_+ = +E_p > 0\right]\right\} \tag{17a}$$

$$\left\{\left[\left(\underline{\lambda}'_\varepsilon = -1\right) \Leftrightarrow \left(\varepsilon_- = -E_p\right)\right] \to \left[\left(\underline{\lambda}'_\varepsilon\right)\varepsilon_- = -E_p > 0\right]\right\} \tag{17b}$$

In this way, see the Equation (17), a solution of the Equation (8), describing a particle at "*apparent*" negative energy ($\varepsilon = -E_p$), is detected as a particle with positive energy $\left[\left(\underline{\lambda}'_\varepsilon\right)\varepsilon_- = +E_p > 0\right]$ but with the sign (−) of the parameter $\underline{\lambda}_\varepsilon$, that is $\left(\underline{\lambda}'_\varepsilon = -1\right)$. To have this possibility, and so to eliminate the negative energies, it would need to redefine the energy in such a way that a possible negative value of this is attributable to the negative value of the parameter $\underline{\lambda}_\varepsilon$, that is $\left(\underline{\lambda}'_\varepsilon = -1\right)$. This aspect can push us toward an alternative road to that travelled by Dirac to resolve the presence of the negative solutions of his equation. Then, we will state that the two equations (Σ_{KG}, Σ^*_{KG}) in "*not separate*" form constitute a complete physical system if the negative solutions $\Psi_{(-)}$ of Σ_{KG} (electrons with negative energy) coincide (that is physically are not distinguishable) with the positive solutions $\Psi^*_{(+)}$ of Σ^* (positrons with positive energy), while those negative $\Psi^*_{(-)}$ of Σ^* (that is positrons with negative energy) coincide with the positive solutions $\Psi_{(+)}$ of Σ (that is electrons with positive energy). This would seem a "contradiction" because there would be particles with negative energy detected as particles with positive energy: this contradiction can be eliminated by the parameter $\underline{\lambda}_\varepsilon$ that helps us to distinguish the negative solution from that positive and to have apparent negative solutions "*without negative energy*" thanks to the conjugation of the system of equations (Σ_{KG}, Σ^*_{KG}). But this is possible "*only and only if*" the negative value of energy is attributable to the negative value of the parameter $\underline{\lambda}_\varepsilon$, $\left(\underline{\lambda}'_\varepsilon = -1\right)$, see the Equation (17). We ask then us how this parameter transforms the energy solutions negative in energy solutions positive.

2.2. The Negative Solutions of the Dirac Equation

Also, in the Dirac equation (Σ_D) is present the α_β matrix with the same form of the Pauli matrix σ_3, which is responsible of presence of the negative solutions [5]:

$$\left\{\left(p_0-(\boldsymbol{\alpha},\boldsymbol{p})-\alpha_\beta mc\right)\hat{\Psi}=0\right\} \tag{18}$$

where (α_i, α_β) are matrices (4x4) built by the Pauli's matrices (σ, 0, 1):

$$\begin{aligned}&\hat{\alpha}_x=\begin{pmatrix}\hat{0} & \hat{\sigma}_x\\ \hat{\sigma}_x & \hat{0}\end{pmatrix},\ \hat{\alpha}_y=\begin{pmatrix}\hat{0} & \hat{\sigma}_y\\ \hat{\sigma}_y & \hat{0}\end{pmatrix},\ \hat{\alpha}_z=\begin{pmatrix}\hat{0} & \hat{\sigma}_z\\ \hat{\sigma}_z & \hat{0}\end{pmatrix},\\ &\hat{\alpha}_0=\begin{pmatrix}\hat{1} & \hat{0}\\ \hat{0} & \hat{1}\end{pmatrix},\ \hat{\alpha}_\beta=\begin{pmatrix}\hat{1} & \hat{0}\\ \hat{0} & -\hat{1}\end{pmatrix}\end{aligned} \tag{19}$$

In fact, Dirac wrote "… *our wave equation has a double number of solutions* $(\Psi_-,\Psi_+)_\varepsilon$ … *in correspondence with them there are half of states with negative energy… these cannot be denied but cannot also be accepted*". After he adds: "*The solutions corresponding to negative values of* p_0 *don't correspond to the observable motions of the electron*". This would mean that the research of a solution of the negative energy problem is not in the electron motion but in an intrinsic characteristic of it, which is connected to the mathematical conjugation of two solutions (Ψ_-, Ψ_+) of Σ_D, as it happens in two equations (Σ_{KG}, Σ^*_{KG}), see in sect. 2.1. The term conjugated refers to the conjugate wave functions, solutions of the Dirac equation (Σ_D) and its conjugate (Σ^*_D). To accept the solutions (Ψ_D, Ψ^*_D) as "reals", an external parameter is admitted, historically interpreted as the electric charge e into the physical system (e, $\boldsymbol{A}$), with ($\boldsymbol{A}$) the 4-vector of the Electromagnetic Field (EMF). In fact, Dirac wrote "… *the solution with negative energy* (*of* $\Sigma(e,\boldsymbol{A})_D$) *is the conjugate to a solution with positive energy of* $\Sigma^*(e,\boldsymbol{A})_D$ *correspondent to an electron with charge* $+e$". For symmetry is also true that "*The conjugate images of the negative solutions of* $\Sigma^*(e,\boldsymbol{A})_D$ *are in correspondence to particles with positive energy and electric charge* $(-e)$, *that is electrons*". Here, the terms [$\Sigma(e,\boldsymbol{A})_D$, $\Sigma^*(e,\boldsymbol{A})_D$] are the two Dirac equations of an electron submitted to the action of an EMF (A):

$$\begin{aligned}&\left\{\left(p_0+\frac{e}{c}A_0\right)-\left[\alpha_1\left(p_1+\frac{e}{c}A_1\right)-\alpha_2\left(p_2+\frac{e}{c}A_2\right)-\alpha_3\left(p_3+\frac{e}{c}A_3\right)\right]-\alpha_\beta mc\right\}\Psi=0\\ &\left\{\left(-p_0+\frac{e}{c}A_0\right)-\left[\alpha_1\left(-p_1+\frac{e}{c}A_1\right)-\alpha_2\left(-p_2+\frac{e}{c}A_2\right)-\alpha_3\left(-p_3+\frac{e}{c}A_3\right)\right]+\alpha_\beta mc\right\}\Psi^*\\ &=0\end{aligned} \tag{20}$$

Note that if Σ_D has physical meaning, then also Σ^*_D must have a physical meaning; it follows that the Ψ^* describes a real particle with positive energy and electric charge ($+e$), that is the positron. We note that in Dirac, unlike the KG equation, the EMF appears correlated to solutions (Ψ_-, Ψ_+) and electric charge ($\pm e$). Recall the parameter $\underline{\lambda}$ in sect. 2.1 to the Equation (17), which allows us to treat the negative solution $\Psi_{(-)}$ connected to conjugate $\Psi_{+(c)}$, see the Equation (16), as a particle with positive energy. Therefore, we need to have two equations (Σ_D,

Σ_D^*) for describe the physics symmetry matter-antimatter: ***an individual Dirac equation represents a physical system, which is incomplete.*** This aspect elicited perplexity in Dirac: "*We cannot affirm that solutions* $(\Psi_D)_-$ *with negative energy represent positrons, because this would make the dynamic relations wrong* (in presence of an EMF A_μ)… *therefore, it is not true that a positron has a negative kinetic energy*". This perplexity pushed Dirac to introduce a background into an universe (the "*Sea of Dirac*") where "*almost all the states to negative energy are everyone busies by electrons* (the negative solutions of Σ_D), *while the no busies remainders* ($((\Psi_D)_-)_{empties}$, (said *gaps*), *will appear of positive energy… because to fill them one needs to add an electron* (to negative energy $(\Psi_D)_-$)… *we will suppose that* (*the gaps*) *are positrons…*".

Even if this road leads to the hypothesis of the quantum vacuum with its virtual processes of pair creation and annihilation, the interpretation of the positron as an empty negative gap leaves us perplexed and would not result, to my knowledge, a decisive road of the problem of having a negative energy in the theory of particles. We notice that the negative energy inevitably conducts to "paradoxes" (if not contradictions) what "*negative mass*" [6], "*antigravity*" and other [7], until reaching the procedure of "*rinormalizzation*" of the mass [8] [9], postulating a negative inertial mass to infinite value that would balance an infinite electromagnetic mass (positive), to give a finite physical mass, ($m_{in}(-\infty) + m_{em}(+\infty) = m_{fis}$): clearly, this aspect is not correct mathematically. Note in ref. [10][11], instead, one shows "*the mass as* ***additional coupling*** *between oscillators of a massless scalar field*": this aspect leads us to argue that "*mass can only be an observable with always positive and never negative values, because the* "*proper*" *mass* ($\boldsymbol{m_0}$) *is the expression of the proper frequency* $\boldsymbol{\omega_0}$ *of oscillations* ($\omega_0 > 0$ *always*) *connected to the additional coupling:* $(\boldsymbol{m_0 = \hbar\omega_0/c^2})$. If we want to avoid of follows the path of the "*Dirac sea*", it is necessary to reconsider the system of the two equations $\Sigma \equiv (\Sigma_D, \Sigma_D^*)$, attempting to complete the Dirac's theory through a representation in which the solutions, positive $(\boldsymbol{\Psi_+})$ and "apparently" negative $(\boldsymbol{\Psi_-})$, are different aspects of an unique physical system that don't admits negative energy. This means that the particles of Σ_D and the particles conjugated of Σ_D^* have to be two different aspects of a same particle with positive energy, individualized by two different "values" of a "***label***" physical greatness, in which one of these two values makes as "apparent" the negative energy of the solutions $(\boldsymbol{\Psi_-})$ and turns it instead into a "positive" solution. We will show that the parameter $\underline{\lambda}_\varepsilon$ is just the electric charge (e), but this, in turn, for it not to be an external label, must be connected to an internal characteristic (r) to a "particle-system", which allows of phagocyte the negative solutions, that is: ($\underline{\lambda} \Leftrightarrow e \Leftrightarrow r$). The completeness is reached thanks to the parameter ($\underline{\lambda} \Leftrightarrow r$), which turns the negative solutions into positive solutions.

3. The Origin of Electric Charge

3.1. The Phase of the Wave

Remember, in sect. 2.1 and in Equation (17), that the negative value of energy is attributable to the negative value of the parameter $\underline{\lambda}_\varepsilon$, $(\underline{\lambda}'_\varepsilon = -1)$. We can add that the passage to two "*eigenvalues*" $\left[(\underline{\lambda}'_\varepsilon = -1),(\underline{\lambda}''_\varepsilon = +1)\right]$ is connected to the conjugation operation of a wave function, see the relation between the two solutions (Ψ_+, Ψ_-) and $((\Psi_+)_c, (\Psi_-)_c)$ in the Equation (15) and Equation (16); ***it follows then that the parameter*** $\underline{\lambda}_\varepsilon$ ***mathematically concerns the phase*** φ ***of the exponential function related to the wave function and exactly the two signs*** **(±)** ***of the phase*** φ, that is $[(\pm\varphi) \Leftrightarrow (\pm\underline{\lambda})]$. Note that the sign (±) can be correlated to the directions, clockwise and counterclockwise, of phase rotation. Then, we can represent these two directions by a parameter with two values, which could coincide with the parameter $\underline{\lambda}_\varepsilon$. Recall in QM the following equations:

$$\left[\left(p = \hbar k = \hbar\omega_k\right),\left(\varepsilon_k = \hbar\omega_k\right),\left(\varepsilon_0 = m_0 c^2 = \hbar\omega_0\right)\right] \quad (21)$$

And the relativistic relation of energy:

$$\left\{E^2 = m^2c^4 + p^2c^2 \Leftrightarrow \omega^2 = \omega_0^2 + k^2c^2\right\} \quad (22)$$

The plain wave solution of KG equation is:

$$\Psi_\lambda = A\exp\left[\frac{i}{\hbar}\left(\boldsymbol{p}\cdot\boldsymbol{x} - \varepsilon t\right)\right] = A\exp\left[\frac{i}{\hbar}\left(\boldsymbol{p}\cdot\boldsymbol{x} - E_p t\right)\right] \equiv A\exp\left[i\left(\boldsymbol{k}\cdot\boldsymbol{x} - \omega_k t\right)\right] \quad (23)$$

where $(\varepsilon = \pm E_p)$; here, one connects the energy $\pm E_p$ to the angular frequency ω, see the Equation (21). Then, one can introduce a parameter λ in the exponent of wave solutions of KG equation, exactly in the wave phase [4]:

$$\Psi_\lambda = A\exp\left[\frac{i}{\hbar}\left(\boldsymbol{p}\cdot\boldsymbol{x} - \lambda E_p t\right)\right] \equiv A\exp\left[i\left(\boldsymbol{k}\cdot\boldsymbol{x} - \lambda\omega_k t\right)\right] \quad (24)$$

By $\varepsilon = \lambda E_p$, we will have:

$$\left\{\left[\varepsilon = \pm E_p = \pm c\sqrt{\boldsymbol{p}^2 + m^2c^2}\right],\left[\lambda\frac{\varepsilon}{E_p}\right],\left[\begin{matrix}\lambda = +1 \Leftrightarrow \varepsilon > 0 \Leftrightarrow \omega > 0\\ \lambda = -1 \Leftrightarrow \varepsilon < 0 \Leftrightarrow \omega < 0\end{matrix}\right]\right\} \quad (25)$$

Note if $\lambda = -1$ one has negative energy but also negative frequency. This parameter is in relation to $(\underline{\lambda}_\varepsilon \Leftrightarrow \underline{\lambda}_\rho)$; recalling Equation (11) and Equation (17), with $[(\underline{\lambda}_\varepsilon \equiv \underline{\lambda}_\rho) = \underline{\lambda} = \lambda e)]$, then we'll have:

$$\left\{\left[\text{for}\left(\lambda = +1\right) \Leftrightarrow \left(\rho\left(\underline{\lambda}\right) > 0, \varepsilon > 0, \omega > 0, \underline{\lambda} = +e\right)\right]\right\} \quad (26a)$$

$$\left\{\left[\text{for}\left(\lambda = -1\right) \Leftrightarrow \left(\rho\left(\underline{\lambda}\right) > 0, \varepsilon < 0, \omega < 0, \underline{\lambda} = -e\right)\right]\right\} \quad (26b)$$

We ask ourselves because the parameter e is just the electric charge, as in literature. Let's not forget that the phase transformations $(\Delta\varphi)$ on the field oscillations are connected to the gauge invariance of interactions. Let us recall, in fact, the generator g of the transformation $U(\Delta\varphi) = \exp(ig\Delta\varphi)$ to which a constant variable Q is connected. As is well known, Q is the electric charge $(\pm e)$, associated with the transformations on the phase φ. By relation $(\varepsilon_k = h\omega_k)$, we could connect $\underline{\lambda}$ to the sign ± of the ω frequency as well as the negative values of energy; ***it follows that we cannot speak anymore of negative values of energy but of negative values of frequency.*** So, the problem of negative solutions moves toward the presence of negative values of the frequency ω associated with the phase φ of the oscillation, where it is ($\varphi = \omega t$). As seen in Equation (26), if one detects the sign ± of the electric charge ($\pm e$), it is as if one detects the sign (±) of the parameter λ associated with the conjugation of the wave function, that is, the sign (±) associated with the phase φ of oscillation of the wave. In an undulatory way, a physical observer ($\boldsymbol{O}_\gamma$) which "observes" a particle would read negative values of the energy (negative solutions) as negative values of the ω angular frequency and, thus, a negative value of the parameter $\underline{\lambda}$, that is $\underline{\lambda} = -e$. It also appears clear that the solutions with positive energy ($\varepsilon > 0$), that is, with positive frequency ($\omega > 0$), will be described by a parameter $\underline{\lambda} = +e$. In conclusion, the wave equations of KG and Dirac would describe particles characterized by the two values (($\pm e$)) of the parameter $\underline{\lambda}$, associated with two values of the frequency ($\pm\omega$) and phase ($\pm\varphi$). Our physical observer ($\boldsymbol{O}_\gamma$) it so must have the ability to detect the negative values and positive values of the angular frequency (that is, the energy) and to distinguish the positive signs ($\omega > 0$) from those negative ($\omega < 0$). From the relation $\varphi(t) = \varphi(t_0) \pm \omega t$, one infers that a negative frequency ($\omega < 0$) corresponds to a phase rotation opposite to that associated with the positive frequency ($\omega > 0$). For mathematical convention, we can associate the negative frequency with a clockwise rotation (cl) of the phase, while the positive frequency with an anticlockwise rotation ($\underline{cl}$) of the phase. Therefore, an observer O_γ could see the negative values of energy or negative frequencies of oscillations as a clockwise rotation of phase. Having set ($\underline{\lambda} = \lambda e$), the physical parameter $\underline{\lambda}$ would then have two "eigenvalues":

[($\underline{\lambda}' = +e$, with ($\lambda = +1$), counterclockwise rotation direction ($\underline{cl}$)]

[($\underline{\lambda}' = -e$, with ($\lambda = -1$), clockwise rotation direction (cl)]

In this context, recalling the phenomenology of particles, we could then say, regarding the Matter-Antimatter theme, that it is described, in a complete manner, by the Dirac and KG equations ($\boldsymbol{\Sigma}$) and by the conjugate equations ($\boldsymbol{\Sigma}^*$), where the positive-energy solutions of $\boldsymbol{\Sigma}$, that is $(\boldsymbol{\Psi}_{+\varepsilon})_{\Sigma}$,, describe electrons with electric charge ($-e$) and clockwise rotation (cl) of the $\boldsymbol{\varphi}$, phase, while the negative-energy solutions $(\boldsymbol{\Psi}_{-\varepsilon})_{\Sigma}$ correspond to positive-energy solutions $(\boldsymbol{\Psi}_{+\varepsilon})_{\Sigma*}$ of the conjugate equations ($\boldsymbol{\Sigma}^*$) but with electric charge ($+e$) and counterclockwise rotation ($\underline{cl}$) of the $\boldsymbol{\varphi}$ phase. Symmetrically, the negative-energy solutions $(\Psi_{-\varepsilon})_{\Sigma*}$ of the conjugate equations (Σ^*) are nothing other than electrons (!). Therefore, we have:

$$\left(\Psi_{-\varepsilon}\right)_{\Sigma} = \left(\Psi_{+\varepsilon}\right)_{\Sigma*} = \left(\Psi_{+\varepsilon}\right)_{+e} \to \text{positrons}\left[\left(+e\right),\left(\underline{cl}\right)\right]$$

$$\left(\Psi_{-\varepsilon}\right)_{\Sigma*} = \left(\Psi_{+\varepsilon}\right)_{\Sigma} = \left(\Psi_{+\varepsilon}\right)_{-e} \to \text{electrons}\left[\left(-e\right),\left(cl\right)\right]$$

This scheme solves the problem of having negative energies (negative frequencies). We could observe that if there were a physical object that read the direction of phase rotation (value of the parameter $\underline{\lambda}$) of the oscillation associated with a particle, it could be asserted that the negative frequency would be seen as the electric charge of a particle with positive energy: the solutions at negative energies would consequently disappear. This is coherent to the definition given of the *proper mass* m_0, see the sect. 2.2, connected to proper frequency ω_0, of the additional coupling. It remains only to understand how the photon (O_γ) can read the direction of phase rotation and determine the phenomenology of electrical interaction where electric charges of the same sign repel each other while those of opposite sign attract each other [3].

3.2. The 2-Dimensional Quantum Oscillator

If in the oscillations of a pendulum it is not possible to distinguish a direction of the phase rotation, instead, one could think that in a quantum oscillator this is possible. In a one-dimensional oscillator with its known descriptive degrees of freedom (amplitude and frequency), however, *it is not possible to know the direction of phase rotation unless an additional internal degree of freedom* (*fd*) *related to the phase φ is added.* The consequences of an additional degree of freedom internal to a quantum oscillator are significant. The new degree of freedom (*fd*) might be be related to the parameter $\underline{\lambda}$ and therefore to the two signs (±) of the electric charge *e*: (*fd* ⇔ $\underline{\lambda}$ ⇔ *e*). Since the eigenvalues of $\underline{\lambda}$ are given by ($\pm e$) and are also connected to the direction of rotation of the phase (*cl*, *cl*), then it follows that the new *fd* could coincide with the direction (*cl*, *cl*) of the phase rotation. This last aspect allows us to represent a quantum oscillator in a two-dimensional way [1]. Therefore, the hypothesis of correlating the sign ($\pm e$) to the direction of phase rotation (*cl*, *cl*) of a wave can be proven true only if we provide a "2-dimensional" representation of the quantum oscillator where it is possible to identify the direction of the phase rotation. Nevertheless, to avoid falling into a vicious circle (the *fd* connected to the direction of phase rotation makes the oscillator 2-dimensional, or if an oscillator is 2-dimensional, then it has an additional *fd* given by the direction of phase rotation), we need to find another reason to induce us to represent a quantum oscillator in 2-dimensional terms. This reason exists. If we study an isolated oscillator, its 1-dim. character would be obvious, but if we consider a field oscillator instead, things change, because the latter is a forced oscillator: a quantum oscillator O_i along a field line, coupled to two lateral field oscillators (O_{i-1}, O_{i+1}), is "forced" by the adjacent oscillators when it exchanges energy with them. A forced oscillator is described in its oscillations by "*Absorptive*" and "*Elastic*" components, as prescribed by the theory of forced oscillations [12]. In the representation of operators of a quantum oscillator (a, a^+), creation and annihilation operators, it is [1]:

$$\left[\left(a = a_{el} + a_{abs} \equiv a_{el} + a_{in}\right), \left(a^+ = a^+_{el} + a^+_{abs} \equiv a^+_{el} + a^+_{in}\right)\right] \quad (27)$$

Here, the subscript *in* indicates the absorptive or "*inertial*" component to distinguish it from the elastic component with the subscript *el*. The theory of forced oscillations tells us that the absorptive and elastic components are out of phase by $\pi/2$; we have:

$$\begin{Bmatrix} a_t = a(t)_{elastic} + a(t)_{inertial} \equiv O\boldsymbol{a} \\ a^+_t = a^+(t)_{elastic} + a^+(t)_{inertial} \equiv O\boldsymbol{a}^+ \end{Bmatrix} \Leftrightarrow \begin{Bmatrix} a_t = a_{(el)}\mathrm{e}^{-i\omega t} + a_{(in)}\mathrm{e}^{-i\left(\omega t - \frac{\pi}{2}\right)} \\ a^+_t = a^+_{(el)}\mathrm{e}^{i\omega t} + a^+_{(in)}\mathrm{e}^{i\left(\omega t - \frac{\pi}{2}\right)} \end{Bmatrix} \quad (28)$$

Here, we can highlight two different directions of rotation of the phase of the two vectors (***Oa***, ***Oa***$^+$) representing the operators (a, a^+), to which corresponds to the following geometric representation in the plane (q, ip), see **Figure 1**:

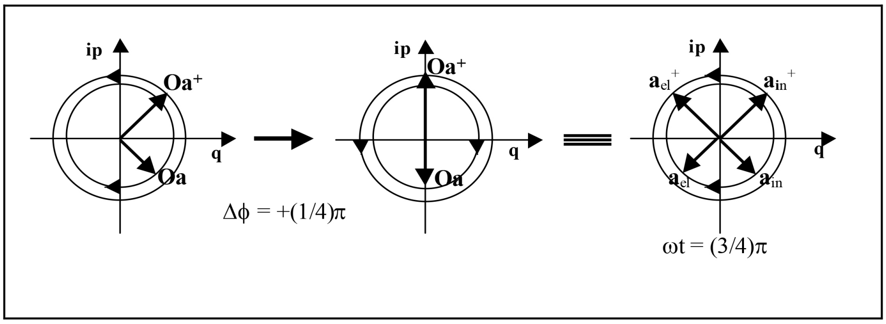


Figure 1. Representation of operators-vectors (a, a^+) with two components in phase plain.

The phase of ωt = $(3/4)\pi$ is reported to the elastic component with counterclockwise direction of rotation of adjoint operator a_{el}^+. Note the "***intrinsic 2-dimensional representation***". A field quantum oscillator could thus be expressed by its intrinsic internal 2-dimensionality. At this point, the two directions of phase rotation (clockwise and counterclockwise) can be represented within a field quantum oscillator, see the Equation (28) and **Figure 1**.

3.3. The Field Oscillator (IQuO)

We call **IQuO** the quantum oscillator of field: IQuO is the acronym for **I**ntrinsic **Qu**antum **O**scillator (for mathematical proofs of IQuO, see ref. [1]-[3]). Recall that in quantum field theory, a field can be represented as a set of "lines" of mutually coupled oscillators along which oscillations (waves) propagate; see Huygens' theorem applied to a particle-field [12]. Without going into too much detail (for further mathematical and physical details, see ref. [1]), it is important to consider that an IQuO oscillator I_k couples laterally to the right and left with the other two adjacent oscillators (I_1,I_2); for this reason, it can be represented as having at least two parts (left and right parts), which we will refer to as two "***sub-oscillators***". If an oscillator is composed of two parts (or two sub-oscillators), it is intuitive to assume that it must have its own spatial extension. Recall that a quantum oscillator [4] [13] has a relationship that defines its oscillation amplitude A_n along an X axis in the oscillation eigenstate $|n\rangle$: $A_n = (l_0/2)(2n+1)^{1/2}$. Here, l_0 would be the elongation in the "vacuum" state, that is (n = 0). Therefore, we are led to assume that an IQuO has its own spatial extension and, thus, is "***not point-like***". Note, these two sub-oscillators allow the oscillator to couple to the others sub-oscillators. We note that a coupling of two oscillators, to occur, must implement an exchange of energy between them and therefore between their respective sub-oscillators. It is therefore clear that it is not possible to have a coupling of I_k with the two lateral oscillators if we consider the energy of an oscillator expressed by a single and whole quantum. Therefore, in this case, it is necessary to distribute the quantum of energy (in the case $n = 1$) in the two component sub-oscillators, that is, it is necessary to split the quantum of energy into two "half-quanta". The field IQuO, therefore, will turn out to be a 2-dim. quantum oscillator with sub-oscillators with half-quanta. This split is suggested by the representation of the probability function $P(x)$ of a quantum oscillator in the Schrödinger treatment, $P(x) = |\Psi(x)|^2$, see **Figure 2** [1]:

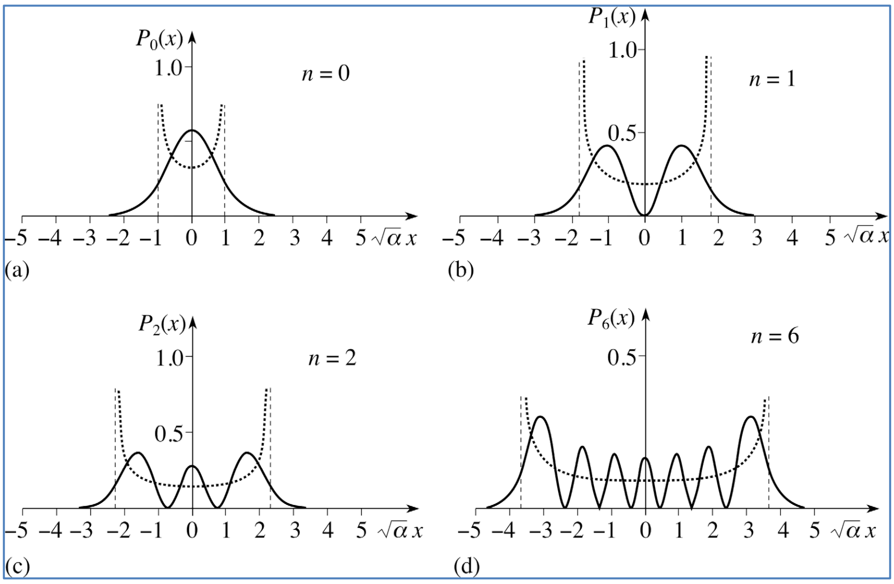


Figure 2. Probability function of quantum oscillator to varying of n quantum number.

The graph shows for ($n = 1$) two curves symmetrical with respect to the vertical axis (Y). If we assume that the graph is timeless and that each curve represents the probability zone where a quantum ($1\hbar$) can be found, then it can be rationally thought that there are two oscillation zones in a quantum oscillator in the state ($n = 1$). If we identify these two oscillation zones with two sub-oscillators into an IQuO, always present, then we can unequivocally mean that the quantum ($1\hbar$) must be divided into two half-quanta ($1/2\hbar$). However, the graph of $P(x)$ speaks clearly: in the two parts, the "quantum" must be revealed in its entirety in 50% of the observation cases and therefore, even admitting the existence of half-quanta (***semi-quanta***), we must have this possibility [1]. This possibility happens in an IQuO because the coupling between two adjacent IQuO of the field implies the overlapping of two their respective lateral sub-oscillators: in a superposition zone, two semi-quanta are equal to one quantum. In the remaining 50% of the cases, we do not have a quantum ($1\hbar$) in each sub-oscillator but at least a half-quantum or "***semi-quantum***" ($1/2\hbar$) which, obviously, cannot be revealed. We must admit this possibility. Note that a sub-oscillator without energy (kinetic energy and elastic potential energy) or without semi-quanta has no physical meaning. This implies that in the two sub-oscillators, the semi-quanta come and go if the following relationship is always valid in an IQuO:

$$\left\{\varepsilon(n)=\left[(n+1/2)h\nu\right]\right\} \tag{29}$$

where n is the number of integer quanta ($1h$). We should point out that the graphs in **Figure 2** concern a single "isolated" quantum oscillator. The vacuum state of an isolated oscillator in (n = 0) is represented by a single curve centred on the Y-axis, see **Figure 2(a)**, with a total energy of ($1/2h$). However, in a field line, the quantum oscillators (IQuO) are all "elastically" coupled to each other and, therefore, are not isolated oscillators and, thus, always consist of two sub-oscillators even in a field in a vacuum state. In an IQuO of a field in the vacuum state (n = 0) with two sub-oscillators and with a total energy of ($1/2h$), we must admit that in each sub-oscillator there is a half semi-quantum ($1/4h$), defined as "***empty semi-quantum***". Let us therefore admit the existence into an IQuO of an empty semi-quantum, denoted by *sq*(o), with energy $\varepsilon = (1/4h)\omega$, distinct from the "***full semi-quantum***", *sq*(•), with energy $\varepsilon = 1/2h)\omega$. The empty semi-quanta allow us to have an IQuO in state (n = 1) with a sub-oscillator having a semi-quantum at the 50% of probability. Returning to **Figure 1**, in which there are the representations of the operators (*a, a*⁺) with their double components, see $\left[\left(a_{el},a_{el}^{+}\right),\left(a_{in},a_{in}^{+}\right)\right]$, and taking into account that we have full semi-quanta *sq*(•) and empty *sq*(o), we note that each of two sub-oscillators of the IQuO$_{(n=1)}$ contains a pair of *sq*(o, •) which move following the oscillation vectors (***Oa, Oa***⁺**)** and the corresponding components $\left[\left(a_{el},a_{el}^{+}\right),\left(a_{in},a_{in}^{+}\right)\right]$. Therefore, we could assign to each component of the operators (*a, a*⁺) a "***semi-quantum operator***" ***sq***(o) or ***sq***(•) with their respective elastic and inertial characteristics:

$$\underset{\mathrm{B_1\text{-}Matrix}}{\left\{\begin{pmatrix} a_{el}\equiv(\bullet)_{el} & a_{in}\equiv(\mathrm{o})_{in} \\ a_{el}^{+}\equiv(\mathrm{o}^{+})_{el} & a_{in}^{+}\equiv(\bullet^{+})_{in}\end{pmatrix}\right\}} <\equiv> \underset{\mathrm{B_2\text{-}Matrix}}{\left\{\begin{pmatrix} a_{el}\equiv(\mathrm{o})_{el} & a_{in}\equiv(\bullet)_{in} \\ a_{el}^{+}\equiv(\hat{\bullet}^{+})_{el} & a_{in}^{+}\equiv(\mathrm{o}^{+})_{in}\end{pmatrix}\right\}} \tag{30}$$

We will obtain, see **Figure 2(b)**, the probabilistic representation of the IQuO at a given time, see **Figure 3**:

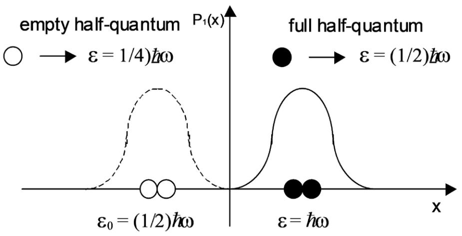


Figure 3. The probabilistic representation of the semi-quantum oscillator.

Precisely, it is:

1) ($\bullet_{in}^{+}$, $\bullet_{el}^{+}$) are creation operators of *sq*(•) (that is each creates an amount of energy ($\varepsilon = 1/2h\nu$) or fill an *sq*(o) with energy ($\varepsilon = 1/4h\nu$)), that is the full $sq(\bullet)_x$ moves toward + X-axis.

2) ($\bullet_{in}$, $\bullet_{el}$) are annihilation operators of *sq*(•) (that is each annihilates an energy quantity of ($\varepsilon = 1/2h\nu$) or empties *sq*(•) of the energy quantity ($\varepsilon = 1/4h\nu$) making

it so empty, ($\bullet \to$ o)).

3) (o_{in}^{+}, o_{el}^{+}) are creation operators of empty *sq*(o) (that is each annihilates an energy quantity of ε).

4) ($\underline{o}_{el}$, $\underline{o}_{in}$) should be annihilation operators of *sq*(o).

Note in Figure 1 that the projections of the operators $\left[\left(a_{el}, a_{el}^{+}\right), \left(a_{in}, a_{in}^{+}\right)\right]$ along the X-axis give us the position of the semi-quanta (o, $\bullet$) along this axis. In summary, we can represent an IQuO, see Figure 4:

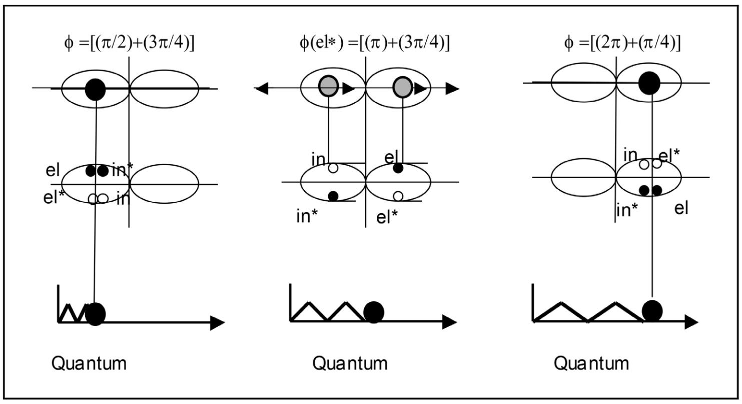


Figure 4. The oscillation of a "*quantum*" along X-axis.

In this figure, the *sq*-operators have rotations in the opposite direction to those of Figure 1. Here, we note the "spatial extension" of the IQuO along the X-axis, and that in the apparently empty area, there are instead "semi-quanta" of energy available for couplings, that is, semi-quanta belonging to the adjacent oscillator along the same field line, as we will see later. Then the distribution of the semi-quanta in the various sub-oscillators of an only IQuO at level *n* will be, see relation Equation (29):

$$\varepsilon(n=0) \equiv \left\{\left[(\text{o}),(\text{o})\right]_1\right\}_{\Psi_0}, \left\{\left[(\text{o}),(\bullet)\right]_1\right\}_{\Psi_0'} \quad (31a)$$

$$\varepsilon(n=1) \equiv \left\{\left[(\text{o}),(\bullet)\right]_1, \left[(\text{o}),(\bullet)\right]_2\right\}_{\Psi_1}, \left\{\left[(\bullet),(\bullet)\right]_1, \left[(\text{o}),(\bullet)\right]_2\right\}_{\Psi_1'} \quad (31b)$$

$$\varepsilon(n=2) \equiv \left\{\left[(\text{o}),(\bullet)\right]_1, \left[(\bullet),(\bullet)\right]_2, \left[(\text{o}),(\bullet)\right]_3\right\}_{\Psi_2} \quad (31c)$$

$$\varepsilon(n=2) \equiv \left\{\left[(\bullet),(\bullet)\right]_1, \left[(\text{o}),(\text{o})\right]_2, \left[(\bullet),(\bullet)\right]_3\right\}_{\Psi_{2b}} \quad (31d)$$

$$\varepsilon(n=2) \equiv \left\{\left[(\bullet),(\bullet)\right]_1, \left[(\bullet),(\bullet)\right]_2, \left[(\text{o}),(\bullet)\right]_3\right\}_{\Psi_{2c}} \quad (31e)$$

The subscript numbers indicate the sub-oscillators; always see Figure 1. The various Ψ' are excited states. From the configurations of Equation (30), it can be deduced that to achieve internal coupling between field oscillators, it is sufficient for the extreme sub-oscillators of the two contiguous IQuO to exchange at least one full *sq*($\bullet$). It should be noted, however, that when two oscillators, each belonging to a different field, couple to describe the interaction between particles (dynamic phase), then they can only exchange one full quantum [($\bullet$) ≡ ($\bullet$), ($\bullet$)], that is, two full *sq*($\bullet$).

3.4. Two Different Types of IQuO: B-IQuO and F-IQuO

Looking the **Figure 1** and **Figure 4**, we could use the representation of Equation (30) about an IQuO with eigenvalue of direction of phase rotation ($\lambda' = -1 \Leftrightarrow cl$) and phase angle of ($5\pi/4$):

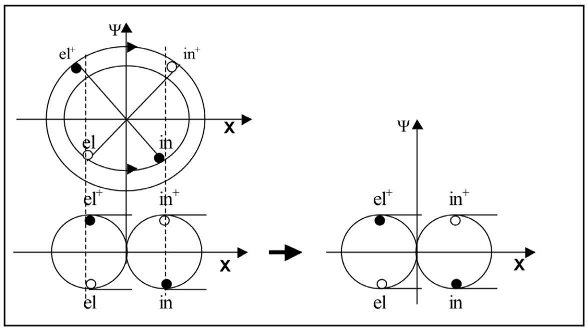


Figure 5. IQuO with eigenvalue $r' = -1$.

Here, we can note that the clockwise direction of operator pair $\left[\left(\bullet_{el}^{+}\right)_{cl},\left(\mathrm{o}_{in}^{+}\right)_{cl}\right]_{+k}$ indicates the movement of *sq* (•,o) toward the +X-axis; the same indication one has in the pair $\left[\left(\mathrm{o}_{el}\right)_{\underline{cl}},\left(\bullet_{in}\right)_{\underline{cl}}\right]_{+k}$; from the scheme of pag. 14 (Equation (30)), one can see that the two operators $\left[\left(\bullet_{el}^{+}\right)_{cl}\right]_{+k} \Leftrightarrow \left[\left(\mathrm{o}_{el}\right)_{\underline{cl}}\right]_{+k}$ are coherent and in action concordance. The same can be said about pairs $\left[\left(\mathrm{o}_{el}^{+}\right)_{cl}\right]_{-k}$ and $\left[\left(\bullet_{in}\right)_{cl}\right]_{-k}$.

The two movements in opposite directions ($+k$, $-k$) of two pairs are coherent with the characteristic of a forced oscillator of an IQuO, where the index (in) points out the absorbitive component of the forced oscillator (see Equation (27)), while the index (el) points out the elastic component. Recall the antagonistic behavior of two components elastic and absorbitive. In an no-isolated IQuO that is in a field line of coupling IQuOs for having the movement of quantum (•,•) along the line in the +X direction ($+k$) we must have another configuration:

$$\left\{\left[\left(\bullet_{el}^{+}\right)_{cl},\left(\mathrm{o}_{in}^{+}\right)_{cl}\right]_{+k},\left[\left(\mathrm{o}_{el}\right)_{\underline{cl}},\left(\mathrm{o}_{in}\right)_{\underline{cl}}\right]_{+k}\right\}.$$

In matrix form [1] [3], for an "isolated" IQuO, see **Figure 5**, and for an IQuO of field, we will have:

$$(\Psi) \equiv \begin{pmatrix} \left(\bullet_{el}^{+}\,\mathrm{e}^{-\frac{i5\pi}{4}} + \mathrm{o}_{in}^{+}\mathrm{e}^{-\frac{i7\pi}{4}}\right)_{+k} \\ \left(\underline{\mathrm{o}}_{el}\mathrm{e}^{\frac{i5\pi}{4}} + \underline{\bullet}_{in}^{\frac{i7\pi}{4}}\right)_{-k} \end{pmatrix}$$

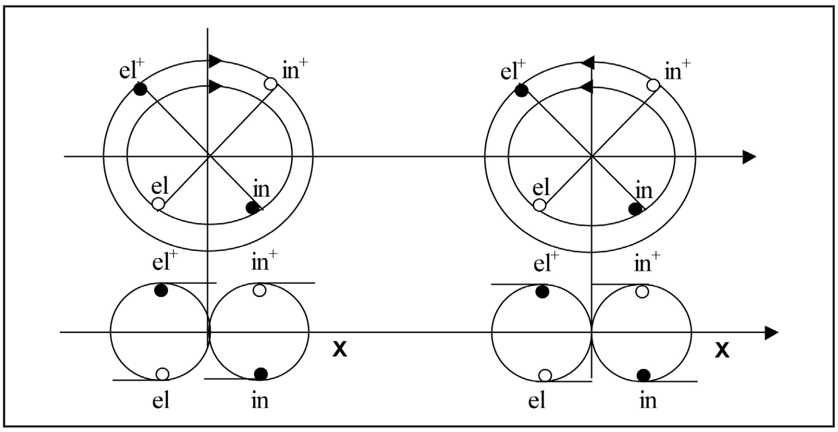
$$(\Psi)_{field} \equiv \begin{pmatrix} \left(\bullet_{el}^{+}\,\mathrm{e}^{-\frac{i5\pi}{4}} + \bullet_{in}^{+}\,\mathrm{e}^{-\frac{i7\pi}{4}}\right)_{+k} \\ \left(\underline{\mathrm{o}}_{el}\mathrm{e}^{\frac{i5\pi}{4}} + \underline{\mathrm{o}}_{in}^{\frac{i7\pi}{4}}\right)_{+k} \end{pmatrix} \tag{32}$$

Here, we have omitted the indices (*cl*, *\underline{cl}*) because we have set the counter-clockwise operators as $\left[(\bullet)_{\underline{cl}},(\circ)_{\underline{cl}}\right]\Leftrightarrow\left[(\underline{\bullet}),(\underline{\circ})\right]$. Note, in **Figure 5**, the semi-quanta are both empty and full; then we have the following possibility for a field IQuO:

$$\left\{\left[\left(\circ_{el}\right)_{cl},\left(\underline{\bullet}_{el}^{+}\right)_{\underline{cl}}\right]_1,\left[\left(\circ_{in}\right)_{cl},\left(\underline{\bullet}_{in}^{+}\right)_{\underline{cl}}\right]_2\right\} \quad \text{Field IQuO}$$

$$\left\{\left[\left(\underline{\circ}_{el}\right)_{\underline{cl}},\left(\bullet_{el}^{+}\right)_{cl}\right]_1,\left[\left(\underline{\circ}_{in}\right)_{\underline{cl}},\left(\bullet_{in}^{+}\right)_{cl}\right]_2\right\} \quad \text{Field IQuO}$$

where the subscript *cl* indicates the clockwise direction of the phase rotation, while the subscript *\underline{cl}* indicates the counterclockwise direction. Here, we have a field IQuO with both directions of phase rotation in operators a and a^{+}. If we have connected a sign of the electric charge to the direction of the phase rotation, then this type of IQuO is electrically "neutral". In the IQuO representation, a photon appears as a quantum (•, •) that propagates along a field line (in this case, an electromagnetic field) made up entirely of "neutral" IQuO in the direction of phase rotation. An IQuO with both directions of phase rotation, and "neutral" in the direction of phase rotation, will be called type ***B***. If we consider electrically charged particles, such as an electron or a positron, we will instead have all operators of *sq* with the same direction of the phase rotation (mono-verse IQuO), that is an IQuO type ***F***. The positron has an electric charge ($+e$), so all the *sq* must rotate in the same direction, namely, counterclockwise (*\underline{cl}*). The electron has an electric charge ($-e$), so all the *sq* must rotate in the same direction, namely, clockwise (*cl*). The following configurations are thus found, see **Figure 6**:



(a) (b)

Figure 6. Two "mono-verse" IQuO in regular shape with two opposite rotations of the phase.

Also, we can consider, as for ***B***-IQuO, a *sq*-structure given by:

$$\left\{\left[\left(\underline{\circ}_{el}\right)_{\underline{cl}},\left(\underline{\bullet}_{el}^{+}\right)_{\underline{cl}}\right]_1,\left[\left(\underline{\circ}_{in}\right)_{\underline{cl}},\left(\underline{\bullet}_{in}^{+}\right)_{\underline{cl}}\right]_2\right\} \quad \text{Positron}$$

$$\left\{\left[\left(\circ_{el}\right)_{cl},\left(\bullet_{el}^{+}\right)_{cl}\right]_1,\left[\left(\circ_{in}\right)_{cl},\left(\bullet_{in}^{+}\right)_{cl}\right]_2\right\} \quad \text{Electron}$$

The representation of the two types of ***F***-IQuO in matrix form will be:

$$\left\{\begin{array}{l}\Phi_{cl} \equiv \begin{pmatrix} \left(\bullet_{el}^{+} e^{-\frac{i5\pi}{4}} + \text{o}_{in}^{+} e^{-\frac{i7\pi}{4}} \right) \\ \left(\text{o}_{el} e^{-\frac{i3\pi}{4}} + \bullet_{in} e^{-\frac{i\pi}{4}} \right) \end{pmatrix}_{2\times 1} \equiv \begin{pmatrix} \bullet_{el}^{+} & \text{o}_{in}^{+} \\ \text{o}_{el} & \bullet_{in} \end{pmatrix}_{2\times 2} \\ \Phi_{\underline{cl}} \equiv \begin{pmatrix} \left(\underline{\bullet}_{el}^{+} e^{\frac{i3\pi}{4}} + \underline{\text{o}}_{in}^{+} e^{\frac{i\pi}{4}} \right) \\ \left(\underline{\text{o}}_{el} e^{\frac{i5\pi}{4}} + \underline{\bullet}_{in} e^{\frac{i7\pi}{4}} \right) \end{pmatrix}_{2\times 1} \equiv \begin{pmatrix} \underline{\bullet}_{el}^{+} & \underline{\text{o}}_{in}^{+} \\ \underline{\text{o}}_{el} & \underline{\bullet}_{in} \end{pmatrix}_{2\times 2} \end{array}\right\}$$

$$\left\{\begin{array}{l}\Phi_{cl} \equiv \begin{pmatrix} \left(\bullet_{el}^{+} e^{-\frac{i5\pi}{4}} + \bullet_{in}^{+} e^{-\frac{i7\pi}{4}} \right) \\ \left(\text{o}_{el} e^{-\frac{i3\pi}{4}} + \text{o}_{in} e^{-\frac{i\pi}{4}} \right) \end{pmatrix}_{2\times 1} \equiv \begin{pmatrix} \bullet_{el}^{+} & \bullet_{in}^{+} \\ \text{o}_{el} & \text{o}_{in} \end{pmatrix}_{2\times 2} \\ \Phi_{\underline{cl}} \equiv \begin{pmatrix} \left(\underline{\bullet}_{el}^{+} e^{\frac{i3\pi}{4}} + \underline{\bullet}_{in}^{+} e^{\frac{i\pi}{4}} \right) \\ \left(\underline{\text{o}}_{el} e^{\frac{i5\pi}{4}} + \underline{\text{o}}_{in} e^{\frac{i7\pi}{4}} \right) \end{pmatrix}_{2\times 1} \equiv \begin{pmatrix} \underline{\bullet}_{el}^{+} & \underline{\bullet}_{in}^{+} \\ \underline{\text{o}}_{el} & \underline{\text{o}}_{in} \end{pmatrix}_{2\times 2} \end{array}\right\} \quad (33)$$

Here, in **Figure 6(a)**, we can note that the clockwise direction of operators pair $\left[\left(\bullet_{el}^{+}\right)_{cl},\left(o_{in}^{+}\right)_{cl}\right]_{+k}$ indicates the movement of $sq\,(\bullet,\text{o})$ toward the +X-axis; instead, the pair $\left[\left(\text{o}_{el}\right)_{cl},\left(\bullet_{in}\right)_{cl}\right]_{-k}$ indicates the movement of $sq\,(\bullet,\text{o})$ toward the −X-axis; from scheme of Equation (30), one can see that the two operators $\left[\left(\bullet_{el}^{+}\right)_{cl}\right]_{+k} \Leftrightarrow \left[\left(\text{o}_{el}\right)_{cl}\right]_{-k}$ are not coherent and, thus, are in action discordance; the same happens in the pair $\left[\left(\text{o}_{in}^{+}\right)_{cl}\right]_{-k} \Leftrightarrow \left[\left(\bullet_{in}\right)_{cl}\right]_{-k}$. This means that the following couplings are not compatible:

$$\left[op\left(\bullet_{el}^{+}\right)_{-k}, op\left(\bullet_{in}^{+}\right)_{-k}\right]_{cl} \Leftrightarrow \left[op\left(\text{o}_{el}\right)_{+k}, op\left(\text{o}_{in}\right)_{+k}\right]_{cl}$$

$$\left[op\left(\bullet_{el}^{+}\right)_{-k}, op\left(\bullet_{in}^{+}\right)_{-k}\right]_{\underline{cl}} \Leftrightarrow \left[op\left(\text{o}_{el}\right)_{+k}, op\left(\text{o}_{in}\right)_{+k}\right]_{\underline{cl}}$$

where the sign (⇎) points out the pairs not compatible. If we admit the possibility given by **Figure 6**, then there must be a "possibility" of coupling the pairs without running into discordance. Since the oscillations of non-scalar fields such as vector and tensor fields, and hence the oscillations of the corresponding IQuOs, take place on multiple oscillation planes, the planes could be combined in such a way as to avoid incompatible couplings. This implies that the oscillation plane of the pair $\left[op\left(\bullet_{el}^{+}\right)_{-k}, op\left(\bullet_{in}^{+}\right)_{-k}\right]_{z}$ with the oscillation along the Z-axis is different from that of the pair $\left[op\left(\text{o}_{el}\right)_{+k}, op\left(\text{o}_{in}\right)_{+k}\right]_{Y}$ which oscillates along the Y-axis.

We can have: $\left\{\left[op\left(\bullet_{el}^{+}\right)_{-k}, op\left(\bullet_{in}^{+}\right)_{-k}\right]_{z}, \left[op\left(\text{o}_{el}\right)_{+k}, op\left(\text{o}_{in}\right)_{+k}\right]_{y}\right\}$. That is:

$$\left\{\left[\left(\bullet_{el}^{+}\right)_{-k}, \left(\bullet_{in}^{+}\right)_{-k}\right]_{z}, \left[\left(\text{o}_{el}\right)_{+k}, \left(\text{o}_{in}\right)_{+k}\right]_{y}\right\}$$

$$\left\{\left[\left(\bullet_{el}^{+}\right)_{-k}, \left(\bullet_{in}^{+}\right)_{-k}\right]_{y}, \left[\left(\text{o}_{el}\right)_{+k}, \left(\text{o}_{in}\right)_{+k}\right]_{z}\right\}$$

where the moment k is along the X-axis, that is the propagation axis. However, we must admit that it is possible that the two pairs $\left[\left(a_{el}^{+}, a_{in}^{+}\right), \left(a_{el}, a_{in}\right)\right]$ of the Equation (31) can couple to create an IQuO with the pairs of annihilation and creation operators with the same phase rotation, see Equation (33). Then the coupling occurs following an exchange of $sq(\bullet)$, which can occur in overlapping or interpenetrating sub-oscillators.

Another relevant note is due: we point out that the phase is not an "observable", while the direction of phase rotation may be observable, because its two eigenvalues λ' can be detected as signs of the that we point out as electric charge ($\pm e$).

The ability to detect the two directions of phase rotation in charged particles is possible through experimental observation using a probe photon. Therefore, we cannot associate an operator with the phase: in ref. [4] it is shown that only the exponential form of phase can be assumed in the role of a "functional operator" ($\Phi \equiv e^{i\varphi}$) [4]. It follows then that we can only associate two eigenstates $|\lambda\rangle$, relating to the two eigenvalues of parameter λ' inserted in the functional ($\Phi \equiv e^{i\lambda\varphi}$); however, this is possible only for fields with IQuO of F-type, see the pair creation where we can observe these two eigenvalues.

3.5. The Lines of Field IQuO

In a non-isolated IQuO, that is in a field line of coupling IQuOs, for having the movement of quantum (•, •) along the line in the +X direction (+k), one must admit the following configuration: $\left\{\left[\left(\bullet_{el}^{+}\right)_{cl}, \left(\bullet_{in}^{+}\right)_{cl}\right]_{+k}, \left[\left(\text{o}_{el}\right)_{\underline{cl}}, \left(\text{o}_{in}\right)_{\underline{cl}}\right]_{+k}\right\}$.

Recall that the quantum field Ψ is a set of coupled quantum oscillators expressed by operators (a, a^{+}). The unique possibility to insert the 2-dimensional geometric aspect of an IQuO is in the component no time $\left(a_0, a_0^{+}\right)$, which will be expressed by a matrix $\Psi(t_0) \equiv \Psi_0$ with elements describing the structure of a $\boldsymbol{B}$-IQuO, see the Equation (32):

$$\Psi(x_i) = \left(\frac{1}{\sqrt{V}}\right)\sum_k \left[\left(\sqrt{\frac{\hbar}{2\omega_k}}\right)\left(a_k + a_{-k}^{+}\right)\right] e^{i(\boldsymbol{k}\cdot\boldsymbol{x})}$$

$$= \left(\frac{1}{\sqrt{V}}\right)\sum_k \left(\sqrt{\frac{\hbar}{2\omega_k}}\right)\begin{pmatrix} \left(\bullet_{el}^{+} e^{-\frac{i5\pi}{4}} + \bullet_{in}^{+} e^{-i7\pi/4}\right) \\ \left(\underline{o}_{el} e^{\frac{i5\pi}{4}} + \underline{o}_{in}^{\frac{i7\pi}{4}}\right) \end{pmatrix}_{(k,t_0)} e^{i(\boldsymbol{k}\cdot\boldsymbol{x})} \tag{34}$$

To transmit a quantum (•, •) along a field line (X-axis) and thus represent a particle, we need the configurations given by **Figure 7**:

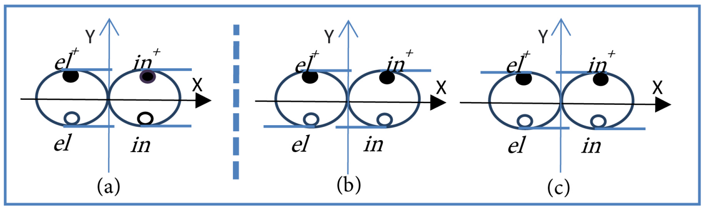


Figure 7. Three types of IQuO.

In **Figure 7(a)** there is a ***B***-IQuO ("Boson" Ψ), while in **Figure 7(b)** and **Figure 7(c)** there are ***F***-IQuO ("Fermion" Φ). The denominations are not accidental since in certain studies about IQuO [1] [3] [11] it is demonstrated that the basic structure of field quantum oscillators has two forms, namely the ***F***-type for "fermions Φ" and the ***B***-type for "bosons Ψ". We can build a field line where two IQuO (I_1, I_2) for connecting one to the other must overlap their sub-oscillators, see **Figure 8**:

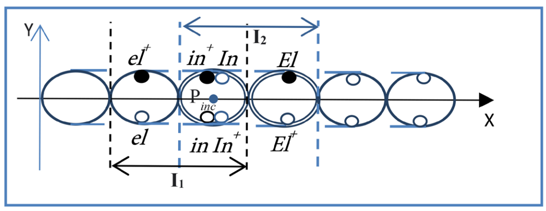


Figure 8. Field line of B-IQuO in which a quantum (•, •) propagates along X-axis.

In **Figure 8**, the *sq* pair $\left[\left(\bullet_{el}^{+}\right),\left(\bullet_{in}^{+}\right)\right]$ of I_1-IQuO proceeds along the X-axis and can be transmitted, always in this direction, to a neighbouring I_2-IQuO. Note the double sub-oscillator with *sq* [(*in, in*$^+$), (*In, In*$^+$)], in which the energy exchanges happen between I_1 and I_2. The image in **Figure 8** indicates a field line extended in space. This is possible because each IQuO of the line has a spatial extension along the X-axis of quantum propagation. This aspect is coherent with the QM when a particle, after an interaction, is in an eigenstate of moment (*k*): it is represented by a field line along the X-axis coincident in direction to the vector ***k***. Therefore, we can assert that a Field IQuO has a space dimension with an oscillation along an X-axis and an intrinsic 2-dimensional representation.

3.6. The Coupling of Two Field IQuO into Processes of Pair Annihilation

The processes of pair creation and annihilation are found, in fundamental terms, in the operations:

$$\left\{\left[(\Psi_1)_\gamma \underline{\oplus} (\Psi_2)_\gamma\right] \rightarrow \left[\left(\Phi_{\underline{cl}}\right)_{+e} + (\Phi_{cl})_{-e}\right]\right\},$$

$$\left\{\left[\left(\Phi_{\underline{cl}}\right)_{+e} \oplus (\Phi_{cl})_{-e}\right] \rightarrow \left[(\Psi_1)_\gamma + (\Psi_2)_\gamma\right]\right\}$$

We denote by $\left(\Phi_{+e} \underline{\oplus} \Phi_{-e}\right)$ the coupling of two fermion fields and by

$\left[(\Psi_1)_\gamma \underline{\oplus} (\Psi_2)_\gamma\right]$ the coupling of two boson fields; the sign $\underline{\oplus}$ represents the reciprocal action operation with components $\{\underline{\oplus} \equiv [\underline{\otimes}, \underline{\oplus}] \equiv [(0'_R, \otimes), (0''_R, \oplus)]\}$.

where:

- ($\otimes$ represents the operation with "interpenetration" of two IQuO, see the shared sub-oscillator in **Figure 8**).
- ($\oplus$ represents the dynamic operation between two IQuO with exchange of *sq*.
- O_R represent the reduction processes from two fields to chains (C_1, C_2) and from (C_1, C_2) to two IQuO (I_1, I_2) or from two IQuO to the shared sub-oscillator $s_{1,2}$.

The operation $[\underline{\otimes} \equiv (0'_R, \otimes)]$ describes the ***non dynamic*** initial phase of reduction ($0'_R$) of fields in two IQuO which reciprocally themselves interpenetrate ($\otimes$), while the $\underline{\oplus}$ -sign indicates, after the interpenetration and the other eventual reduction process ($0''_R$), the ***dynamic coupling*** by exchanges of $sq(\bullet,\bullet)$ pairs between two IQuO (I_1, I_2) of two fields (Φ_1, Φ_2) or (Ψ_1, Ψ_2). We can represent the operation $\underline{\oplus}$ also in the following way:

$$\left\{\underline{\oplus} \equiv [\underline{\otimes}, \underline{\oplus}] \equiv [(0'_R \otimes), (0''_R \oplus)]\right\} \equiv \underline{\oplus}_{\underline{\otimes}} = \underline{\otimes}_{\underline{\oplus}} \tag{35}$$

With the two properties $[\otimes_\oplus = \oplus_\otimes, \ \underline{\otimes}_{\underline{\oplus}} = \underline{\oplus}_{\underline{\otimes}}]$, where we can exchange the order of operations. Note in **Figure 7(b)**, **Figure 7(c)**, the coupling by ($\underline{\oplus}$)-operation of the two IQuO Fermions (with opposite directions of the phase rotation) gives rise to two IQuO of the Boson type:

$$\begin{aligned}(\Phi_1 \underline{\oplus} \Phi_2) &\to \{\Phi_1[(0'_R \otimes), (0''_R \oplus)]\Phi_2\} \to \left\{\Phi_1\left[0_{\varphi\varepsilon}(0_{\sigma\varepsilon} \otimes), (0_{\theta\varepsilon} \oplus)\right]\Phi_2\right\} \\ &\to \left\{C_{k_1}[(0_{\sigma\varepsilon} \otimes), (0_{\theta\varepsilon} \oplus)]C_{k_2}\right\} \\ &\to \left\{I_{Fcl}[(\otimes), (0_{\sigma\varepsilon} \oplus)]I_{F\underline{cl}}\right\} \equiv \left(I_{Fcl} \otimes_\varepsilon I_{F\underline{cl}}\right)_{\oplus_{\sigma\varepsilon}} \\ &\to \left(I_{B2} \underline{\otimes} I_{B1}\right)_{0_R} \to (I_{B2} + I_{B1})\end{aligned} \tag{36}$$

where the operator $O_{\varphi\varepsilon}$ has reduced (by reciprocal phase shifts $\Delta\varphi_1 = -\Delta\varphi_2$ with a reciprocal exchange of energy (ε) by $sq(\text{o}\leftrightarrow\bullet)$) the two fields in the chains (C_1, C_2) with moment (k_1, k_2) while the operator $O_{\sigma\varepsilon}$ reduces (by reciprocal phase shifts $\Delta\sigma_1 = -\Delta\sigma_2$ with a reciprocal exchange of energy (ε) by $sq(\text{o}\leftrightarrow\bullet)$)) the two chains in the two IQuO (I_{F1}, I_{F2}) in a state of reciprocal interpenetration $\otimes$. In this state, the pair exchange of *sq*

$$\left[\left(\bullet^+_{el}\right),\left(\bullet^+_{in}\right)\right] \leftrightarrow \left[\left(\bullet^+_{El}\right),\left(\bullet^+_{In}\right)\right]$$

realized by coupling

$$\left[\left(\bullet^+_{El}\right),\left(\bullet^+_{In}\right)\right] \leftrightarrow \left[\left(\text{o}_{el}\right),\left(\text{o}_{in}\right)\right], \left[\left(\bullet^+_{el}\right),\left(\bullet^+_{in}\right)\right] \leftrightarrow \left[\left(\text{o}_{El}\right),\left(\text{o}_{In}\right)\right]$$

with energy exchange (ε) by $sq(\text{o}\leftrightarrow\bullet)$ exchange, see the $(I_{Fcl} \otimes_\varepsilon I_{F\underline{cl}})_{\oplus_{\sigma\varepsilon}}$, realizes, by the operation $\underline{\oplus}_{\sigma\varepsilon}$, the two new pairs of B-IQuO not separated state $(I_{B2} \underline{\otimes} I_{B1})_{\underline{O_R}}$, which can then be separated by an "observation" $\underline{O}_R$ operated either by some particle or by an instrumental apparatus. Therefore the $\otimes$-operation originates that physical state which in quantum physics is called "***entanglement***". This can be clearly seen in **Figure 9**:

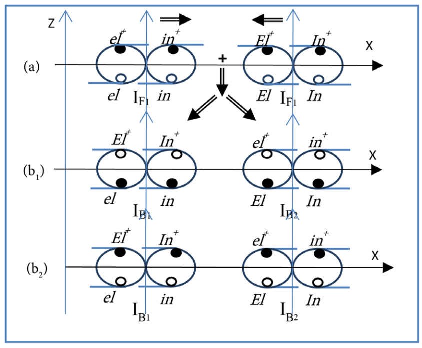


Figure 9. Pair annihilation process.

In **Figure 9(a)**, we show only two terminal IQuO (I_{F1}, I_{F2}) of two chains (C_{F1}, C_{F2}), as the same in **Figure 9(b1)** and **Figure 9(b$_2$)** for two IQuO (I_{B1}, I_{B2}). The calculation by matrices is:

$$
\begin{aligned}
&(\Phi_{cl})_{e^-}\,\underline{\oplus}\,(\Phi_{\underline{cl}})_{e^+}=(\Phi_{cl})_{e^-}\left[\underline{\otimes}_{O_{(\phi,\varepsilon)},O_{(\sigma,\varepsilon)}}\right]_{\oplus}(\Phi_{\underline{cl}})_{e^+}\\
&=\left(C_{\Phi(cl)}\right)_{e^-(+k)}\left[\underline{\otimes}_{O_{(\sigma,\varepsilon)}}\right]_{\oplus}\left(C_{\Phi(\underline{cl})}\right)_{e^+(-k)}=\left(I_{cl}\right)_{e^-(+k)}\left[(\underline{\otimes})\right]_{\oplus(\theta,\varepsilon)}\left(I_{\underline{cl}}\right)_{e^+(-k)}\\
&=\left\{\left[\begin{pmatrix}\left(\bullet^+_{el}e^{-\frac{i5\pi}{4}}+\bullet^+_{in}e^{-\frac{i7\pi}{4}}\right)_{cl}\\ \left(o_{el}e^{-\frac{i3\pi}{4}}+o_{in}e^{-\frac{i\pi}{4}}\right)_{cl}\end{pmatrix}_{e^-(+k)}\right]\underline{\otimes}_{\oplus(\theta,\varepsilon)}\left[\begin{pmatrix}\left(\underline{\bullet}^+_{el}e^{\frac{i3\pi}{4}}+\underline{\bullet}^+_{in}e^{\frac{i\pi}{4}}\right)_{\underline{cl}}\\ \left(\underline{o}_{el}e^{\frac{i5\pi}{4}}+\underline{o}_{in}e^{\frac{i7\pi}{4}}\right)_{\underline{cl}}\end{pmatrix}_{e^+(-k)}\right]\right\}_{\left(a^+\leftrightarrow\underline{a}^+\right)_{O_\varepsilon}}\\
&=\left\{\left[\begin{pmatrix}\left(\underline{\bullet}^+_{el}e^{\frac{i3\pi}{4}}+\underline{\bullet}^+_{in}e^{\frac{i\pi}{4}}\right)_{\underline{cl}}\\ \left(o_{el}e^{\frac{i3\pi}{4}}+o_{in}e^{\frac{i\pi}{4}}\right)_{cl}\end{pmatrix}_{e^-(+k)}\right]\left[\underline{\oplus}_{(\theta,\varepsilon)}\right]_{\otimes}\left[\begin{pmatrix}\left(\bullet^+_{el}e^{-\frac{i5\pi}{4}}+\bullet^+_{in}e^{-\frac{i7\pi}{4}}\right)_{cl}\\ \left(\underline{o}_{el}e^{\frac{i5\pi}{4}}+\underline{o}_{in}e^{\frac{i7\pi}{4}}\right)_{\underline{cl}}\end{pmatrix}_{e^+(-k)}\right]\right\}_{\left(a\leftrightarrow\underline{a}\right)_{O_\varepsilon}}\\
&=\left\{\begin{pmatrix}\left(o^+_{el}e^{-\frac{i5\pi}{4}}+o^+_{in}e^{-\frac{i7\pi}{4}}\right)_{cl}\\ \left(\underline{\bullet}_{el}e^{\frac{i5\pi}{4}}+\underline{\bullet}_{in}e^{\frac{i7\pi}{4}}\right)_{\underline{cl}}\end{pmatrix}_{(+k)}\otimes_{\oplus(\theta,\varepsilon)}\begin{pmatrix}\left(\underline{o}^+_{el}e^{\frac{i3\pi}{4}}+\underline{o}^+_{in}e^{\frac{i\pi}{4}}\right)_{\underline{cl}}\\ \left(\bullet_{el}e^{-\frac{i3\pi}{4}}+\bullet_{in}e^{-\frac{i\pi}{4}}\right)_{cl}\end{pmatrix}_{(-k)}\right\}_{O_\varepsilon}\\
&=\begin{pmatrix}\left(\bullet^+_{el}e^{-\frac{i5\pi}{4}}+\bullet^+_{in}e^{-\frac{i7\pi}{4}}\right)_{cl}\\ \left(\underline{o}_{el}e^{\frac{i5\pi}{4}}+\underline{o}_{in}e^{\frac{i7\pi}{4}}\right)_{\underline{cl}}\end{pmatrix}_{\gamma(+k)}\otimes_R\begin{pmatrix}\left(\underline{\bullet}^+_{el}e^{\frac{i3\pi}{4}}+\underline{\bullet}^+_{in}e^{\frac{i\pi}{4}}\right)_{\underline{cl}}\\ \left(o_{el}e^{i-\frac{3\pi}{4}}+o_{in}e^{-\frac{i\pi}{4}}\right)_{cl}\end{pmatrix}_{\gamma(-k)}\\
&=\begin{pmatrix}\left(\bullet^+_{el}e^{-\frac{i5\pi}{4}}+\bullet^+_{in}e^{-\frac{i7\pi}{4}}\right)_{cl}\\ \left(\underline{o}_{el}e^{\frac{i5\pi}{4}}+\underline{o}_{in}e^{\frac{i7\pi}{4}}\right)_{\underline{cl}}\end{pmatrix}_{\gamma(+k)}+\begin{pmatrix}\left(\underline{\bullet}^+_{el}e^{\frac{i3\pi}{4}}+\underline{\bullet}^+_{in}e^{\frac{i\pi}{4}}\right)_{\underline{cl}}\\ \left(o_{el}e^{i-\frac{3\pi}{4}}+o_{in}e^{-\frac{i\pi}{4}}\right)_{cl}\end{pmatrix}_{\gamma(-k)}
\end{aligned}
\tag{37}
$$

This process shows that the superposition of two fermion chains is equivalent to a superposition of two boson chains that can fit on a single field line. From this aspect we can deduce the demonstration (which will be reported in the next article) that two electric charges with opposite sign attract each other while two electric charges with the same charge repel each other. The process opposite to the annihilation process is called the "***pair creation***"; the demonstration of this process is analogous to that reported in Equation (37) once the initial fermions have been exchanged with two initial bosons (read the **Figure 9** from **Figure 9(b2)** to **Figure 9(b1)** to **Figure 9(a)**).

4. Conclusions

The new paradigm (IQuO hypothesis) highlighted in this study not only allows us to identify the origin of the two signs associated with electric charges but also opens new avenues that lead to deeper understandings of the physical world of particles. In the second part of the study on the electric charge by the IQuO idea, we will see that the photon gives rise to an action on electron that will take place in two phases: a first phase (not-dynamic) of reciprocal phase shifts between the two fields [3], implemented through exchanges of energy semi-quanta *sq* (half-quanta) between IQuO, which is followed by a second phase of exchanges of "whole" quanta of energy that determines the dynamic action between photon and electron which, in the case of two electric charges, will determine the attraction or repulsion between them.

As shown in previous studies, the consequences of the IQuO hypothesis [1]-[3] are the possibility of discovering an internal structure of all particles, as the interacting particles, Leptons and Quarks, and interaction particles as Bosons [10] [14]-[17], which paves the way for the formulation of a geometric model of particles [11] [18]-[20]. Furthermore, using the IQuO representation of fields allows us to describe the fundamental processes of interactions [3] [21], the creation and annihilation of pairs [1] [3] with base forms of fermions and bosons and to physically define some fundamental characteristics of particles beyond the electric charge, such as mass [11], color charge [14], spin [11], magnetic moment of an electron in QM [11], the muon mass [20] and the prevision of the Higgs mass [20] [21], and, finally, the masses of light quarks (u, d) and light hadrons, as nucleons.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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