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A New Paradigm in Quantum Fields: The Quantum Oscillator with Semi-Quanta (IQuO) (Part Two)

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Abstract

In this second part of a study about quantum field oscillators with sub-oscillators and semi-quanta (IQuO), it is possible to show that in the initial phase of an interaction between two particles a *no-dynamic* process of reduction from a non-local to a local state takes place which cannot be described by Hamiltonian. We then describe the coupling of two IQuO of different particle-fields either at one point in space or at two distant points via an intermediary chain of coupled IQuO. The first aspect provides an understanding of the basic processes of creating and annihilating a pair. The second aspect describes the behaviour of two electrically charged particles through a process of phase shifts between the respective IQuO chains (C_{F1}, C_{F2}) implemented in a quantum entanglement via an intermediary chain (C_B) of IQuO that originates changes in the direction of the two (C_{F1}, C_{F2}) distance-correlated ones. Thus, the semi-quanta structure of an IQuO and quantum entanglement identify the origin of the empirical law of attraction and repulsion between two electric charges.

Keywords

IQuO, Quantum Entanglement, Phase, Fermion, Boson, Electric Charge

1. Introduction

In physics, the law is known that particles with opposite electric charges attract each other while particles having the same electric charge repel each other. In this article we show the origin of this fundamental aspect of interactions between particles. This is possible in the context of an unprecedented representation of the oscillator of a quantum field (IQuO) that derives from an in-depth study of its structure. In the first part [1] of a study (*in phase of submission in JHEPGC*) on the field oscillator, its structure IQuO was represented, where IQuO is the acronym for **I**ntrinsic **Qu**antum **O**scillator [2] [3]. IQuO can be described by a structure of sub-oscillators crossed by semi-quanta of energy without altering the physical law of interactions in which energy is transmitted by "integer" quanta between interacting particles.

We saw that by using the structure of an IQuO, it is possible to associate the sign of an electric charge with the direction clockwise and counterclockwise of the rotation of the phase associated with the oscillation of the wave representing a particle having an electric charge. This would explain the physical origin of the double sign of the electric charge because this is just represented by of the two directions of rotation of the phase. In this article, we show that using a boson-type IQuO (see the photon), it is possible to detect the direction of rotation of the phase of a Fermion-type IQuO (an electron) from its "double" behavior, the "repulsive" one and "attractive", with other charged particles. Again, through the IQuO representation, we will show that the process of interaction between two particle-fields (Φ_1, Φ_2) develops in two stages: a "*no-dynamic*" first stage, with the mutual phase shift action between the respective oscillators, to achieve the coupling, and a "*dynamic*" second phase, with exchanging semi-quanta pairs [$sq(\bullet,\bullet)$] (or integer quanta) of energy to realize the interaction. In the first stage, see sect. 2.1, the process of reducing the wave function associated with a particle-field through the action of an O_R reduction operator is described. The reduction process [($O_{R(\varphi)} \equiv O_k$), ($O_{R(\varphi)} \equiv O_x$)], with ($O_k$, O_x) projection operators in eigenstates, takes place at the beginning of the coupling between any two IQuO (I_1, I_2) of two field-particles (Φ_1, Φ_2) realized by exchanging semi-quants (operator O_ε) that induce mutual phase shifts (operator O_φ) in the respective membership chains (C_1,C_2) of the field oscillators. The action of these two operators is simultaneously associated with the action of complementary operators (O_x^{-1}, O_k^{-1}) that transform eigenstates into nonlocal states. We show that the simultaneous action of the two operators $\left\{\left[O_x O_k^{-1}\right],\left[O_x O_k^{-1}\right]\right\}$ expresses the Heisenberg uncertainty principle ($\Delta x \Delta k \geq 2\pi$). The reduction process thus makes it possible to carry out the coupling of two fields (Φ_1, Φ_2), see section 2.2, which precedes the interaction between the respective particles. The initial phase of coupling (Φ_1, Φ_2) is described by a nondynamic O_R reduction operation with mutual phase shifts ($\Delta\varphi_1 = -\Delta\varphi_2$) and exchange of semi-quants, [$O_R = (O_{(x,k)} \equiv O_\varphi) \cdot O_\varepsilon$]. After the O_R reduction phase, the interaction phase ($\oplus$) with integer quantum exchange ($\underline{O}_\varepsilon$) takes over. To express the interaction between the two fields mathematically, in Sect.2.3, a composite operation acting on the two fields is then introduced: ($\Phi_1 \underline{\oplus} \Phi_2$) where [$\underline{\oplus} \equiv O_R \cdot \oplus$]. The interaction thus can be represented by a composite operation consisting of a reducing action and then a combining operation of the reduced states. In Sect. 2.3, 2.4 and in Sect. 2.5 briefly shows what emerged in the first part of the study on IQuO: the existence of Field-IQuO "monoverse" in direction of phase rotation, two IQuO types (F-IQuO for Fermions and B-IQuO for bosons), the processes of pair creation with F-IQuO and annihilation in two B-IQuO bosons and the sign of electric charge ($\pm e$) expressed by the two directions of phase rotation. In sect. 3.1 we show geometrically that the coupling between a C_B chain, composed of B-IQuO, and a C_F chain, composed of F-IQuO, determines a change in the direction of the C_B chain. In Sect. 3.2, we then show geometrically that two chains of F-IQuO (F_1, F_2), can couple even when placed far apart, via an intermediary C_B-chain, which induces correlated phase shifts on the two respective extreme IQuO (I_1, I_2). In this way, see the Sect. 3.3, a coupling between two distant particles in space is described in terms of "***quantum entanglement***" showing that the two (F_1, F_2) chains diverge if they have the same direction of phase rotation (that is electric charges of the same sign) while they converge if they have opposite direction (that is electric charges of opposite sign), see the Sect. 3.4. This thus demonstrates why electric charges of the same sign repel each other while those with opposite signs attract each other. This completes the study undertaken on the quantum oscillator (IQuO) by thus demonstrating that the sign of the electric charge is connected to the direction of the phase rotation of the wave function associated with a particle.

2. The Reduction Process in IQuO-Representation

2.1. The Process of Wave Function Reduction

In the first part [1] of our study on the quantum field oscillator, we formulated a new representation of it in terms of sub-oscillators traversed by semi-quanta. The field oscillator expressed in this form has been denoted as IQuO and we have associated with it the IQuO-representation, see also ref. [2]-[4]. Consider two particles expressed by their respective scalar fields (Φ_1, Φ_2), given by [5]:

$$\left\{\begin{aligned}\Phi_1 &= \sum_k \varpi_k \left[\left(a_{1k}\left(\mathrm{e}^{-i\hat{r}\omega_k t+\alpha}\right)+a^{+}_{1(-k)}\left(\mathrm{e}^{i\hat{r}\omega_k t+\alpha}\right)\right)\left(\mathrm{e}^{ikx}\right)\right]\\ \Phi_2 &= \sum_k \varpi_k \left[\left(a_{2k}\left(\mathrm{e}^{-i\hat{r}\omega_k t+\beta}\right)+a^{+}_{2(-k)}\left(\mathrm{e}^{i\hat{r}\omega_k t+\beta}\right)\right)\left(\mathrm{e}^{ikx}\right)\right]\end{aligned}\right\} \tag{1}$$

where it is:

$$\begin{gathered}\Phi\left(x_i,t\right)=\left(\frac{1}{\sqrt{V}}\right)\sum_k q_k\left(t\right)\mathrm{e}^{i(\boldsymbol{k}\cdot\boldsymbol{x})}=\left(\frac{1}{\sqrt{V}}\right)\sum_k\left[\left(\sqrt{\frac{\hbar}{2\omega_k}}\right)\left(a_k+a^{+}_{-k}\right)\right]\mathrm{e}^{i(\boldsymbol{k}\cdot\boldsymbol{x})}\\ \varepsilon_{(n_1,n_2,\cdots,n_k)}=\sum_k\left[\hbar\omega_k\left(n_k+\frac{1}{2}\right)\right],\quad P_{(n_1,n_2,\cdots,n_k)}=\sum_k\left[\hbar k_k\left(n_k\right)\right]\end{gathered} \tag{2}$$

where we denote by ($\varphi_k = \boldsymbol{k}\cdot\boldsymbol{x}$) the instantaneous phase of the oscillation relative to the *k*-mode associated with the wave function Φ. We will show that in the IQuO representation the interaction between two particle-fields (Φ_1, Φ_2) takes place in two stages: the first stage is the "*non-dynamic*" process of wave function reduction while the second stage is the "*dynamic*" process of interaction. As is well known, the interaction between two particles occurs when there is an exchange of energy between them. If the particles are represented by extended fields, the coupling between the two particle-fields (Φ_1, Φ_2) is obtained in space through a "*local*" elastic coupling between any two IQuO (I_1, I_2) of these two fields. This is because the exchange of energy between two particles cannot occur at all points of their respective representative fields. This condition leads us to admit, once again, the process of reduction of the wave function in quantum field theory (collapse of the wave function). In this way, if the interaction between particles implies an exchange of "*integer*" quanta of energy governed by the Hamiltonian H of the interacting system, it is intuitive to admit that the reduction process "precedes" the interaction and therefore cannot be described by the Hamiltonian of the system. This consideration implies a profound revision of the famous problem of the collapse of the wave function present in Quantum Mechanics (QM). If, for the QM, observing for an observer means "interacting", it becomes mandatory to introduce the observer, with its instruments of observation and measure, into the Hamiltonian of the system as well. This gives rise to the problem of the boundary between the macroscopic and microscopic realities of physics. However, we must not forget the duplicity of behavior of a particle (wave-corpuscular), which leads us to represent it as a "field-quantum" so if we admit a "point interaction" between two particles, with an exchange of energy, we must admit that the respective fields must "reduce" to two local oscillators in mutual "elastic coupling" with each other. Even today, a definitive solution to these two aspects (the measurement problem or observation and the reduction problem) there is not in literature of QM. However, if we demonstrate in the IQuO representation, even thanks to the theory of oscillations and waves, that the interaction between particles, including also the interaction present in measuring instruments, is "subsequent" ($t_R < t_{int}$) to a reduction process from a non-local to a local state of the oscillator fields, then the two problems mentioned above are on the way to a probable and definitive solution. This would mean that the reduction process is separate from the interaction process and that it takes place in a different way. This is possible if one assumes that:

- The reduction process concerns a physical system that can in any case be traced back to a system of oscillators
- The reduction process would occur in the "initial" phase of a random elastic coupling between any two IQuO-oscillators (I_1, I_2) of two respective fields (Φ_1, Φ_2) where each of these, for descriptive simplicity, can be represented by a lattice of "*j-chains*" $(C_j)_i$, each of them composed of coupled oscillators
- The reduction process manifests itself through reciprocal phase shifts (phase variation) between oscillators that reciprocally couple
- The phase shifts between (I_1, I_2) propagate at the phase propagation velocity $v_\varphi > c$, as predicted by wave theory, along their respective belonging chains (C_1, C_2)
- The phase shifts are produced by exchanges of sq(•,**o**) pair between the field oscillators without, however, involving exchanges of "*integer*" quanta or pairs of sq(•,•)

This last assert defines the reduction process as a "*non-dynamic action*": the exchange (see refer [4]) of a pair (•,**o**) between two IQuO (I_1, I_2) does not imply the presence of interaction (!) between the two particles. Therefore, it is the “initial” phase shifts produced by the exchanges of *sq*(•,**o**) between two IQuO (I_1, I_2) that “reduces” the physical system represented by the two respective fields (Φ_1, Φ_2).

We note that at the end of the reduction process the coupling between the two IQuO (I_1, I_2) can result, see the one part [1] and ref. [4], in two configurations (A, B), see **Figure 1**:

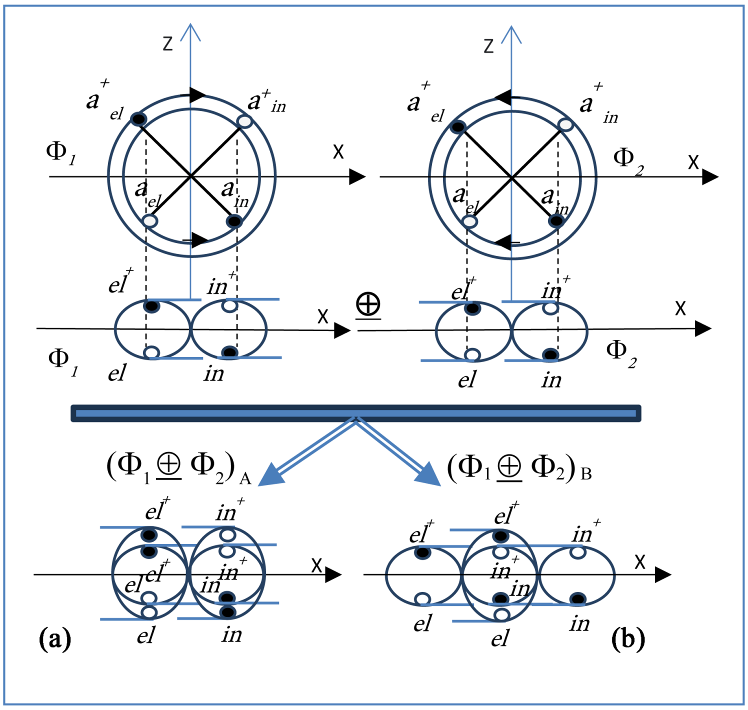

Figure 1. Final configurations in reduction stage of two IQuO couplings.

These configurations [$(\Phi_1 \underline{\oplus} \Phi_2)_a$, $(\Phi_1 \underline{\oplus} \Phi_2)]_b$ are given by adaptation phase shifts caused by *sq* switching from a sub-oscillator of I_1 to that of I_2 and vice versa. Energy exchange with phase shift between *sq* occurs between full *sq* (•) and empty *sq* (**o**) that is (• ⇔ **o**). When these configurations are reached, simultaneous exchange of two pairs (• ⇔ **o**) and thus an integer quantum (•, •) is possible, thus opening the “dynamic” interaction phase. In **Figure 1(a)**, the I_1-IQuO overlaps on the I_2-IQuO: the exchange of energy between full and empty *sq* (• ⇔ **o**) results in the possibility of originating a pair of IQuO single-moving in two opposite directions (***r***) of phase rotation (that is the operators (a, a^+) of each IQuO all have the same direction of rotation (***r***)). In **Figure 1(b)**, a sub-oscillator of I_1 overlaps on the sub-oscillator of I_2: in this case, initiates a dynamic interaction phase of elastic and inelastic type between the particles.

The nondynamic process of reduction can be associated with an $\boldsymbol{O_R}$ operator [6] [7] that acts in two different ways, $\boldsymbol{O_R} \equiv (O_x, O_k)$:

1) Reduction to an eigenstate $|k_i\rangle$ relative of the moment p_i (with $p_i = hk_i$) to a k_i-mode of oscillation: $O_R \equiv O_k$

2) Reduction to a local eigenstate $|x_i\rangle$ of the position x_i: $O_R \equiv O_x$

First case $O_R \equiv O_k$

In the first case, the action of a *reduction operator* O_k will then only be focused on the operator q_k of Φ in Equation (2), acting by phase shift [$\exp(i\varphi_s)$] on the q_{ki} oscillation mode, where $s \in (k_1 \ldots k_n)$. So, the O_k operator reduces the state vector Φ to an eigenstate Φ_s: $[\mathrm{O}_k \Phi = \Phi_s]_{(k=s)}$, where O_k is a *projection operator* ($|k_i\rangle\langle k_i|$ with $k_{(k=s)} = (|s\rangle\langle s|)$. A due note: the physics presented here can be verified in any physics laboratory with teaching aids such as a "*slinky*" [8]. Recall that to induce a mode of oscillation an external force must act, see the experiments by a slinky:

1) with the same frequency as that of the k-mode: $\omega_{est} = \omega_k$

2) in an impulsive manner (see the swing example) at a given point (x_i) but in φ-phase (phase *concordance*) with the oscillation at that point of the k-mode: $\varphi_{est}(x_i) = \varphi_k(x_i)$.

In this last case (*concordant phase shift*) the chains (C_1, C_2) can assume the mode characterized by the wavelength $\lambda(k_i)$. We remember that along a chain of elastically coupled oscillators ($\mathrm{I_k}$), a "constructive" superposition of oscillation modes can arise generating the so-called "wave packet". Let us consider the state vector Φ describing a wave packet. For simplicity, we set [$\alpha = \beta = 0$, $r = +1$] in Equation (2); it follows [5]:

$$\left\{\begin{matrix} \Phi(x,t) = \sum_k \left[A_k(t)\left(\mathrm{e}^{ikx}\right)\right] \\ A_k(t) = \sum_k \varpi_k \left[\left(a_k\left(\mathrm{e}^{-i\omega_k t}\right) + a^{+}_{(-k)}\left(\mathrm{e}^{i\omega_k t}\right)\right)\right] \end{matrix}\right\} \tag{3}$$

Which we can represent in the following form:

$$\begin{aligned} \Phi(x,t) &= \sum_k \left[A_k(t)\left(\mathrm{e}^{ikx}\right)\right] = \sum_k \left[\left(a_k\left(\mathrm{e}^{-i\omega_k t}\right) + a^{+}_{(-k)}\left(\mathrm{e}^{i\omega_k t}\right)\right)\left(\mathrm{e}^{ikx}\right)\right] \\ &= \sum_k \left[\left(a_k\left(\mathrm{e}^{-i\omega_k t}\right)\left(\mathrm{e}^{ikx}\right) + a^{+}_k\left(\mathrm{e}^{i\omega_k t}\right)\left(\mathrm{e}^{-ikx}\right)\right)\right] \\ &= \sum_k \left[\left(a_k\left(\mathrm{e}^{\left[i(kx - i\omega_k t)\right]}\right) + a^{+}_k\left(\mathrm{e}^{\left[-i(kx - i\omega_k t)\right]}\right)\right)\right] \\ &= \sum_k \left[\left(a_k\left(\mathrm{e}^{i(p_k \cdot x_k)/\hbar}\right) + a^{+}_k\left(\mathrm{e}^{-i(p_k \cdot x_k)/\hbar}\right)\right)\right] \end{aligned} \tag{4}$$

where $(p_k \cdot x_k)/h = (kx - \omega_k t)$. We express by means of a column matrix the non-local state in k (with $k = 2\pi/\lambda_k$), that is $\Phi(k)$ for [h]:

$$\Phi(k) = \begin{pmatrix} A_1(k_1) \\ \vdots \\ A_n(k_n) \end{pmatrix} = \begin{pmatrix} \left(a_{k_1}\left(\mathrm{e}^{ip_{k_1} \cdot x_{k_1}}\right) + a^{+}_{k_1}\left(\mathrm{e}^{-ip_{k_1} \cdot x_{k_1}}\right)\right) \\ \vdots \\ \left(a_{k_1}\left(\mathrm{e}^{ip_{k_1} \cdot x_{k_1}}\right) + a^{+}_{k_1}\left(\mathrm{e}^{-ip_{k_1} \cdot x_{k_1}}\right)\right) \end{pmatrix} \equiv \begin{pmatrix} A_{k_1}\left(\mathrm{e}^{i\varphi_{k_1}}\right) \\ \vdots \\ A_{k_n}\left(\mathrm{e}^{i\varphi_{k_n}}\right) \end{pmatrix} \tag{5}$$

The action of a "reduction operator" $\boldsymbol{O_k}$ will then only be focused on the operator A_{ki} of Equation (3). This operator can be regarded as a "projector" $|k\rangle\langle k|$ and will correspond to the product of three matrices $A \times B \times C$. The first matrix (A) correspond to the phase shift matrix $\{\phi_{sk} = \exp[i(\varphi_s - \varphi_k)]\}$, with [$k = (k_1, \ldots k_n)$, $s = (s_1, \ldots s_n)]_{(k \equiv s)}$, φ_k are the characteristic phases of k-modes and $\exp(\varphi_s)$ is the phase shift produced by I_1 on the I_2. We demonstrate, see the Equation (5), that $\{\phi_{sk}\cdot\Phi(k)=\lambda\Phi(k)\}$, that is $\Phi(k_i)$ are eigenstates of the phase shifts matrix ϕ_{sk}. The second (*B*) matrix is a diagonal matrix (δ_{ik}), therefore we will have: an O_{ik} matrix-operator consisting of

$$\boldsymbol{O}_k \equiv \left(\left(O_{ik}\right)\right)=\left(\left(\phi_{sk}\right)\right)\times\left(\left(\delta_{ik}\right)\right)=\left(\left(\exp\left[i\left(\varphi_s-\varphi_k\right)\right]\right)\right)\times\left(\left(\delta_{ik}\right)\right)\equiv\left(\left(O_\varphi\right)\right)$$

where the unique value $s\in(k_1,\dots,k_n)$. In matrix form it is:

$$O_\varphi=\begin{pmatrix}\exp\left[i\left(\varphi_s-\varphi_{k_1}\right)\right] & 0 & 0\\ 0 & \ddots & 0\\ 0 & 0 & \exp\left[i\left(\varphi_s-\varphi_{k_n}\right)\right]\end{pmatrix}\tag{6}$$

The third matrix (*C*) is another diagonal matrix $\delta_{sk}(A_k)$; therefore, we will have:

$$\left(\left(O_R\right)\right)\equiv\left(\left(O_k\right)\right)=\left(\left(O_{ik}\left(\varphi_{(k=s)}\right)\right)\right)=\left(\left(\exp\left[i\left(\varphi_s-\varphi_k\right)\right]\right)\right)\times\left(\left(\delta_{ik}\right)\right)\times\delta_{sk}$$

The $O_R\equiv O_k$ action on the $\Phi(k)$ is:

$$\begin{aligned}O_k\Phi(k)&=\begin{pmatrix}\delta_{sk}\mathrm{e}^{\left[i\left(\phi_s-\phi_{k_1}\right)\right]} & 0 & 0\\ 0 & \ddots & 0\\ 0 & 0 & \delta_{sk}\mathrm{e}^{\left[i\left(\phi_s-\phi_{k_n}\right)\right]}\end{pmatrix}\begin{pmatrix}A_{k_1}\left(\mathrm{e}^{i\phi_{k_1}}\right)\\ \vdots\\ A_{k_n}\left(\mathrm{e}^{i\phi_{k_n}}\right)\end{pmatrix}\\ &=\begin{pmatrix}\delta_{sk}A_{k_1}\mathrm{e}^{\left[i\left(\phi_s-\phi_{k_1}\right)\right]}\left(\mathrm{e}^{i\phi_{k_1}}\right)\\ \vdots\\ \delta_{sk}A_{k_n}\mathrm{e}^{\left[i\left(\phi_s-\phi_{k_n}\right)\right]}\left(\mathrm{e}^{i\phi_{k_n}}\right)\end{pmatrix}=\begin{pmatrix}\delta_{sk}A_{k_1}\left(\mathrm{e}^{i\phi_{k_s}}\right)\\ \vdots\\ \delta_{sk}A_{k_n}\left(\mathrm{e}^{i\phi_{k_s}}\right)\end{pmatrix}=A_{k_s}\left(\mathrm{e}^{i\phi_{k_s}}\right)\equiv\Phi\left(k_s\right)\end{aligned}\tag{7}$$

thus obtaining, after reduction, a single eigenstate $\Phi(k_s=s)$ or an oscillation mode with λ_s.

Second case $O_R\equiv O_x$

Let us consider the reduction of the field to a local eigenstate of position $|x_i\rangle$. If the phase shifts are different from $[\exp(-i\varphi_s)]$, that is "*discordant*", then no oscillation mode is formed, and the two fields are reduced to the two oscillators (I_1, I_2) that are coupling. The "discordant" phase shift propagates along all the chains of the field at superluminal phase velocity (that is for spatial intervals) breaking the phase concordance between the contiguous oscillators and thus "destroying" the various monochromatic modes of oscillation of the chains (eigenstates Φ_k) and those of even a possible wave packet propagating along a chain. Discordant phase shifts induce along the chain an "indeterminate" (or "*uncertainty*") state in the *k*-modes, consistent with the axioms of the quantum mechanics. This step can be described by the action of an "inverse" operator to the reduction operator (O_k) defined as $[O_R\equiv(O_k)^{-1}]$. The *x* position of the two IQuO $(I_1, I_2)_x$ is now well determined; in this case the fields are *reduced* into a limited spatial range Δx in which the two IQuO with their oscillation amplitudes are located. Therefore, to a discordant phase shift action, we associate the *position operator* O_x, that is $(|x_i\rangle\langle x_i|)$.

The Heisenberg uncertainty relations

In the case of discordant phase shifts, we can thus associate two operators with the O_R reduction process: the operator O_x (that is $(|x_i\rangle\langle x_i|)$), simultaneously with the operator $(O_k)^{-1}$. We will then say that the two operators are associated $\mathbf{O}_R = [(O_k)^{-1} \cdot O_x]$. We associate an "*uncertainty*" of k with operator $(O_k)^{-1}$, that is $\underline{\Delta}k$. By symmetry, just as there is a relation between O_x and $(O_k)^{-1}$, then there will also be a relation $\mathbf{O}_R = [O_k \cdot (O_x)^{-1}]$, with an uncertainty $\underline{\Delta}x$. Since in a position and pulse measurement we have a reduction process, the measurement errors $(\Delta x, \Delta k)$ could be indeterminacy values of the measured physical quantity, that is: $[(\Delta x = \underline{\Delta}x), (\Delta k = \underline{\Delta}k)]$. Then, we can consider the products $\left[\Delta x \cdot \underline{\Delta}k\right]_{\left(O_x,(O_k)^{-1}\right)}$, $\left[\underline{\Delta}x \cdot \Delta k\right]_{\left(O_k,(O_x)^{-1}\right)}$; we suspect that it is:

$$\left[\underline{\Delta}x \cdot \underline{\Delta}k\right]_{\left(O_x,(O_k)^{-1}\right)} = \left[\underline{\Delta}x \cdot \underline{\Delta}k\right]_{\left(O_k,(O_x)^{-1}\right)} = \left[\underline{\Delta}x \cdot \underline{\Delta}k\right]_{\left((O_k)^{-1},(O_x)^{-1}\right)} \tag{8}$$

where $[((O_k)^{-1}, (O_x)^{-1}) \Leftrightarrow \Psi]$ indicates a non-local state, as in a wave packet. Recall that in a wave packet there is $[(\Delta\nu \cdot \Delta t \geq 1) \Leftrightarrow (\Delta x/\Delta\lambda \geq 1)]$ relations apply, which we will write as: $\{[(\Delta\nu \cdot \Delta t \geq 1) \Leftrightarrow (\Delta x/\Delta\lambda \geq 1)] \Leftrightarrow \underline{\Delta}x \cdot \underline{\Delta}k \geq 2\pi\}$

Let us recall De Broglie's relation $p = hk$; it is easily shown that if we go to indeterminacy $(\underline{\Delta})$ it would be $\underline{\Delta}p = \hbar\underline{\Delta}k$. Therefore, we have:

$$\left[\underline{\Delta}x \cdot \underline{\Delta}k \geq 2\pi\right] \to \left[\underline{\Delta}x \times \left(\underline{\Delta}p/\hbar\right) \geq 2\pi\right] \to \left[\underline{\Delta}x \cdot \underline{\Delta}p \geq 2\pi\hbar\right] \tag{9}$$

These are the well-known Heisenberg uncertainty relations [9].

In whatever type of reduction, at the end of this process there is an "*adaptation phase*" with a Δt_{ad}, in which there is an instantaneous reciprocal induction of phase change (*phase-shifting action*) between two IQuO (I_1, I_2); let us conjecture that it is:

$$\Delta\varphi_1 = -\Delta\varphi_2 \tag{10}$$

and the phase shift will be expressed by the operator O_φ (*phase shift action operator*), with $[O_\varphi = [\exp(-i\varphi)]$. To the phase shifts given by exchanges of semi-quanta $sq(\bullet,\mathbf{o})$, not integers, occurring between the two IQuO (I_1, I_2), we will associate the operator O_ε (*operator of semi-quanta exchange*) that it exchange the $sq(\bullet,\mathbf{o})$ between two oscillators (I_1, I_2): $[sq_1(\bullet) \Leftrightarrow sq_2(\mathbf{o}), sq_2(\bullet) \Leftrightarrow sq_1(\mathbf{o})]$. Therefore, we will associate a reduction operator O_R given by $[O_R = O_\varphi\, O_\varepsilon]$. Note that the exchange of a pair $sq(\bullet,\bullet)$ can be given by the combination of two pair-exchange operators $O_\varepsilon\,(sq(\bullet,\mathbf{o}))$, that is: $\underline{O}_\varepsilon\,(sq(\bullet,\bullet)) = O_\varepsilon\,(sq(\bullet,\mathbf{o})) \cdot O_\varepsilon\,(sq(\bullet,\mathbf{o}))$. In this case, the operator $\underline{O}_\varepsilon$ determines the exchange of a quantum $(\bullet,\bullet)$ and is thus present in the dynamic phase of the interaction. Having finished the initial phase of reduction, the coupling of the two terminals becomes "dynamic" and the interaction phase begins with exchange of integer quanta ($sq(\bullet,\bullet)$ pairs) of energy between the two terminals of the respective chains, now these in a given mode of oscillation. This reminds us of the interaction of particles [10] with given initial momentum (p_{i1}, p_{j2}). At this stage the system will be described by the Hamiltonian of the complete global system, from whose symmetries the conservations of total energy, momentum and total angular momentum will arise. In addition, the phase shifts produced in both the "*nondynamic*" and "*dynamic*" phases do not alter the signs of the electric charge, since the latter is given by invariance by gauge transformations involving just the phase [11] [12]. In the IQuO model [13] this corresponds to an invariance of the direction of rotation of the phase in the case of phase shifts produced in the reducing phase.

2.2. The Coupling between Two IQuO

We denote by ($\Phi_1 \underline{\oplus} \Phi_2$) the coupling of two fields where the sign $\underline{\oplus}$ is the reciprocal action operation with components $\underline{\oplus} \equiv (O_R, \oplus)$. O_R describes the *non-dynamic* initial reduction phase while the $\oplus$ sign indicates, after the reduction process, the *dynamic* coupling by exchanges of *sq*(•,•) pairs between two IQuO (I_1, I_2) of two fields (Φ_1, Φ_2). As we well know, in inelastic processes other particles can be created than the initial ones, see the creation of pairs, where the final fields (Ψ_1, Ψ_2) are different from the initial ones (Φ_1, Φ_2). To deal with such a process, let us consider for simplicity's sake that we have already two reduced fields in a local *k*-moment state, that is (Φ_{1k}, Φ_{2k}), consequence of the previous reduction process with an operator $O_R = O_k$, see the Equation (7). Suppose that by chance two IQuO (I_1, I_2) of the two respective fields (Φ_{1k}, Φ_{2k}) couple together in the same x point (let us not forget that a quantum oscillator has a well-defined spatial dimension (oscillation amplitude), that is Δx). Initially, a transition phase there is (into a time Δt_{tr}) with a mutual adjustment between respective oscillation states of the IQuO (I_1, I_2) of two respective fields. During this time interval Δt_{tr} the reciprocal phase shifts (see Equation (10), that is $|\varphi_1| = |-\varphi_2| = \varphi$) in discordance reduce the two fields to two (I_1, I_2) oscillators. This reduction process is operated by the operator $O_R = O_x$ to which a phase shift operator $(O_\varphi)_x$ is corresponding

$$\left(O_\varphi\right)_x = \begin{pmatrix} e^{i\varphi_1} & 0 \\ 0 & e^{i\varphi_2} \end{pmatrix}_x = \begin{pmatrix} e^{i\varphi} & 0 \\ 0 & e^{-i\varphi} \end{pmatrix}_x \tag{11}$$

The operator $(O_\varphi)_x$, associated with the phase shifts ($\varphi_1 = -\varphi_2$), acts on the fields (Φ_{1k}, Φ_{2k}); since the matrix O_φ is a (2 × 2) matrix, the fields must be expressed by column matrices (2 × 1). The "unique" system Φ will be represented by a state with two matrices:

$$\Phi \equiv \left\{ \begin{pmatrix} \Phi_{1k} \\ 1 \end{pmatrix}, \begin{pmatrix} 1 \\ \Phi_{2k} \end{pmatrix} \right\}$$

Note that the operator $(O_\varphi)_x$ acts both on the Φ_{1k} by phase shifts ($\varphi_1 = -\varphi_2$) than on the Φ_{2k}. We then will admit an operation:

$$\left(\Phi_1 \underline{\oplus} \Phi_2\right) = \left\{ \oplus_{O_\varphi} \left(\Phi_{1k}, \Phi_{2k}\right) \right\} = \left\{ \left[\Phi_{1k} \times \left(O_\varphi \times \Phi_{2k} \right) \right]_{\oplus} \right\} \tag{12}$$

with O_φ operating to right than left. Remember that $\underline{\oplus} \equiv (O_R, \oplus)$ where $\oplus$ is the dynamic operation and here $O_R \equiv O_\varphi$. Besides, we will associate the operator O_ε to the phase shifts ($\varphi_1 = -\varphi_2$) given by exchanges of semi-quants *sq*(•,o), not integers, occurring between the two IQuO (I_1, I_2). Therefore, in the coupling between the two fields (Φ_{1k}, Φ_{2k}), the operator O_R will correspond the operators O_R

$\equiv (\mathrm{O}_\varepsilon, (\mathrm{O}_\varphi)_x)$. Then, we will have:

$$\begin{aligned}
&\Phi_{1k} \underline{\oplus} \Phi_{2k} \\
&= \left\{ \mathrm{O}_\varepsilon \cdot \left[\Phi_{1k} \cdot \left(\left(\mathrm{O}_\varphi \right)_x \cdot \Phi_{2k} \right) \right] \right\}_\oplus = \left\{ \mathrm{O}_\varepsilon \cdot \left[\begin{pmatrix} \Phi_{1k} \\ 1 \end{pmatrix} \cdot \left[\begin{pmatrix} \mathrm{e}^{i\varphi} & 0 \\ 0 & \mathrm{e}^{-i\varphi} \end{pmatrix}_x \cdot \begin{pmatrix} 1 \\ \Phi_{2k} \end{pmatrix} \right] \right] \right\}_\oplus \\
&= \left\{ \mathrm{O}_\varepsilon \cdot \left[\begin{pmatrix} \Phi_{1k} \\ 1 \end{pmatrix} \cdot \left[\begin{pmatrix} \mathrm{e}^{i\varphi} \\ \mathrm{e}^{-i\varphi} \Phi_{2k} \end{pmatrix} \right]_x \right] \right\}_\oplus = \left\{ \mathrm{O}_\varepsilon \cdot \left[\Phi_{1k} \mathrm{e}^{i\varphi} + \mathrm{e}^{-i\varphi} \Phi_{2k} \right] \right\}_\oplus \\
&= \left[\Phi_{1k} \mathrm{e}^{i\varphi} + \mathrm{e}^{-i\varphi} \Phi_{2k} \right]_{\mathrm{O}_\varepsilon (\bullet \to \mathrm{o})}
\end{aligned} \tag{13}$$

The action of the second exchange operator $\mathrm{O}_\varepsilon(sq_2(\bullet,\mathbf{o}))$ can induce a process of reduction but if we have a sequence of actions of $\mathrm{O}_\varepsilon(sq_i(\bullet,\mathbf{o}))$, they will follow a sequence of phase shifts as long as at the end of the global process we have that $[\Delta\varphi_1 = -\Delta\varphi_2]$ to which corresponds $[\Delta k_1 = -\Delta k_2]$ with the final eigenstates (k_1', k_2'). There is this possibility when a coupling of type of **Figure 1(b)** happens.

2.3. The Coupling between Two Fields-Particles with Pair Creation

Now we consider a coupling between two fields-particles as in **Figure 1(a)**, where the I_1-IQuO overlaps on the I_2-IQuO. Firstly, we need to precise that if we understand the particle always as a field, where all quantum oscillators of field are coupled, then any interaction between fields-particles must not alter the direction of phase rotation r of each field. This mean that when a field originates, all coupled field oscillators are in the same eigenstate $|r'\rangle$, and the interactions are of "***gauge***" type [14], that is the interactions produce phase shifts but without altering the direction of phase rotation (r'). The eigenstates' scheme of the r operator, relative to the physical system of the two coupled IQuO, is:

$$\boxed{|\Phi\rangle_{(\text{IQuO 1 + IQuO 2})} = |\Phi\rangle_{(1)} \underline{\oplus} |\Phi\rangle_{(2)} \Rightarrow \begin{cases} |\Phi(r' = \pm 1)\rangle_{(1)} \underline{\oplus} |\Phi(r' = \pm 1)\rangle_{(2)} \\ |\Phi(r' = \pm 1)\rangle_{(1)} \underline{\oplus} |\Phi(r' = \mp 1)\rangle_{(2)} \end{cases}} \tag{14}$$

Let us first examine the two possible combinations of the "zero eigenvalue" of (r):

$$(|\Phi_1(r' = \pm 1)\rangle) \underline{\oplus} (|\Phi_2(r' = \mp 1)\rangle).$$

In **Figure 1(a)**, the coupling between two fields can occur at a given point (x) of the space between the two corresponding oscillators $(\mathrm{I}_1, \mathrm{I}_2)$; the initial reduction phase begins with the action of the operator O_x. This operator, in addition to locally reducing a field, see the projector $(|x_i\rangle\langle x_i|)$, makes k "*indeterminate*", as if an inverse operator of O_k had been applied, that is O_k^{-1}. However, the local coupling of the two oscillators, after a preliminary adaptation phase, can determine a state in which the two IQuO constitute a single IQuO (see **Figure 1(a)**), like a single field Φ to which a single moment k_0 is associated. The pair creation process passes through this physical state of "*uniqueness*". This means that the coupling $(\mathrm{I}_1, \mathrm{I}_2)$ can be described by initially considering a system of two fields (Φ_1, Φ_2) with a same single moment k_0. Recall in a pair creation the two exiting particles have the same energy and impulse $|k|$ and the same mass ($m_0 = \hbar\omega_{0k}/c^2$). So, to deal with such a process, we could consider for simplicity's sake two reduced fields already in a local k-moment state, that is $\Phi \equiv (\Phi_{1k}, \Phi_{2k})$ on which an operator O_x acts. We'll have (for simplicity one sets $\alpha = \beta$ in Equation (1)) from the Equation (1) that:

$$\left\{\begin{aligned} \Phi_{1x}(r' = -1) = \varpi_k\left(a_k\mathrm{e}^{i\omega_k t} + a_k^{+}\mathrm{e}^{-i\omega_k t}\right)\left(\mathrm{e}^{ikx}\right) \\ \Phi_{2x}(r' = +1) = \varpi_k\left(a_k\mathrm{e}^{-i\omega_k t} + a_k^{+}\mathrm{e}^{i\omega_k t}\right)\left(\mathrm{e}^{ikx}\right) \end{aligned}\right\}_{(k=k_0)} \tag{15}$$

By of Equation (12), applying the Equation (13), we will then have:

$$\boxed{\begin{aligned} &\Phi_{1x} \oplus_{(\varepsilon,\varphi)} \Phi_{2x} \\ &= \left\{\left[\varpi_k\left(a_k\mathrm{e}^{i\omega_k t} + a_k^{+}\mathrm{e}^{-i\omega_k t}\right)\left(\mathrm{e}^{ikx}\right)\right] \oplus_{(\varepsilon,\varphi)} \left[\varpi_k\left(a_k\mathrm{e}^{-i\omega_k t} + a_k^{+}\mathrm{e}^{i\omega_k t}\right)\left(\mathrm{e}^{ikx}\right)\right]\right\} \\ &= \left\{\left[\varpi_k\left(a_k\mathrm{e}^{i\omega_k t} + a_k^{+}\mathrm{e}^{-i\omega_k t}\right)\left(\mathrm{e}^{ikx}\right)\right]\mathrm{e}^{i\varphi} + \mathrm{e}^{-i\varphi}\left[\varpi_k\left(a_k\mathrm{e}^{-i\omega_k t} + a_k^{+}\mathrm{e}^{i\omega_k t}\right)\left(\mathrm{e}^{ikx}\right)\right]\right\}_{\oplus_\varepsilon} \\ &= \left\{\left[\varpi_k\left(a_k\left(\mathrm{e}^{i\omega_k t + i\varphi}\right) + a_k^{+}\left(\mathrm{e}^{-i\omega_k t + i\varphi}\right)\right)\left(\mathrm{e}^{ikx}\right)\right] + \left[\varpi_k\left(a_k\left(\mathrm{e}^{-i\omega_k t - i\varphi}\right) + a_k^{+}\left(\mathrm{e}^{i\omega_k t - i\varphi}\right)\right)\left(\mathrm{e}^{ikx}\right)\right]\right\}_{\oplus_\varepsilon} \end{aligned}} \tag{16}$$

In the first part of this study on the IQuO the calculation of the sum ($\Phi_1 \underline{\oplus} \Phi_2$) leads to two new fields ($\Psi(\alpha)$, $\Psi(\beta)$) which are respectively expressed by IQuO with annihilation and creation operators (a, a^+) having the same direction $\boldsymbol{r}$ of the phase rotation but with $r'(\Psi_\alpha)$ opposite to $r'(\Psi_\beta)$:

$$\boxed{\begin{aligned} \Phi_{1x} \oplus \Phi_{2x} &= \left(\mathrm{e}^{i\pi/4}\right)\left(\mathrm{e}^{ikx}\right)\left\{\left[\left(a_k^{+} + a_k\left(\mathrm{e}^{-i\pi/2}\right)\right)\left(\mathrm{e}^{-i\omega_k t}\right)\right] + \left[\left(a_k + a_k^{+}\left(\mathrm{e}^{-i\pi/2}\right)\right)\left(\mathrm{e}^{i\omega_k t}\right)\right]\right\} \\ &= \left(\mathrm{e}^{i\pi/4}\right)\left(\mathrm{e}^{ikx}\right)\left\{\left[\left(a_k^{+} - ia_k\right)\left(\mathrm{e}^{-i\omega_k t}\right)\right] + \left[\left(a_k - ia_k^{+}\right)\left(\mathrm{e}^{i\omega_k t}\right)\right]\right\} \\ &= \left(\mathrm{e}^{-i\pi/4}\right)\left(\mathrm{e}^{ikx}\right)\left\{\left[\left(\alpha_k\right)\left(\mathrm{e}^{-i\omega_k t}\right)\right] + \left[(\beta)\left(\mathrm{e}^{i\omega_k t}\right)\right]\right\} \\ &= \Psi_1\left(\alpha(t)\right) + \Psi_2\left(\beta(t)\right) \end{aligned}} \tag{17}$$

The Hamiltonian operator H of the physical system is established, as usual, by the field operator and its conjugate (setting $\beta = \gamma^+$), thus obtaining [11]:

$$\boxed{H = \sum_{-\infty}^{+\infty}\hbar\omega_k\left(\alpha_k^{+}\alpha_k + \gamma_k^{+}\gamma_k + 1\right)} \tag{18}$$

As in the first reduction process, a second sq_2' (•, o) pair, initiates a reduction process by switching from the IQuO pair $(\mathrm{I}_1, \mathrm{I}_2)_x$ to the field pair ($\Psi(\alpha)$, $\Psi(\beta)$) with eigenstates (k_1', k_2'). If we have $|\varphi_1| = |\varphi_2| = \varphi$, it follows that the induced eigenstates by the reciprocal displacement action between the two IQuO are the same for both chains $k_1 = k_2 = k_s$. Recall in a pair creation the two particles have the same energy and impulse k_s (!) and the same mass ($m_0 = \hbar\omega_{0k}/c^2$). In conclusion, we have assumed a coupling with an initial global reduction process ($\underline{\mathrm{O}}_R$) given by a sequence of operators:

$$\underline{\mathrm{O}}_R = \mathrm{O}_{k'} \cdot \mathrm{O}_k^{-1} \cdot \mathrm{O}_x \cdot \mathrm{O}_x^{-1} \cdot \mathrm{O}_k = \mathrm{O}_{k'} \tag{19}$$

where we have considered [($\mathrm{O}_x \cdot \mathrm{O}_x^{-1} = \mathrm{I}$), ($\mathrm{O}_k^{-1} \cdot \mathrm{O}_k = \mathrm{I}$)] with I Identity Operator. Recall associating to operators (O_x, O_k) the operators $(\mathrm{O}_\varepsilon)_\mathrm{i}$. The action of the operation $\underline{\oplus}$ given by Equation (12) determines that the fields ($\Psi(\alpha)$, $\Psi(\beta)$) are invariants for not local gauge transformations on the wave function: in fact, an identical phase shift on all the oscillators in the chain does not change the $|k\rangle$ mode, see the Equation (15). For complex fields, see Equation (17), the literature assigns an electric charge to this type of particle-field. The combination (Φ_1 $\underline{\oplus}$ Φ_2) determines two IQuO with representation:

$$\begin{cases} \Psi(\alpha)_{cl} = \left\{ \left[\left(\bullet_{el}^{+}\right)_{cl} + \left(\mathrm{o}_{in}^{+}\right)_{cl} \mathrm{e}^{i(-\pi/2)} \right] \left(\mathrm{e}^{-i\omega t}\right), \left[\left(\mathrm{o}_{el}\right)_{cl} \mathrm{e}^{i(-\pi/2)} + \left(\bullet_{in}\right)_{cl} \right] \left(\mathrm{e}^{-i\omega t}\right) \right\}_{cl} \\ \Psi(\beta)_{\underline{cl}} = \left\{ \left[\left(\bullet_{el}^{+}\right)_{\underline{cl}} \mathrm{e}^{i(-\pi/2)} + \left(\mathrm{o}_{in}^{+}\right)_{\underline{cl}} \mathrm{e}^{i(\pi)} \right] \left(\mathrm{e}^{i\omega t}\right), \left[\left(\mathrm{o}_{el}\right)_{\underline{cl}} + \left(\bullet_{in}\right)_{\underline{cl}} \mathrm{e}^{i(+\pi/2)} \right] \left(\mathrm{e}^{i\omega t}\right) \right\}_{\underline{cl}} \end{cases} \quad (20)$$

where the *cl-index* indicates clockwise direction, and the *$\underline{cl}$-index* indicates anti-clockwise direction. The graphic representation is, see **Figure 2**:

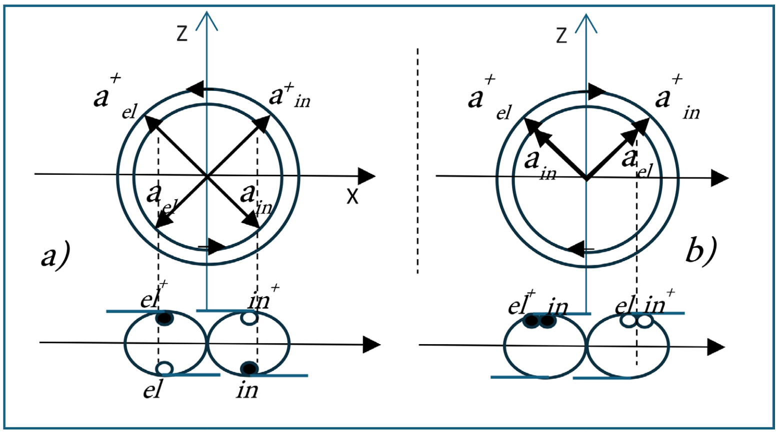

Figure 2. Two IQuO with equal operators in the phase rotation but with opposite rotations.

We note that the two new IQuO have *sq* operators all with the same direction of phase rotation ("*mono-verse*" IQuO). One of the two fields (**Figure 2(a)**) is not as regular in shape as the other, so it requires the intervention of a field Φ_φ that with a phase shift makes it regular in shape. As we mentioned in the first part of the study, this indicates to us that around a mono-verse IQuO in the direction of phase rotation there are fields acting with corrective phase shifts called "*gauge*" fields. As it is well known, the Φ_φ field is a gauge field and the transformation induced by it is called "***gauge transformation***" [11] [14]. We also know the fields Φ_φ act on electrically charged particles-fields. Therefore, we can consider the hypothesis of associating the monoverse fields ($\Psi_{\underline{cl}}$, Ψ_{cl}) with a sign ($\pm q$) of electric charge q connected to two directions of phase rotations: ($\Psi_{\underline{cl}}$, Ψ_{cl}) ⇔($+q$, $-q$). The existence of the Φ_φ corrector field indicates that a "***mono-verse***" IQuO cannot exist in a way "isolated", see the QED. This, as we know from the literature, is analogous to the description in QED where every electric charge is "dressed" by virtual photon fields [11] [15]. This, as we know from the literature, occurs locally because the field in question operates local gauge transformations to make the interacting fields locally symmetrical. The correcting field will be the photon. The coupling mechanism ($\Phi_1 \underline{\oplus} \Phi_2$) of two B-IQuO [1] [2] [3] can have a particular situation in which the exchange of the *sq* to form two F-IQuO is direct and with a matrix of phase shift given by ($|\varphi_1| = |\varphi_2| = 0$). This happens with a particular configuration given by, see **Figure 3**:

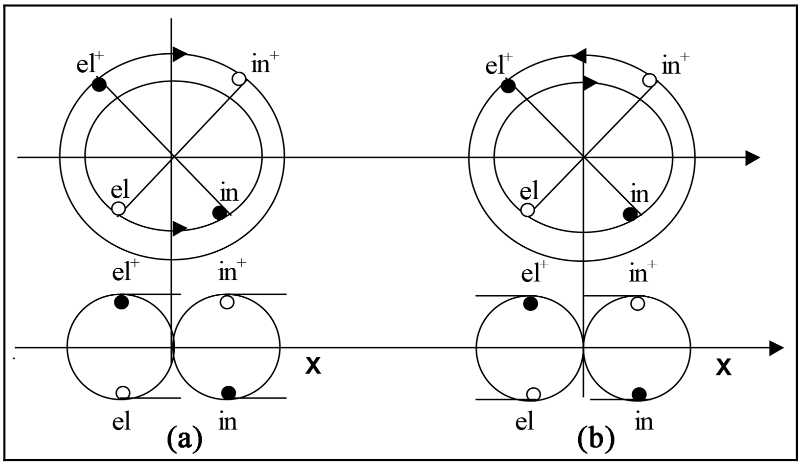

Figure 3. Two IQuO 2-dim. with phase rotation opposites ($\varphi = \omega t = 3\pi/4$), and different eigenvalues $r(\pm 1)$.

With matrices:

$$\left\{ \left(\left(\Phi_1\right)\right) \equiv \begin{pmatrix} \left(\bullet_{1el}^{+} \mathrm{e}^{-i(5/4)\pi} + o_{1in}^{+} \mathrm{e}^{-i(7/4)\pi}\right) \\ \left(o_{1el} \mathrm{e}^{i(5/4)\pi} + \bullet_{1in} \mathrm{e}^{i(7/4)\pi}\right) \end{pmatrix} \quad \left(\left(\Phi_2\right)\right) \equiv \begin{pmatrix} \left(\bullet_{2el}^{+} \mathrm{e}^{i(3/4)\pi} + o_{2in}^{+} \mathrm{e}^{i(1/4)\pi}\right) \\ \left(o_{2el} \mathrm{e}^{-i(3/4)\pi} + \bullet_{2in} \mathrm{e}^{-i(1/4)\pi}\right) \end{pmatrix} \right\} \tag{21}$$

With indices (cl, <u>cl</u>). By Equation (11), in an "ideal" way ($|\varphi_1| = |\varphi_2| = 0$), we obtain:

$$\begin{aligned} \Phi_1 \underline{\otimes} \Phi_2 &= \begin{pmatrix} \Phi_1 \\ 1 \end{pmatrix} \cdot \left[\begin{pmatrix} \mathrm{e}^{i\varphi} & 0 \\ 0 & \mathrm{e}^{-i\varphi} \end{pmatrix}_{\oplus_\varphi} \cdot \begin{pmatrix} 1 \\ \Phi_2 \end{pmatrix} \right]_{\oplus_\varepsilon} \\ &= \left[\begin{pmatrix} \Phi_1 \\ 1 \end{pmatrix} \oplus_\varphi \begin{pmatrix} 1 \\ \Phi_2 \end{pmatrix} \right]_{\oplus_\varepsilon} = \Psi_\alpha + \Psi_\beta \end{aligned} \tag{22}$$

That is:

$$\begin{aligned} \left(\Phi_1 \underline{\oplus} \Phi_2\right) &= \left\{ \begin{pmatrix} \left(\bullet_{1el}^{+} \mathrm{e}^{-i(5/4)\pi} + o_{1in}^{+} \mathrm{e}^{-i(7/4)\pi}\right)_{cl} \\ \left(o_{1el} \mathrm{e}^{i(5/4)\pi} + \bullet_{1in} \mathrm{e}^{i(7/4)\pi}\right)_{\underline{cl}} \end{pmatrix} \oplus_\phi \begin{pmatrix} \left(\bullet_{2el}^{+} \mathrm{e}^{i(3/4)\pi} + o_{2in}^{+} \mathrm{e}^{i(1/4)\pi}\right)_{\underline{cl}} \\ \left(o_{2el} \mathrm{e}^{-i(3/4)\pi} + \bullet_{2in} \mathrm{e}^{-i(1/4)\pi}\right)_{cl} \end{pmatrix}_{\oplus_\varepsilon} \right\} \\ &= \begin{pmatrix} \left(\bullet_{1el}^{+} \mathrm{e}^{-i(5/4)\pi} + \bullet_{1in}^{+} \mathrm{e}^{-i(7/4)\pi}\right) \\ \left(o_{2el} \mathrm{e}^{-i(3/4)\pi} + o_{2in} \mathrm{e}^{-i(1/4)\pi}\right) \end{pmatrix}_{cl} + \begin{pmatrix} \left(\bullet_{2el}^{+} \mathrm{e}^{i(3/4)\pi} + \bullet_{2in}^{+} \mathrm{e}^{i(1/4)\pi}\right) \\ \left(o_{1el} \mathrm{e}^{i(5/4)\pi} + o_{1in} \mathrm{e}^{i(7/4)\pi}\right) \end{pmatrix}_{\underline{cl}} \end{aligned} \tag{23}$$

Graphically it is, see **Figure 4**:

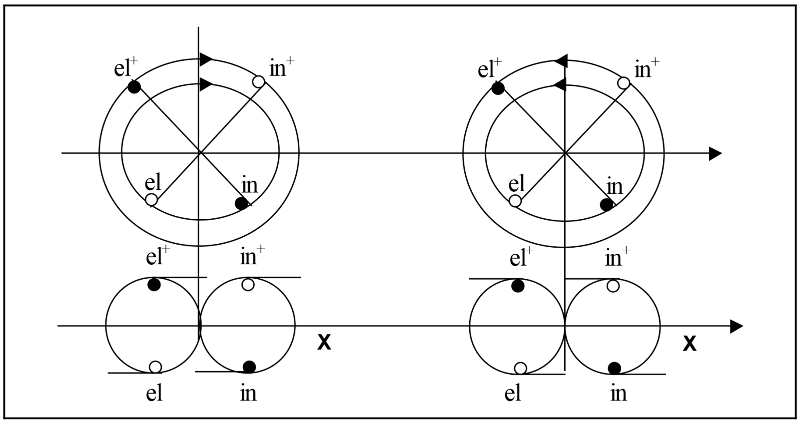

Figure 4. Two IQuO in regular shape with opposite rotations of the phase.

We proved that a Ψ field with a mono-verse IQuO has an electric charge Q with eigenvalue ($q = +1$, $q = -1$). Then, we calculated the electric charge of the (Ψ_{cl}) field in the semi-quanta representation with matrices:

$$\Psi_{cl} \equiv \begin{pmatrix} \left(o_{2el}\mathrm{e}^{-i\pi/2} + o_{2in}\right)_{cl} \\ \left(\overset{+}{\bullet}_{1el}\mathrm{e}^{-i\pi} + \overset{+}{\bullet}_{1in}\mathrm{e}^{-i3\pi/2}\right)_{cl} \end{pmatrix} \tag{24}$$

$$\left(\Psi_{cl}\right)^{+} \equiv \begin{pmatrix} \left(\overset{+}{\bullet}_{el}\mathrm{e}^{i\pi/2} + \overset{+}{\bullet}_{in}\right)_{\underline{cl}} \\ \left(o_{el}\mathrm{e}^{i\pi} + o_{in}^{i3\pi/2}\right)_{\underline{cl}} \end{pmatrix} \tag{25}$$

Using the well-known definition of the electric charge [2] and the commutation relations with semi-quanta (see appendix in ref. [5]) it then follows that:

$$\boxed{\begin{aligned} Q_{cl} &= \int\left[\left(\left(\Psi_{(cl)}^{+}\right)\right)\sigma_3\left(\left(\Psi_{(cl)}\right)\right)\right]\mathrm{d}V \\ &= \int\begin{pmatrix} \left(\overset{+}{\bullet}_{el}\mathrm{e}^{i\pi/2} + \overset{+}{\bullet}_{in}\right) \\ \left(o_{el}\mathrm{e}^{i\pi} + o_{in}^{i3\pi/2}\right) \end{pmatrix}\begin{pmatrix} \left(o_{el}\mathrm{e}^{-i\pi/2} + o_{in}\right) \\ -\left(\overset{+}{\bullet}_{el}\mathrm{e}^{-i\pi} + \overset{+}{\bullet}_{in}e^{-i3\pi/2}\right) \end{pmatrix}\mathrm{d}V \end{aligned}} \tag{26}$$

where σ_3 is a Pauli's matrix. Calculating:

$$\boxed{\begin{aligned} Q'_{cl} &= \left[\left(\left(\overset{+}{\bullet}_{el}\mathrm{e}^{i\pi/2}\right) + \overset{+}{\bullet}_{in}\right)\left(o_{el}\mathrm{e}^{-i\pi/2} + o_{in}\right) - \left(o_{el}\mathrm{e}^{i\pi} + o_{in}^{i3\pi/2}\right)\left(\overset{+}{\bullet}_{el}\mathrm{e}^{-i\pi} + \overset{+}{\bullet}_{in}\mathrm{e}^{-i3\pi/2}\right)\right] \\ &= \left(i\overset{+}{\bullet}_{el}o_{in} - i\overset{+}{\bullet}_{el}\mathrm{e}^{-i\pi}o_{in}^{i3\pi/2}\right) + \left(\overset{+}{\bullet}_{in}o_{el}\mathrm{e}^{-i\pi/2} - \overset{+}{\bullet}_{in}\mathrm{e}^{-i3\pi/2}o_{el}\mathrm{e}^{i\pi}\right) \\ &= \left[\overset{+}{\bullet}_{el}, o_{el}\right] + \left[\overset{+}{\bullet}_{in}, o_{in}\right] + i\left[\overset{+}{\bullet}_{el}, o_{in}\right] + i\left[o_{el}, \overset{+}{\bullet}_{in}\right] = -1 \end{aligned}} \tag{27}$$

We can state that an IQuO with a clockwise direction of phase rotation has a negative value of the physical quantity Q of the Ψ_{cl} field. One also demonstrates that with the following matrix:

$$\Psi_{\underline{cl}} = \begin{pmatrix} \left(o_{el}\mathrm{e}^{-i\pi/2} + o_{in}\right)_{\underline{cl}} \\ \left(\overset{+}{\bullet}_{el}\mathrm{e}^{i\pi} + \overset{+}{\bullet}_{in}\mathrm{e}^{i\pi/2}\right)_{\underline{cl}} \end{pmatrix} \tag{28}$$

We find:

$$\boxed{\begin{aligned} Q_{\underline{cl}} &= \int\left[\left(\left(\Psi^{+}_{(+)}\right)\right)\sigma_3\left(\left(\Psi_{(+)}\right)\right)\right]\mathrm{d}V \\ &= \int\begin{pmatrix}\left(o_{el}\mathrm{e}^{-i\pi}+o_{in}\mathrm{e}^{-i\pi/2}\right) \\ \left(\bullet^{+}_{el}\mathrm{e}^{i\pi/2}+\bullet^{+}_{in}\right)\end{pmatrix}\begin{pmatrix}\left(\bullet^{+}_{el}\mathrm{e}^{i\pi}+\bullet^{+}_{in}\mathrm{e}^{i\pi/2}\right) \\ -\left(o_{el}\mathrm{e}^{-i\pi/2}+o_{in}\right)\end{pmatrix}\mathrm{d}V \\ &= \left[\left(o_{el}\mathrm{e}^{-i\pi}+o_{in}\mathrm{e}^{-i\pi/2}\right)\left(\bullet^{+}_{el}\mathrm{e}^{i\pi}+\bullet^{+}_{in}\mathrm{e}^{i\pi/2}\right)-\left(\bullet^{+}_{el}\mathrm{e}^{i\pi/2}+\bullet^{+}_{in}\right)\left(o_{el}\mathrm{e}^{-i\pi/2}+o_{in}\right)\right] \\ &= o_{el}\,\bullet^{+}_{el}+o_{el}\,\bullet^{+}_{in}\,\mathrm{e}^{-i\pi/2}+o_{in}\,\bullet^{+}_{el}\,\mathrm{e}^{i\pi/2}+o_{in}\,\bullet^{+}_{in} \\ &\quad -\bullet^{+}_{el}o_{el}-\bullet^{+}_{el}o_{in}\mathrm{e}^{i\pi/2}-\bullet^{+}_{in}o_{el}e^{-i\pi/2}-\bullet^{+}_{in}o_{in} \\ &= \left[o_{el},\bullet^{+}_{el}\right]+\left[o_{in},\bullet^{+}_{in}\right]+i\left[\bullet^{+}_{in},o_{el}\right]+i\left[o_{in},\bullet^{+}_{el}\right]=+1 \end{aligned}} \quad (29)$$

In conclusion, we can state that the sign of the electric charge is determined by the direction of rotation of the phase and the structure of the matrix representing the IQuO-particle. In conclusion, we can assert that: the ($\Phi_1 \underline{\oplus} \Phi_2$) coupling of two IQuO has generated two particles-IQuO with opposite electric charge (q): $(\Psi_{\underline{cl}})_{+1}$, $(\Psi_{cl})_{-1}$. We have thus demonstrated that the (±) sign of the electric charge is related to the direction of the phase rotation of an oscillation IQuO. We denote the IQuO of type $\Phi_{(cl,\,\underline{cl})}$ as Boson-IQuO, having both directions of phase rotation, and the IQuO of type $[(\Psi_{\underline{cl}})_{+1}, (\Psi_{cl})_{-1}]$ as Fermion-IQuO. Note that an IQuO-chain is correspondent to a Field line.

2.4. The Two Types of Representative IQuO: F-IQuO and B-IQuO

Note that in **Figure 3**, the two pairs of *sq* $\left[\left(\underline{o}_{el},\underline{\bullet}_{in}\right),\left(o^{+}_{in},\bullet^{+}_{el}\right)\right]$ in the two images **Figure 3(a)** and **Figure 3(b)** the two pairs of *sq operators* $\left[\left(o_{el},\bullet_{in}\right),\left(\underline{o}^{+}_{in},\underline{\bullet}^{+}_{el}\right)\right]$, act in "**agreement**", in the same direction of propagation along the X axis (see the projection along X-axis): the operator $\left(\bullet^{+}_{el}\right)_{+\mathrm{X}}$ creates a full *sq* (•) of elastic energy at the point *x* in the +X direction also $(\mathbf{o}_{\mathrm{el}})_{+\mathrm{X}}$ annihilating an empty *sq* (o) of elastic energy in the point x in the +X direction, actually creates an *sq* full (•) of elastic energy, in the same +X direction, *i.e.* $\left(\bullet^{+}_{el}\right)_{-\mathrm{X}} \equiv \left(\mathbf{o}_{el}\right)_{+\mathrm{X}}$. This is a characteristic of IQuO of boson type (**B-IQuO**).

Instead in **Figure 4**, the *sq-operators* are "**discordant**", act in opposite directions along the X axis of propagation, and are not coherent, that is $\left(\bullet^{+}_{el}\right)_{-\mathrm{X}} \neq \left(\mathbf{o}_{el}\right)_{+\mathrm{X}}$. This makes "**antagonists**" the *sq*-operators of **Figure 4**. We noticed immediately that the antagonism between operators (one creates energy in the +X direction while the other in the -X direction) makes "contradictory" the representation of a F-IQuO. It follows that the mono verso IQuO certainly represent "charged" IQuO ($q = \pm 1$) but, by themselves, they cannot represent particles. Since there are no massless charged particles, we could assume that monoverse IQuO are IQuO representative of *massive* coupling [2] [3] [16], that is of massive particles. A first possibility to have F-IQuO with massive couplings, no-discordant *sq* operators and mono-verse could be a phase shift between the plane of oscillation of the pair (a^{+}_{el}, a^{+}_{in}) and that of the pair (a_{el}, a_{in}). So, we proposed a form of F-IQuO in which the pair of the operators (a^{+}_{el}, a^{+}_{in}) of each F-IQuO oscillates on a plan phase-shifted respect to that of the pair (a_{el}, a_{in}), see **Figure 5**:

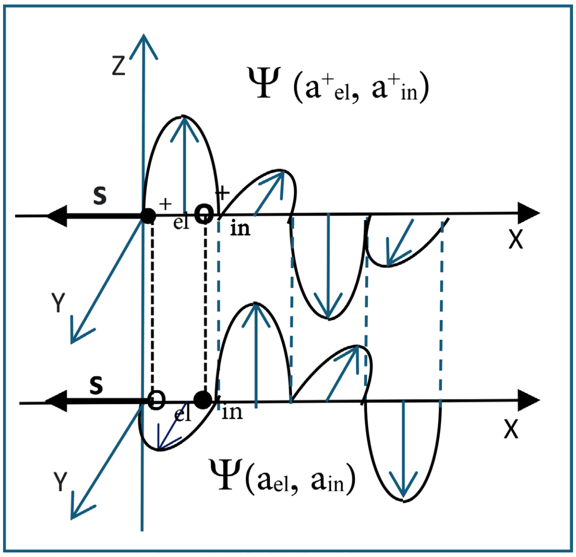

Figure 5. F-IQuO with "phase-shifted planes" between the a-operators and a⁺.

Where ***s*** is the spin vector associated to succession of planes which, as one can well see in **Figure 5**, can exploit in two directions of rotation. The phase shift of the planes of oscillation implies, as we have already seen in ref. [16], the existence of a semi-integer spin, given that the wave function results with a period of 4π, see just the **Figure 5**, as in ***Fermions***. Instead, the IQuO that do not have phase-shifted oscillation planes between *a*-operator and a^+, then we will indicate them as B-IQuO and, by exclusion, they will describe particles of the ***Boson*** type.

2.5. The Processes of Pair Creation and Annihilation

The processes of pair creation and annihilation are found, in fundamental terms, in the operations: $(\Phi_1 \underline{\oplus} \Phi_2) \rightarrow [(\Psi_{\underline{cl}})_{+e} + (\Psi_{cl})_{-e}]$, $[(\Psi_{\underline{cl}})_{+e} \underline{\oplus} (\Psi_{cl})_{-e}] \rightarrow (\Phi_1 + \Phi_2)$

Using the representations in **Figure 3**, we can represent the creation and annihilation processes more simply with the following figures, **Figure 6(a)**, **Figure 6(b)**:

Note, in the pair creation of **Figure 6(a)**, that the two B-IQuO simultaneously perform the following *sq* exchanges:

$$\left\{\left[el^+(\bullet)_{cl} \oplus El(\boldsymbol{o})_{cl}\right]_{(\bullet\rightarrow\mathbf{o})}, \left[in^+(\boldsymbol{o})_{cl} \oplus In(\bullet)_{cl}\right]_{(\mathbf{o}\leftarrow\bullet)}\right\}$$
$$\equiv\left\{\left[el^+(\boldsymbol{o})_{cl}, in^+(\bullet)_{cl}\right], \left[El(\bullet)_{cl}, In(\boldsymbol{o})_{cl}\right]\right\}_{F^-}$$

$$\left\{\left[El^+(\bullet)_{\underline{cl}} \oplus el(\boldsymbol{o})_{\underline{cl}}\right]_{(\bullet\rightarrow\mathbf{o})}, \left[In^+(\boldsymbol{o})_{\underline{cl}} \oplus in(\bullet)_{\underline{cl}}\right]_{(\mathbf{o}\leftarrow\bullet)}\right\}$$
$$\equiv\left\{\left[El^+(\boldsymbol{o})_{\underline{cl}}, In^+(\bullet)_{\underline{cl}}\right], \left[el(\bullet)_{\underline{cl}}, in(\boldsymbol{o})_{\underline{cl}}\right]\right\}_{F^+}$$

Vice versa in the pair annihilation process (**Figure 6(b)**) we will have:

$$\left\{\left[el^+(\boldsymbol{o})_{cl} \oplus El(\bullet)_{cl}\right]_{(\mathbf{o}\leftarrow\bullet)}, \left[in^+(\bullet)_{cl} \oplus In(\boldsymbol{o})_{cl}\right]_{(\bullet\rightarrow\mathbf{o})}\right\}$$
$$\equiv\left\{\left[el^+(\bullet)_{cl}, in^+(\boldsymbol{o})_{cl}\right], \left[El(\boldsymbol{o})_{cl}, In(\bullet)_{cl}\right]\right\}_{B1}$$

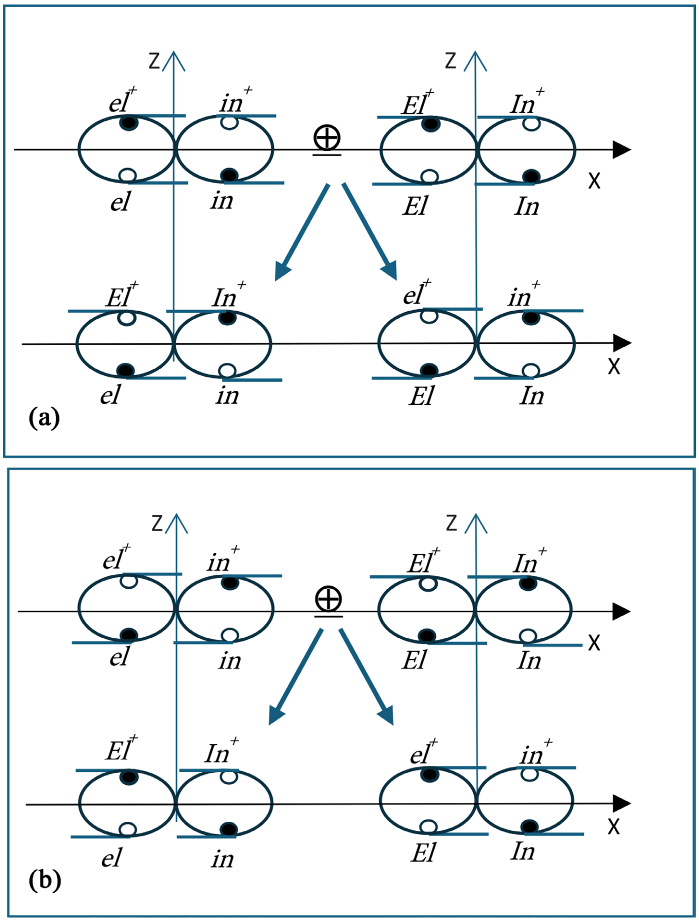

Figure 6. The couplings of two B-IQuO origins two mono-verse F-IQuO (a) and vice versa (b).

$$\left\{\left[El^{+}(\boldsymbol{o})_{\underline{cl}}\oplus el(\bullet)_{\underline{cl}}\right]_{(\mathbf{o}\leftarrow\bullet)},\left[In^{+}(\bullet)_{\underline{cl}}\oplus in(\boldsymbol{o})_{\underline{cl}}\right]_{(\bullet\rightarrow\boldsymbol{o})}\right\}$$
$$\equiv\left\{\left[El^{+}(\bullet)_{\underline{cl}},In^{+}(\boldsymbol{o})_{\underline{cl}}\right],\left[el(\boldsymbol{o})_{\underline{cl}},in(\bullet)_{\underline{cl}}\right]\right\}_{B2}$$

In the coupling of two B-IQuO generating a pair of F-IQuO, only one exchange of a full *sq* (•) could occur for each pair of operators (*a, a*$^{+}$), that is, see **Figure 7**:

We will have that:

$$\left\{\left[el^{+}(\bullet)_{cl}\oplus El(\mathbf{o})_{cl}\right],\left[in^{+}(\mathbf{o})_{cl}\oplus In(\bullet)_{cl}\right]_{(\mathbf{o}\leftarrow\bullet)}\right\}$$
$$\equiv\left[\left[el^{+}(\bullet)_{cl},in^{+}(\bullet)_{cl}\right],\left[El(\boldsymbol{o})_{cl},In(\boldsymbol{o})_{cl}\right]\right]_{F^{-}}$$

$$\left\{\left[El^{+}(\bullet)_{\underline{cl}}\oplus el(\boldsymbol{o})_{\underline{cl}}\right],\left[In^{+}(\boldsymbol{o})_{\underline{cl}}\oplus in(\bullet)_{\underline{cl}}\right]_{(\mathbf{o}\leftarrow\bullet)}\right\}$$
$$\equiv\left\{\left[El^{+}(\bullet)_{\underline{cl}},In^{+}(\bullet)_{\underline{cl}}\right],\left[el(\boldsymbol{o})_{\underline{cl}},in(\boldsymbol{o})_{\underline{cl}}\right]\right\}_{F^{+}}$$

Or we will have:

$$\left\{\left(el^{+}(\boldsymbol{o})_{cl},in^{+}(\boldsymbol{o})_{cl}\right],\left[El(\bullet)_{cl},In(\bullet)_{cl}\right]\right\}_{F^{-}}$$

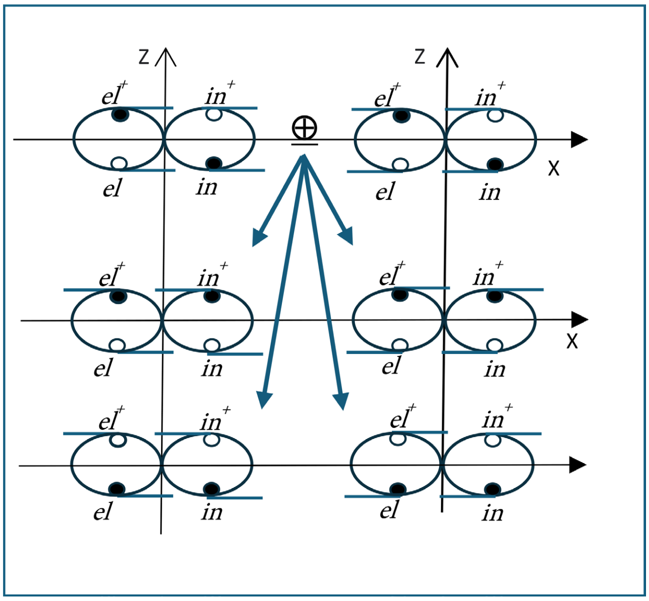

Figure 7. The couplings of two B-IQuO origins mono-verse F-IQuO with pairs of *sq* full for the operators (a, a^+).

$$\left\{\left[El^+(\boldsymbol{o})_{\underline{cl}}, In^+(\boldsymbol{o})_{\underline{cl}}\right], \left[el(\bullet)_{\underline{cl}}, in(\bullet)_{\underline{cl}}\right]\right\}_{F^+}$$

Note the equivalences

$$\left\{\left[el^+(\bullet)_{cl}, in^+(\bullet)_{cl}\right], \left[El(\boldsymbol{o})_{cl}, In(\boldsymbol{o})_{cl}\right]\right\}_{F^-}$$

$$\equiv \left\{\left[el^+(\boldsymbol{o})_{cl}, in^+(\boldsymbol{o})_{cl}\right], \left[El(\bullet)_{cl}, In(\bullet)_{cl}\right]\right\}_{F^-}$$

$$\left\{\left[El^+(\bullet)_{\underline{cl}}, In^+(\bullet)_{\underline{cl}}\right], \left[el(\boldsymbol{o})_{\underline{cl}}, in(\boldsymbol{o})_{\underline{cl}}\right]\right\}_{F^+}$$

$$\equiv \left\{\left[El^+(\boldsymbol{o})_{\underline{cl}}, In^+(\boldsymbol{o})_{\underline{cl}}\right], \left[el(\bullet)_{\underline{cl}}, in(\bullet)_{\underline{cl}}\right]\right\}_{F^+}$$

3. The Phenomena of Repulsion and Attraction of Two Electric Charges

3.1. The Reciprocal Phase Shifts between B-IQuO Chain and F-IQuO Chain

We now show that the property of repulsion and attraction between two electric charges originates in the IQuO representation of a field. In this way we have further proof that the representation of the field with IQuO has a deep physical meaning. Remember that a field can be represented by "lines" of coupled field oscillators. We denote by the C term a "chain" a field line, where the *sq*(•) propagate from one IQuO to the contiguous other F-type IQuO are basic oscillators of "Fermion" particles [16] while B-type IQuO are basic oscillators for Boson particles. We can treat the phase shift induced by a chain C_B of B-IQuO (Φ_B field) on a chain C_F of F-IQuO (Ψ_F field). Here, we are trying to describe what happens to field oscillators in a scattering process between an electron (Ψ_F fermion field) and a photon (Φ_B boson field); we note that the theory of interactions describes scattering processes by dealing with "*wave-particles*" without ever considering what happens at the level of field oscillators (this is a "*positivist*" point of view of the QM) [6]. The consequence of the reciprocal mutual phase shift ($-\Delta\varphi_1 = +\Delta\varphi_2$) between C_B and C_F can be the variation of direction of the X-axis along which the C'_F chain lies, see **Figure 8**:

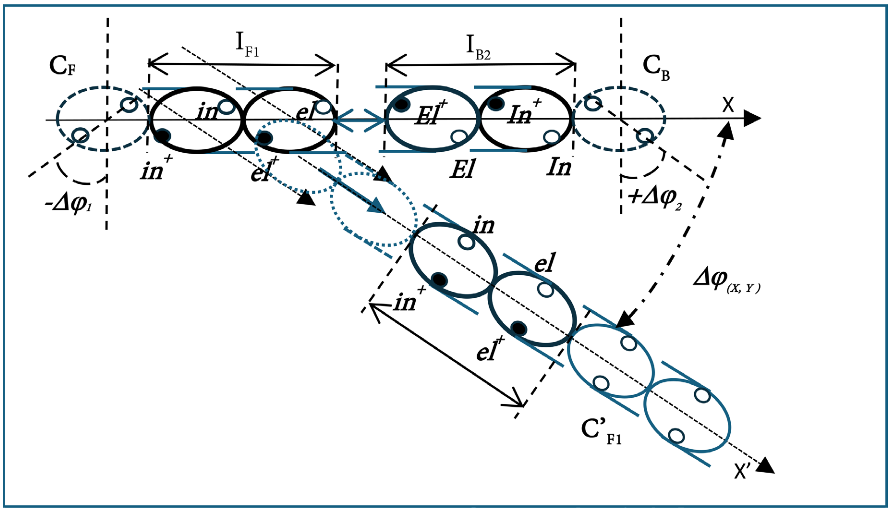

Figure 8. Rotation $\Delta\varphi_{(X,Y)}$ of axis X after phase shift $-\Delta\varphi_1$.

This is caused by the coupling of I_{F1} with I_{B2}, which gives origin to a phase shift of the *sq* in I_{F1} and thus a change of the initial configuration leading to a different final configuration; the latter can have the same shape as the initial configuration when viewed, however, from an axis system (X', Z') rotated by an angle ($|\Delta\varphi_{(X,X')}| = -\Delta\varphi_1$) with respect to the system (X,Z). We speak of "configuration rotation", **Figure 9**:

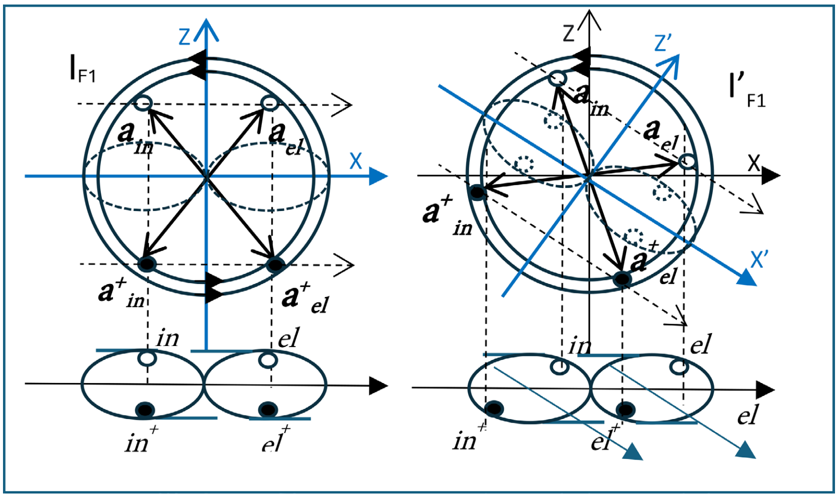

Figure 9. Rotation of the oscillation plane of I_{F1} after phase shift.

Note that the oscillation plane of I_{F1} is now rotated and with it the *sq* propagation axis coinciding with a new $C_{F'}$ chain, see **Figure 8**. The phase shift ($-\Delta\varphi_1$) induced by C_B on I_{F1} breaks the original chain C_{F1} (X-axis) and rotates the oscillation plane of I_{F1} from (X, Z) to (X', Z'): the new oscillation of IQuO I'_{F1} originates a new chain C'_{F1}, where the *sq* (•) pair of I'_{F1} can flow and to become a quantum (•, •) of the "line" new C'_{Fi} of the field Ψ_F. Consistent with QM, we might describe this process in the following way: in the case of a IQuO-field (Ψ_F) an "external" $\text{IQuO}_{(n=1)}$ I_B can induce a coupling along a line of coupled sub-oscillators $I_{(n = 0)}$ of the "empty" field of Ψ_F, that is $\Psi_F{}^{\circ}$, which gives rise to a new field chain C'_{F1} of Ψ_{F1}. It follows that the action of an "external" field displacement on a field line Ψ_F can give rise to a new field line in another direction X'. What has just been described can be formalised in the following way: $(C_B \underline{\oplus} C_{F1})_X \rightarrow (C'_{F1})_{X'}$. Remember $\underline{\oplus} \equiv (O_R, \oplus)$ where $\oplus$ is the dynamic operation and here $O_R \equiv (O_\varepsilon \cdot O_\varphi)$, see also Equation (12).

3.2. Superposition of Two Fermion Chains on a Guide Chain of Boson Type (Pauli's Principle)

Let us now consider the case of two chains $(C_{1cl}, C_{2\underline{cl}})_F$ of monoverse F-IQuO (the subscript *cl* indicates a clockwise direction of phase rotation while *c͟l* indicates a counterclockwise direction). We point out that the two chains identify two identical particles. We can consider that the two chains $(C_1, C_2)_F$ lie on two parallel axes (X_1 // X_2). If we superimpose the axes, and thus the chains, we obtain a "constructive" superposition of the two chains only if they originate a "double" chain-Boson (C_B), see **Figure 6(b)**, in which *sq* (•) can flow passing from an IQuO to the other contiguous. This means that two identical fermions but with opposite electric charge can overlap and form a single but double chain of bosonic fields, see the processes of pair creation and annihilation. On the other hand, as we know well, two identical fermions in all physical variables cannot overlap on the same field line. This aspect, see **Figure 6**, results from the impossibility of superposing two F-IQuO with the same direction of phase rotation (that is with the same electric charge). Another possible superposition is that of a C_F chain with a C_B chain. In **Figure 8**, one sees the phase shift induced by C_B on C_F that results in the variation (rotation) of the axis of C_F. We could then admit a phase shift that does not vary the direction of C_F but rather allows the *sq* of C_F to flow along C_B. Recall that the oscillation of the wave associated with an electron proceeds in two different planes, see **Figure 5** and in ref. [16] it was shown that the electron structure flows along a B-IQuO line (C_B chain) which can thus be considered a kind of "guide" see the concept in electromagnetics of waveguide. Then we admit a special or adaptive initial phase shift between I_{F1} and C_{B1} based on the equality $[-\Delta\varphi(F_1) = \Delta\varphi(B_1)]$, which allows a *sq* to flow along C_B. In **Figure 10**, we show the phase shift undergone by the two IQuO with $[\Delta\varphi(F_1) = -(\pi/4), \Delta\varphi(B_1) = +(\pi/4)]$.

The phase shift will allow $In^+(\bullet)_{F1}$ to move to point A and exchange a *sq*(•) with $in^+(\mathbf{o})_{B1}$. We denote this phase shift as "concordant" if it allows a bosonic chain to originate. The phase shift information $\Delta\varphi_{(B1)}$ then propagates along the entire C_{B1} chain. Symmetrically, what happened in I_{F1} must happen in I_{F2} with the C_{B2} chain: $-\Delta\varphi_{(F2)} = \Delta\varphi_{(B2)}$. The coupling of the two chains (C_{B1}, C_{B2}) to generate a single boson chain C_B must be concordant in such a way as to allow the propagation of *sq*(•) boson-type in it, C_B, and to finally realise the overlapping chain of C_{F1} and C_{F2}, that is C_B, see **Figure 11**:

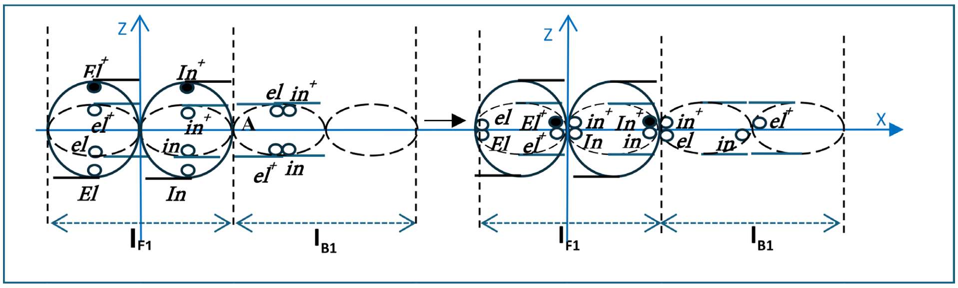

Figure 10. Guideline of the intermediary boson.

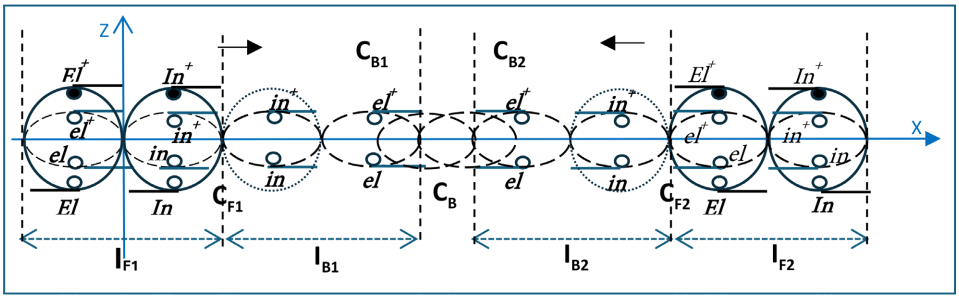

Figure 11. Guideline of superposition of two intermediary boson.

Besides, since I_{F2} is a counterclockwise monoverse IQuO and represents a C_{F2} chain where a particle is moving along the (-X) axis, it will happen that the two particles, chains (C_{F1}, C_{F2}), will move towards each other along the unique propagator C_B, see **Figure 11**. So, we will have that along X-axis on a guide chain C_B can move two particles (C_{F1}, C_{F2}) with opposite directions of phase rotation. On the other hand, in the case of two chains (C_{F1}, C_{F2}) consisting of monoverse IQuO but with the same direction of phase rotation $[(C_{1cl}, C_{2cl})_F, (C_{1\underline{cl}}, C_{2\underline{cl}})_F]$ it is found that an overlap of these is not possible because does not origin an unique C_B chain. This determines, in the case of identical particles with F-IQuO chains, the "*Pauli Exclusion Principle*".

3.3. Quantum Correlation at Distance between Two Fermion Chains by an Intermediary Boson Chain

We now show that the two just-described behaviours of the chains (C_{F1}, C_{F2}) determine the behaviour of electrically charged particles, and, exactly, the attraction of particles with opposite electric charges and the repulsion if of electric charges of the same sign. Let us consider two particles of opposite electric charge represented by chains of F-IQuO, that is two particles with opposite directions of phase rotation $[(C_{1cl}, C_{2\underline{cl}})_F$. Also, we consider the intermediary chain of boson type C_B. The quantum theory of interactions tells us that the system composed of interacting particles and the interacting constitute a "*non-separated*" quantum system in a non-local state: this is because the reduction process following "observation-interaction" is not included in the Hamiltonian theory of interactions. In this case, only the various probabilities of elastic and inelastic diffusion can be calculated. Therefore, the chains $(C_{1cl}, C_{2\underline{cl}})_F$, even if separated in space, result in "*quantum correlation*" or non-separated state through the "*lattice*" of intermediate chains (propagators) of B-IQuO (C_B). Recall the quantum system constituted by the three chains (C_{F1}, C_{F2}, C_B) is as a Feynman diagram with two particle lines and an intermediate propagator of various order. In these terms, the description of an interaction through the system $(C_{1cl}, C_{2\underline{cl}})_F$ and (C_B) is physically equivalent to that of the quantum theory of interactions. As mentioned earlier, the chain C_B can induce phase shifts in the two chains (C_{1F}, C_{2F}) which, in the case of non-aligned chains along the same X-axis, in turn give rise to a rotation of the axes of (C_{1F}, C_{2F}), see **Figure 8**. The physical aspect of phase shifting and rotations implies that the system (C_{F1}, C_{F2}, C_B) is correlated in its components, that is the rotations induced by C_B in (C_{1F},C_{2F}) are interdependent: there is an internal "constraint" between the phase shifts in (C_{1F}, C_{2F}), as happens in the distance correlations in QM, see quantum entanglement in the polarization processes of two photons with polarizers placed at a distance (EPR) [17]. This correlation "at space distance" is admissible thanks to IQuO representation, where the phase shifts are superluminal and energetic changes are realized by *sq* (**o**,•) pair and no by integer quanta (•,•). In fact, it is then noted that the physics of correlated states in QM is a physics in which the "spatial distance" between components interconnected by another component appears as to be reduced to the distance between the "oscillators" representing those components. So, taking the two chains (C_{1F}, C_{2F}) of an extended system of IQuO in the space of chains (C_{F1}, C_{F2}, C_B), where C_B is the system that physically connects them, the spatial distance between (C_{F1}, C_{F2}) is given by the spatial distance $d(I_{F1}, I_{F2})$ of two extreme IQuO (I_{F1}, I_{F2}) of (C_{1F}, C_{2F}) coinciding with the linear dimension $d(I_{CB})$ of the representative IQuO I_{CB} of the chain CB, that is: $d(I_{F1}, I_{F2}) = d(I_{CB})$. Thus, the correlation between the extremes of the two chains (C_{F1}, C_{F2}) occurs as if all three systems (C_{F1}, C_{F2}, C_B) were "concentrated" in a spatial dimension given by the linear dimension of an IQuO. These assertions are supported by the fact that the phase shifts along the C_B chain propagate at a phase velocity that is superluminal, and since there is a reference system in which this velocity is almost infinite (simultaneity of events at the extremes of the chain), then we could say that in such a system the distance between the extremes would be practically zero or almost. Thanks to the IQuO representation it is so possible to explain the phenomenon of correlation at a distance [18], contemplated by the theory of quantum mechanics, without resorting to additional dimensions to the four dimensions of relativity.

3.4. Direction Property of Repulsion and Attraction between Electric Charges

The distance "constraint" just mentioned is a consequence of the space "locality" of the non-separated system (C_{F1}, C_{F2}, C_B): a non-separated system of two monoverse F-IQuO chains (fermions) with the same direction of phase rotation [(C_{1cl}, C_{2cl})$_F$, ($C_{1\underline{cl}}$, $C_{2\underline{cl}}$)$_F$] cannot originate for any rotation of the axes of the respective chains, a single system consisting of a single "multiple" boson-like C_B chain formed by the two chains of B-IQuO, (C_{B1}, C_{B2}) connecting the two chains (C_{F1}, C_{F2}) and the two overlapping chains (C_{F1}, C_{F2}). If, on the other hand, the chains (C_{1F}, C_{2F}) are with opposite direction of phase rotation, [(C_{1cl}, $C_{2\underline{cl}}$)$_F$, ($C_{1\underline{cl}}$, C_{2cl})$_F$], then we will have that the system can originate for any rotations of the axes of the respective chains, a single system consisting of a single "multiple" boson-type chain formed by two superposed B-IQuO chains, (C_{B1}, C_{B2}) and a superposed boson chain of the two chains (C_{F1}, C_{F2}). This means that a rotation of following a phase shift is correlated in any case to that performed by the C_{F2}: ($C_{F1} \Leftrightarrow C_B$) e ($C_{F2} \Leftrightarrow C_B$). The phase shift operator O_φ in ($C_{F1} \Leftrightarrow C_B$) is conditioned by the phase shift between ($C_{F1} \Leftrightarrow C_B$); we will write [$O_\varphi$ (C_{F1}, C_B) $\Leftrightarrow$ O_φ (C_{F2}, C_B)]. The non-separability ($C_{F1} \cap C_{F2}$), even at a distance, is a consequence of the coupling between the two chains realized through the coupling of two respective IQuO ends (I_{F1}, I_{F2}) with the common bosonic chain C_B. This non-separability arises from the following aspect: while the phase shift $\Delta\varphi_{(F1,B1)}$ ($\Delta\varphi_{(F2,B2)}$) is reductive (O_φ), the phase shift $\Delta\varphi_{(F2,B2)}$ ($\Delta\varphi_{(F1,B1)}$) is instead "extensive" ($O^{-1}{}_\varphi$), that is it restores the non-locality of the chain C_B. In these terms, despite the reciprocal phase shifts, the system (C_{F1}, C_{F2}, C_B) is non-separated and therefore the two phase shifts at the extremes (I_{F1}, I_{F2}) are always "correlated" at a distance. This determines that "paradoxical" aspect mentioned earlier, which can help to understand quantum entanglement: the two chains ($C_{F1} \cap C_{F2}$) assume a physical state in which they "appear" no longer separated in space that is, as if they were at "zero distance". What we have said is described by the mathematical formalism of QM in terms of physics in the space of states: quantum entanglement in a physical system is the non-separation in space of the constituents of the system described by state vectors. The same happens in our system of two F-IQuO chains connected at a distance by a common chain of B-IQuO. The system always manifests a "some" non-locality ("null" spatial distances) and non-separability (connections through intermediate chains).

Returning to our two chains, their rotations are not so independent nor random but are determined by phase shifts that tend to build a "bosonic" chain if (C_{1cl}, $C_{2\underline{cl}}$)$_F$ or to deny it if (C_{1cl}, C_{2cl})$_F$, ($C_{1\underline{cl}}$, $C_{2\underline{cl}}$)$_F$. Since the two IQuO "vertices" (I_{F1}, I_{F2}) are symmetric in the interaction process of the two chains (C_{1cl}, $C_{2\underline{cl}}$)$_F$ it follows that a reciprocal local phase shift of B-IQuO on one of the two F-IQuO corresponds to one in equal modulus; the sign, however, is determined by the combinations:

$$[(C_{1cl}, C_{2\underline{cl}})_F, (C_{1\underline{cl}}, C_{2cl})_F], [(C_{1cl}, C_{2cl})_F, (C_{1\underline{cl}}, C_{2\underline{cl}})_F]$$

It follows, then, **Figure 12**.

The angular phase shift is random in modulus but equal in the two extreme oscillators (I_{F1}, I_{F2}) with the signs conditioned by the directions of the respective phase rotations. In the case of opposite phase rotations, the bosonic chain condition determines the following phase shift distributions:

$$\Delta\varphi_1 = -\pi/4,\ \ \Delta\varphi_2 = -\Delta\varphi_1 = +\pi/4$$

Looking at **Figure 12**, we notice that the new propagation directions of two F-IQuO chains (blue color), after coupling with a B-IQuO, are converging; this tells us that the two particles (with opposite charge and opposite directions of phase rotation) are attracting each other. In the case of phase rotations equal in direction, the "fermionic" chain condition determines the following phase shift distributions:

$$\Delta\varphi_1 = +\pi/4,\ \ \Delta\varphi_2 = -\Delta\varphi_1 = -\pi/4$$

Now note in **Figure 13** the divergence of the propagation axes to avoid an overlap denied by the Pauli principle for F-type IQuO:

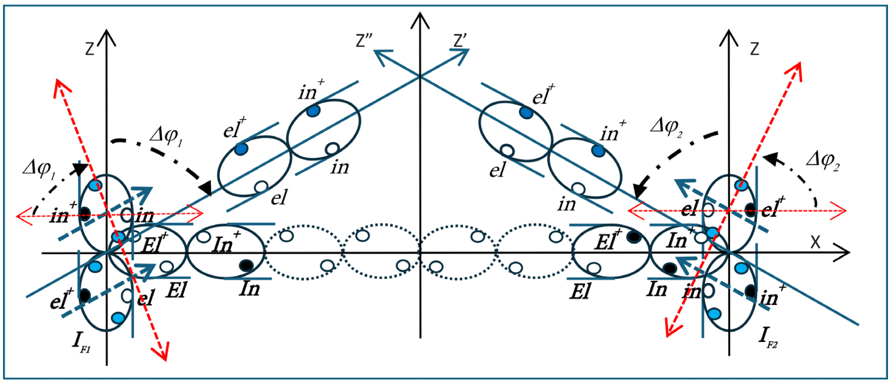

Figure 12. The couplings of two chains of F-IQuO by an intermediary Boson chain.

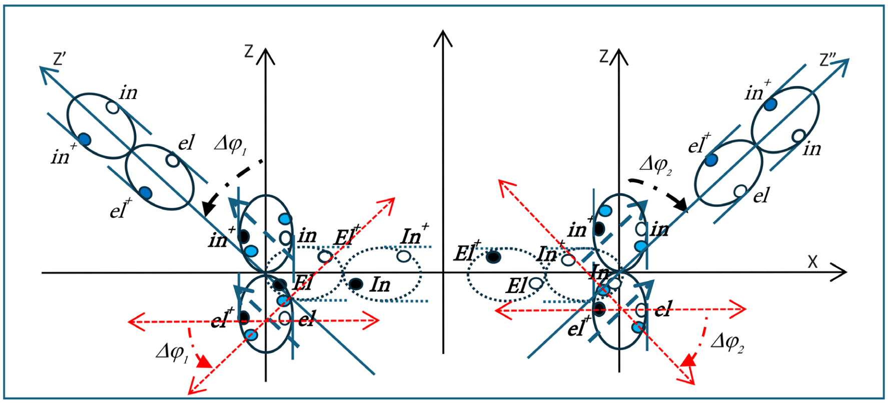

Figure 13. Divergence of the outgoing chains of two IQuO with the same direction of phase rotation.

In general, if we have two F-IQuO chains with equal direction of phase rotation, the new propagation directions of two F-IQuO chains (blue color), after coupling with a B-IQuO, are now divergent. This tells us that the two particles (with equal charge and equal directions of phase rotation) are repelling each other.

4. Conclusions

The idea of treating a field oscillator as a forced oscillator when traversed by the field quantum is a harbinger of important innovations in quantum mechanics (QM) and particle physics. In QM, this idea makes pass from the "ordinary" quantum oscillator to the "intrinsic" oscillator called IQuO, whose structure in sub-oscillators with semi-quanta allows:

1) to be able to "observe" the direction of rotation of the phase in an IQuO.

2) to describe the elastic coupling in a point between two oscillators of two different particle-fields.

The first point highlights the possibility of identifying a relationship between the sign of the electric charge (±) of a particle-field with the two directions of rotation of the phase of its basic oscillators. This is an important step because it gives us the possibility of explaining the origin of the two signs of electric charge and the property of electric bodies to attract or repel each other. This article thus demonstrates the meaning of that empirical convention of electromagnetic phenomena which is expressed in the attraction and repulsion of electric charges. In the second point, the coupling between IQuO of two different fields, aspects of considerable importance emerge:

• the possibility, through the introduction of mutual phase shift operators, to describe the process of reduction of the representative wave function of the particle, postulated by quantum physics [6] [9].

• the possibility of carrying out the coupling process in detail and determining the type of emerging particles, a fundamental aspect of interactions [14] [15].

In this way, it is possible to explain the fundamental mechanism behind the process of pair creation and thus the formation of antimatter. This is possible because two forms of IQuO (F-IQuO, B-IQuO) are identified, which allow a deeper understanding of the difference between fermionic and boson fields. Furthermore, by coupling an F-IQuO (basic IQuO constitutive of an electron) with a given phase rotation and a B-IQuO (IQuO constitutive of a photon) it is possible to explain the phenomenon of attraction and repulsion of two electric charges. In fact, starting from the coupling of an F-IQuO with a B-IQuO it is possible to show the F-IQuO behaves differently depending on its phase rotation direction. It is thus evident from these considerations that with the IQuO model of a particle-field, a new descriptive paradigm of the phenomenology of particles treated by the Standard Model is introduced into physics: this new paradigm is that particles are structures of IQuO couplings. From the arguments presented in the article, such as that of the relation between phase rotation, phase rotation direction invariance and gauge fields, the model IQuO is totally consistent with the descriptive principles of the SM, indeed, thanks to the structure of the IQuO, we also have the possibility to complete the SM, because:

- in addition to explaining the origin of the sign (±) of an electric charge, we are also able to explain the origin of the colour charge possessed by quarks, see ref. [4] [19]
- Thanks to the "sub-structure" of an IQuO, it is possible to couple field IQuO, which are representative of a particle, in such a way as to form a well-defined

structure with geometric shape. This latter aspect gives rise to a new descriptive paradigm for the phenomenology of interacting particles: that of treating massive particles no longer in a point-like manner but as geometric structures with a spatial dimension (λ)

- The new paradigm defines a new representative model of SM particles, which has been referred to as the Geometric Particle Model [19] [20] with acronym (PGM). In this way, SM particles and the phenomenology they express can be classified according to their structure.

In conclusion it can be said that thanks to the IQuO idea, it is possible to build a particle model completely in agreement with the standard model, explaining its phenomenology in an exhaustive, predictive, and self-consistent way. In this way, a deeper understanding of the universe of particles and the laws that govern them is achieved because it is possible to "structure" the phenomenology generated by them and, up to this moment, known.

Conflicts of Interest

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

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