


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

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Abstract

We propose a novel extension of quantum field theory by introducing Intrinsic Quantum Oscillators (IQuO) to describe the internal degrees of freedom of a particle. IQuO is composed of sub-oscillators with semi-quanta and are described by creation operators and annihilation with two components each. In the interaction between two particles, thanks to the structure with semi-quanta of an IQuO, it is possible to show that in the initial phase of a coupling between two particle-fields, a *non-dynamic* process of reduction from a non-local to a local state takes place. Besides, IQuO allows us to demonstrate a direct correlation between the two directions of phase rotation of the wave function of a particle and the two signs of its electric charge. This connection provides a new understanding of particle-antiparticle pair creation and their associated virtual boson fields. Finally, two distinct IQuO configurations, B-IQuO and F-IQuO, explain the fundamental difference between fermions and bosons.

Keywords

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

1. Introduction

All phenomenology describing electric attraction and repulsion between particles is based on the conventional assignment to them of a tag ($\pm e$) interpreting the dual behaviour. In this article, the first part of a study about the field quantum oscillator and particles, we will attempt to find the origin of the two signs (\pm) of electric charge. This is possible in the context of an unprecedented representation of the oscillator of a quantum field that derives from an in-depth study of its structure. The starting point of this study is a conjecture of Dirac in which he hypoth-

esized the existence of an internal degree of freedom within a particle to physically explain spin [1]. He thought to find it in a quantum oscillator since a particle is represented by a field of coupled oscillators [2]. He thus introduced a phase operator φ , but Glover [3] [4] showed that this led to a contradiction [3]-[5]. This article demonstrates that instead, the introduction of an operator r representing the direction of phase rotation, clockwise and counterclockwise, eliminates Dirac's error and introduces an internal degree of freedom in the oscillator, see Sect. 2.1. This means that the two directions "clockwise-counterclockwise", eigenvalues ($r' = \pm 1$), must be experimentally *observed*. We hypothesize the physical phenomenon correlated with the two directions ($r' = \pm 1$) is the presence of the two signs of the electric charge ($\pm e$) in electromagnetic interactions. However, to highlight the two directions of phase rotation, the operators describing the oscillation (a, a^*) must be composed by two components each. This aspect is already found in the forced oscillator according to the theory of oscillations, see Sect. 2.2, but we also note that a field oscillator is *forced* (driven) when it is traversed by a quantum of energy coming from an external agent, as happens in interactions. This aspect can be generalized by always describing the field oscillator as a two-component **Intrinsic Quantum Oscillator**, which we indicate with the acronym IQuO. Furthermore, we demonstrate, see Sect. 2.3, that the introduction of the observable r is at the very basis of quantum mechanics (QM) because it transforms the descriptive variables (a, a^*) of an oscillation into non-commuting operators. All this brings us to the roots of QM with two additional pieces of information: an internal degree of freedom and the operators (a, a^*) with two components. In quantum field theory the implications are revolutionary and confirm what has already emerged in our previous studies, see the references: the IQuO model brings innovative solutions to both QM problems and those of the Standard Model (SM) of particles. The first shocking implication with IQuO oscillators, see Sect. 2.4, is that the quantum field oscillator can be described by a structure composed of sub-oscillators, traversed by semi-quanta of energy, without affecting the physical laws of interactions. With these properties, an IQuO has a mathematical representation, by means of matrices (Sect. 2.5), and a geometrical one, through two-dimensional configurations in phase space (see Sect. 2.6), of creation and annihilation operators of "*semi-quanta*" that replace the operators (a, a^*). In section 3, the coupling between two IQuO (I_1, I_2) of two different particles-fields (Φ_1, Φ_2) is addressed. We show that this coupling takes place in two phases: the non-dynamic phase of reduction and the dynamic phase of the interaction between the two particles. About the first phase, we show the reduction process of the wave functions (Φ_1, Φ_2), see Sect. 3.1, and the coupling process, Sect. 3.2, with an exchange of semi-quanta, which leads to the creation of a pair of "*mono-verse*" fields in the phase rotation of the semi-quantum operators ($r'_1 = +1, r'_2 = -1$). It is immediately found that the arrangement of semi-quanta with a given direction of phase rotation reveals two types of fields IQuO, Sect. 3.3: B-IQuO, where operators of semi-quanta appear with both clockwise and counterclockwise rotating phases, and F-

IQuO, where the operators of semi-quanta all have the same direction of phase rotation or are “mono-verse”). This discovery is a consequence of the coupling of two B-IQuO (B_1, B_2) which originates two F-IQuO (F_1, F_2) with two opposite directions of phase rotation after a process of wave function reduction (Sect. 3.1). This seems to be the basic process in the creation of a particle-antiparticle pair. In fact, it is noted that a B-IQuO is a basic oscillator of bosons, while an F-IQuO is a basic oscillator of fermions (Sect. 3.3). In fact, in Sect. 3.3, it is noted that to avoid a “non-regular” geometric shape of one of the two IQuO (F_1, F_2), originated by the coupling of (B_1, B_2), it is necessary to add a B-type IQuO which, by means of appropriate phase shifts, makes the geometric shape of the “non-regular” IQuO as regular. This aspect is the basis of QED: a particle is surrounded by virtual photons that continuously phase the charged particles. Also in section 3.3, we show that to physically accept a monoverse IQuO (particle), the complete oscillation of the semi-quanta must occur on several different planes. It is also shown that the period of this oscillation is 4π . These two aspects are just characteristic of particles (IQuO) called “fermions”. Finally, in Sect. 3.4, we calculate the value and sign of the electric charge through the matrices of the F-IQuO; we can then confirm the initial hypothesis of the correlation between r and the sign (\pm) of the electric charge. A final note on the IQuO model: by means of correlation ($r \Leftrightarrow \pm e$) one can demonstrate why two electric charges reciprocally repel or attract, but this topic will be dealt with in the second part of the article about the IQuO (next future article).

2. The Quantum Oscillator with Semi-Quanta (IQuO)

2.1. The r Operator of the Two Directions of Phase Rotation

In Dirac, just speaking of fermions, points out that, Ref. [1]: “... if we consider spin operators σ (operators indicating rotations) and combine them with an operator ζ that anti-commutes, then we can obtain quantum oscillators of (fermion) field described by operators (η, η^+) that anti-commute”. After, Dirac posed the following hypothesis:

$$\eta = \frac{1}{2}\zeta(\sigma_x - i\sigma_y), \quad \eta^+ = \frac{1}{2}\zeta(\sigma_x + i\sigma_y) \quad (1)$$

With ζ operator which anti commute ($[(\zeta^+, \zeta)]_{(+)} = i\hbar$), but also commutes with σ operators and it is $(\zeta)^2 = 1$. Then Dirac proved:

$$\left\{ \eta^2 = 0, \eta^{+2} = 0, (\eta\eta^+)^2 = \eta\eta^+, (\eta\eta^+) = n \right\} \quad (2)$$

$$[\eta^+\eta + \eta\eta^+]_{(+)} = 1$$

The Dirac showed $(\eta\eta^+)' = n' = (0,1)$, that is (η, η^+) are operators describing quantum oscillators associated with fermion particles. Therefore, the anti-commutation property of the operator ζ combined with the properties of rotations result in particles with spin (1/2). Recall that in the quantum (harmonic) oscillator the operators (a, a^+) can be placed in the form [2]:

$$a_t = a_0 e^{i\omega t}, \quad a_t^+ = a_0^+ e^{-i\omega t} \quad (3)$$

These relations represent the time evolution of the operators (a, a^\dagger) where (ωt) is the phase φ of the oscillation. Since (η, η^\dagger) also represent quantum oscillators (Fermion field oscillators), then we can write:

$$\eta_t = \eta_0 e^{i\omega t}, \quad \eta_t^\dagger = \eta_0^\dagger e^{-i\omega t} \quad (4)$$

Where η_t is the operator η at time t and η_0 the operator at the initial time $t = 0$. From the Equations (4) and (2d), it follows that:

$$\left\{ \begin{array}{l} \eta \eta^\dagger = n \\ \eta \eta^\dagger = \eta_0 \eta_0^\dagger \end{array} \right\} \Rightarrow \eta_0 \eta_0^\dagger = n \quad (5)$$

where n is self-adjoint, $n = n^\dagger$. For an oscillator ($n_t = n_0$). Dirac posed that [3]:

$$\eta_t = e^{i\varphi_{op}} \sqrt{n}, \quad \eta_t^\dagger = \sqrt{n} e^{-i\varphi_{op}} \quad (6)$$

Introducing a phase operator (φ_{op}). Using Equations (4)-(6), we obtain that:

$$\begin{aligned} & \left\{ \begin{array}{l} (\eta = \eta_0 e^{i\omega t}), (\eta^\dagger = \eta_0^\dagger e^{-i\omega t}) \\ \left(\eta = e^{i(\omega t)_{op}} \sqrt{n}, \left(\eta^\dagger = \sqrt{n} e^{-i(\omega t)_{op}} \right) \right) \end{array} \right\} \\ & \Rightarrow \left\{ \eta = \eta_0 e^{i\omega t} = e^{i(\omega t)_{op}} \sqrt{n}, \quad \eta^\dagger = \eta_0^\dagger e^{-i\omega t} = \sqrt{n} e^{-i(\omega t)_{op}} \right\} \\ & \left\{ \begin{array}{l} \eta \eta^\dagger = n \\ \eta \eta^\dagger = \eta_0 e^{i\omega t} \eta_0^\dagger e^{-i\omega t} = \eta_0 e^{i\omega t} e^{-i\omega t} \eta_0^\dagger = \eta_0 \eta_0^\dagger = n \\ \eta \eta^\dagger = e^{i(\omega t)_{op}} \sqrt{n} \sqrt{n} e^{-i(\omega t)_{op}} = e^{i(\omega t)_{op}} n e^{-i(\omega t)_{op}} = e^{i(\omega t)_{op}} e^{-i(\omega t)_{op}} \end{array} \right\} \end{aligned} \quad (7)$$

The last equation comes from the relation ($\eta \eta^\dagger = n$) which leads us to admit the commutation of $[(\exp(i\omega t)_{op})]$ with n . This would mean that we can simultaneously observe the number of quanta n of an oscillator and its phase φ , that is, its position x . But this is not true because n commutes with the energy ($E \equiv H$), where H is Hamiltonian, while the x -position does not. There is something wrong with Dirac's hypothesis, Equation (6). Instead, if the φ -phase (with $\varphi = \omega t$) is a "number" and we believe that $(\exp(i\omega t))$ is also a *number*, then we can have, by Equation (4), that $\eta_0 = (n)^{1/2}$. We recall, from the properties of the spin operator, that: $\sigma_\pm = \sigma_x \pm i\sigma_y$. We can then express (η, η^\dagger), see Equation (1), such as:

$$\eta = \frac{1}{2} \zeta \sigma_+, \quad \eta^\dagger = \frac{1}{2} \zeta \sigma_- \quad (8)$$

By means of the properties of matrices $\sigma [(\sigma_x)^2 = (\sigma_y)^2 = 1]$, we find that $\eta \eta^\dagger = \zeta^2 = n$, that is $\zeta = (n)^{1/2}$. Thus, we will find the Equation (6) if we place the operator σ in exponential form of Euler: $\sigma \rightarrow \exp(i\omega t)$. Comparing Equation (3) with Equation (8) we obtain:

$$\begin{aligned} \eta &= \eta_0 e^{i\omega t} = \frac{1}{2} \zeta \sigma_+, \quad \eta^\dagger = \eta_0^\dagger e^{-i\omega t} = \frac{1}{2} \zeta \sigma_- \\ \sigma &\Leftrightarrow e^{i\omega t}, \quad \zeta \Leftrightarrow (\eta_0 \equiv \sqrt{n}) \end{aligned} \quad (9)$$

Since σ_i -spin are operators, we expect from Equation (8) that $[(\exp(i\omega t))_{op}]$,

$(\exp(-i\omega t))_{\sigma-}$ would also be operators (!): this tells us that even if *the phase of an oscillation is a number (angle), instead, $(\exp(i\omega t))$ should be an operator*. Dirac's hypothesis would be partially restored: the phase φ is not an operator but, instead $[(\exp(i\omega t))_{\sigma+}, (\exp(-i\omega t))_{\sigma-}]$ must be. Let us note that in these relations we are linking phase to spin, that is to rotations. We ask ourselves to which rotations we could connect the phase. Besides, we wonder what could make the terms $[(\exp(i\omega t))_{\sigma+}, (\exp(-i\omega t))_{\sigma-}]$ into operators. We again think that something is missing in the expression $(\exp(i\omega t))$. Don't be in contradiction with the Equation (9) is necessary to conjecture that an operator needs to be added in $(\exp(i\omega t))$. To understand well this hypothesis, it is necessary to return to the spin. In the case of a spin, we could indeed associate an *internal* rotation with the particle spin, as Dirac conjectured [1], and to the phase of this rotation an intrinsic oscillation described by η -operators, see the Equations (9) and (1). Note that this aspect would be valid for quantum oscillators of fermion type, where the phase $\exp(i\omega t)$ is linked to the "sign" of the spin operator, see $[(\exp(i\omega t) \Leftrightarrow \sigma_+), (\exp(-i\omega t) \Leftrightarrow \sigma_-)]$. Remember that the spin eigenvalues are connected to two rotation directions. This makes us realise the direction of *phase rotation* in the rotations is an operator (r) with eigenvalues coincident to that of spin. Now, recall, the connection [phase rotation \Leftrightarrow oscillation] would be a characteristic of any type of oscillation. Then, we can conjecture that in every oscillation the rotation of a certain phase (φ) can be related to a physics variable (r) with two eigenvalues ($\pm r'$). Note that a rotation has two rotation directions and since the two eigenvalues $\pm r'$ are observables in the "*spin*" then also the two rotation directions of phase ($\pm r'$) of any oscillator, must be *observables*. Let us recall that Dirac thought [4] to a *phase operator* (φ) in a quantum oscillator and, therefore, also of field oscillators, but this last aspect, as before we have noted and as Davidov [3] pointed out referring to the works of Susskind and Glogower [5], could lead to some "unclear" aspects in quantum oscillator theory, if not even to contradictions, see next section. This *unclearness* could stem from an incompleteness: something is missing in the description of the quantum oscillator. The first step to complete the quantum oscillator is proper to introduce an r -operator in the phase rotation. So, we suppose that the phase $\exp(i\omega t)$ can become an operator (or precisely *functional operator*) in any quantum oscillator only if we introduce an r -operator of the direction of phase rotation, that is $[\exp(i\omega t) \rightarrow \exp(ir\omega t)]$, and if we admit (as is the case with spin) that the phase $\exp(i\omega t)$ is also connected to the *sign* of a specific operator q : $[(\exp(i\omega t) \Leftrightarrow q_+), (\exp(-i\omega t) \Leftrightarrow q_-)]$. Note that with the operator r [6] [7], we associate an "internal degree of freedom" with any quantum oscillator. In support of our conjecture about r operator, we report what Fain demonstrated [3]: "*The eigenstate of energy (eigenstate of n) is degenerate concerning to the sign relative to the direction of phase rotation ($\pm\varphi$); the sign (\pm) is associated with the operator I (we have called it r) with eigenvalues ± 1 , which commutes with the Hamiltonian operator H* ". Therefore, to complete the theory of the quantum oscillator, we must associate an operator r to the phase variable φ in $\exp(i\omega t)$, whose eigenvalues are

$r' = \pm 1$ relative to the two rotation directions of the phase. Recall the Hamiltonian operator H and n the operator number of the quanta: these operators endowed with simultaneously definable eigenstates, are commuting. In fact, the eigenvalues of the Hamiltonian operator are:

$$E_n = \left(n + \frac{1}{2} \right) \hbar \omega$$

where $n (1, 2, \dots)$ are the eigenvalues of the n operator. As a novelty in QM, in any type of oscillation, we introduce an operator \mathbf{r} expressing the direction of the phase rotation: this operator has the eigenvalues $r' = \pm 1$ and commutes with H and, accordingly, with n . In an isolated quantum oscillator, the energy can degenerate into eigenvalues of (\mathbf{r}) , as it is degenerated in the direction of the phase rotation. We have:

$$\left[E_n = \left(n + \frac{1}{2} \right) \hbar \omega \right]_{(r'=\pm 1)}$$

Therefore, we define by $\mathfrak{S}(H, n)_{(r'=\pm 1)}$ a space of Ψ states, having as basis the eigenvectors of the $(H, n)_{(r'=\pm 1)}$ operators, that is $\left[(|\Psi\rangle)_{(r'=\pm 1)} \equiv (|\Psi_H\rangle|\Psi_n\rangle)_{(r'=\pm 1)} \right]$. If we have diversified σ into (σ_+, σ_-) , see the Equation (9), by of the eigenvalues ($r' = \pm 1$), we could also try to diversify η_0 into $[(\eta_0)_+, (\eta_0)_-]$, see again Equation (9). In this way, we could suppose:

$$\begin{aligned} \zeta_\eta &\rightarrow \sqrt{n_+}, \quad \zeta_{\eta^+} \rightarrow \sqrt{n_-} \\ \sigma_+ &\leftrightarrow e^{i\omega t} = (e^{i\omega t})_{(r'=+1)}, \quad \sigma_- \leftrightarrow e^{i\omega t} = (e^{-i\omega t})_{(r'=-1)} \end{aligned} \quad (10)$$

And so, to have:

$$\left\{ \eta = (\sqrt{n_+})(e^{i\omega t}) = (\sqrt{n_+})(e^{i\omega t})_{(r'=+1)}, \eta^+ = (\sqrt{n_-})(e^{i\omega t}) = (\sqrt{n_-})(e^{-i\omega t})_{(r'=-1)} \right\} \quad (11)$$

We then wonder so if the definition of *functional operator* given to the term $\exp(i\omega t)$, with the eigenvalues of \mathbf{r} -operator ($r' = \pm 1$), is just connected to the difference $\{[(\eta_0)_- \neq (\eta_0)_+], [(\eta)_- \neq (\eta)_+]\}$, see the Equation (11) where $[(\eta_0)_+ = (n_+)^{1/2}, (\eta_0)_- = (n_-)^{1/2}]$. In order not to contradict Equations (6) and (8), we could assume that the ζ operator undergoes a *splitting* into two components (ζ_+, ζ_-) , becoming ζ_+ or ζ_- . Obviously, ζ is intact when the oscillator is in an indeterminate state of the phase direction. The veracity of this “*paradoxical*” hypothesis is linked to the possibility that the direction \mathbf{r} of the rotation phase can only be observed in a quantum oscillator but no into classic oscillator. To demonstrate this connection (see Equation (11)), we recall the theory of oscillations.

2.2. The Operators (a, a^+) of Quantum Oscillator with Two Components

Be the classical oscillator in the (q, p) coordinates of the phase plane; its Hamiltonian is:

$$H = \left(\frac{p^2}{2m} \right) + \left(\frac{m\omega_0^2 q^2}{2} \right)$$

With equations of motion

$$\begin{cases} \frac{dp}{dt} = -m\omega_0^2 q \\ \frac{dq}{dt} = \left(\frac{p}{m} \right) \end{cases}$$

Its general solutions are linear combinations of two independent oscillations [2]:

$$\begin{cases} q(t) = q(0)\cos(\omega_0 t) + \left(\frac{p(0)}{m\omega_0} \right) \sin(\omega_0 t) \\ p(t) = p(0)\cos(\omega_0 t) - (m\omega_0)q(0)\sin(\omega_0 t) \end{cases} \quad (12)$$

Instead, in forced damped oscillator ($\Gamma \neq 0$), the general solution is [9] [10]:

$$(q(t))_{damp} = (e^{-(\Gamma/2)\Gamma t}) [A_s \sin(\omega_s t) + B_s \cos(\omega_s t)]$$

With $\omega_s = \omega_{est}$ and $\omega_s \neq \omega_0$, where $q(t)_{damp}$ is any coordinate. Note that there are two terms. The energy of the oscillator is:

$$E(t) = E_0 (e^{-\Gamma t}) = (e^{-\Gamma t}) \left[\frac{1}{2} M (\omega_s^2 + \omega_0^2) \left(\frac{1}{2} A_s^2 + \frac{1}{2} B_s^2 \right) \right] \quad (13)$$

If ($\Gamma \approx 0$), the exponential decay term is approximately constant during an oscillation; in this case we have:

$$(q(t))_{damp} \approx (\cos t) [A_s \sin(\omega_s t) + B_s \cos(\omega_s t)] \quad (14)$$

The energy (with $\omega_s \approx \omega_0$) is:

$$E(t) \approx E_0 = \left[\frac{1}{2} M (2\omega_s^2) \left(\frac{1}{2} A_s^2 + \frac{1}{2} B_s^2 \right) \right] = M \omega_s^2 \left(\frac{1}{2} A_s^2 + \frac{1}{2} B_s^2 \right) \quad (15)$$

We also note here two energy components. In the driven oscillator there is also a two-term solution (again with damping). Outside the initial phase, the oscillator adapts to the external force, oscillates with frequency $\omega_a = \omega_{ext} \neq \omega_0$ and admits a solution with two components: one absorptive amplitude (A_{abs}), and the other elastic (A_{el}). Thus, it is:

$$(q(t))_{adaptive} = [A_{abs} \sin(\omega_a t) + B_{el} \cos(\omega_a t)] \quad (16)$$

with a mean energy (in a cycle) given by:

$$\langle E(t) \rangle_{T_a} = \left[\frac{1}{2} M (\omega_a^2 + \omega_0^2) \left(\frac{1}{2} A_{abs}^2 + \frac{1}{2} A_{el}^2 \right) \right] \quad (17)$$

So, the energy is expressed through the two absorptive and elastic components. If $\Gamma \approx 0$ and ($\omega_a = \omega_{ext}$) $\approx \omega_0$, the oscillator has an adaptive oscillation (resonance) with two energy components:

$$\langle E(t) \rangle_{T_a} \approx \left[\frac{1}{2} M (\omega_a^2) (A_{abs}^2 + A_{el}^2) \right]$$

where it is $\tau_a = 2\pi/\omega_a$. Now, let us we consider an oscillator belonging to a chain of elastically coupled oscillators (a field). The coupling between two oscillators can determine a reciprocal action of one on the other. Then, we think of each oscillator of the chain as a driven oscillator by the neighboring oscillators, with frequency set $\omega_{ext} \neq \omega_0$ (where ω_0 is the frequency of the individual single “isolated” oscillator q). We’ll say that the system of coupled oscillators is well adapted to the *external* frequency ($\omega_{ext} = \omega_k$), where ω_k is now the frequency of the k -mode oscillation of the chain of a field [8] [9]. It follows that the single field oscillator is like an oscillator (with a damping coefficient $\Gamma \approx 0$) adapted to the field frequency ω_k . In conclusion, *the field-oscillator is an adapted oscillator which can be described by two oscillating components, see the Equation (16)*. This has notable consequences in the field theory. To discover these consequences, we recall the classical oscillator expressed in (a, a^+) complex coordinates; it is:

$$a = \left[\left(\sqrt{\frac{m\omega}{2\hbar}} \right) \left(q + \frac{ip}{m\omega} \right) \right], \quad a^+ = \left[\left(\sqrt{\frac{m\omega}{2\hbar}} \right) \left(q - \frac{ip}{m\omega} \right) \right] \tag{18}$$

Note that the generalised coordinates (q, p) are expressed in the plane (q, ip) , see the operators (a, a^+) . We could consider the plane (iq, p) for symmetry, see the operators (b, b^+) . We might also have:

$$\left\{ \left[b = \left(\sqrt{\frac{m\omega}{2\hbar}} \right) \left(\frac{p}{m\omega} + iq \right) \right], \quad b^+ = \left[\left(\sqrt{\frac{m\omega}{2\hbar}} \right) \left(\frac{p}{m\omega} - iq \right) \right] \right\}$$

$$\left\{ \left[(b = ia^+), (b^+ = -ia) \right], (a = ib^+), (a^+ = -ib) \right\}$$

It is well known that the equations of motion of the oscillator are invariant by change of the coordinate system used; therefore, we can choose the coordinate plane (q, ip) with operators (a, a^+) and equation of motion given by:

$$\left\{ \begin{aligned} \left(\frac{da_t}{dt} \right) &= -i\omega a_t \\ \left(\frac{da_t^+}{dt} \right) &= i\omega a_t^+ \end{aligned} \right\}$$

and with solutions

$$\{ a_t = a_0 \exp(-i\omega t), \quad a_t^+ = a_0^+ \exp(i\omega t) \} \tag{19}$$

where $\{ [a_0 = a(0), a_0^+ = a^+(0)] \}$. The solutions (a_t, a_t^+) could be related to a pair of vectors $(\mathbf{Oa}, \mathbf{Oa}^+)$ with opposite phase rotation, see **Figure 1**.

The two solutions may concern the two opposite rotations of the phase. In classical mechanics the two possibilities are hidden: an oscillating pendulum going backwards in time (clockwise rotation of the representative curve in **Figure 1** is indistinguishable from one that goes forwards in time (counterclockwise rotation). Considering, instead, the eigenvalues of \mathbf{r} (that is, one detects the two direc-

tions of rotation of the phase) as “physical observables”, the two rotating vectors (\mathbf{Oa} , \mathbf{Oa}^+), associated with classical coordinates (a , a^+), must be somehow different when we observe the direction of rotation of the phase in an oscillation, but they must not be different when we observe the oscillator in its “uniqueness”, for example we are observing its energy but we don't look at where the oscillator is. Recall that the coordinates (a , a^+) always describe the same oscillator. One might think that a “*new physics*” could be devised, in which these two different possibilities (eigenstates) can be individually detected in some physical phenomena but can coexist in other phenomena of non-locality: we will talk about *complementarity* of two possibilities in local states. An intuition suggests, looking at **Figure 1**, that the only possibility of having a difference between the two rotating vectors is in their *norms* or *modules*. This possibility was raised in the previous section when we discussed the norm of the two operators (η , η^+). In this new original physics [1], the two different possibilities of rotation would be expressed by a difference in the norm of the two vectors (\mathbf{Oa}) and (\mathbf{Oa}^+) of the phase rotation, see **Figure 2**.

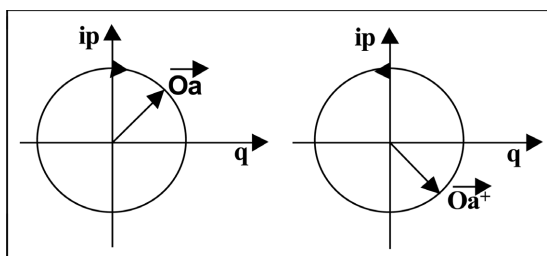


Figure 1. Phase vectors (\mathbf{Oa} , \mathbf{Oa}^+).

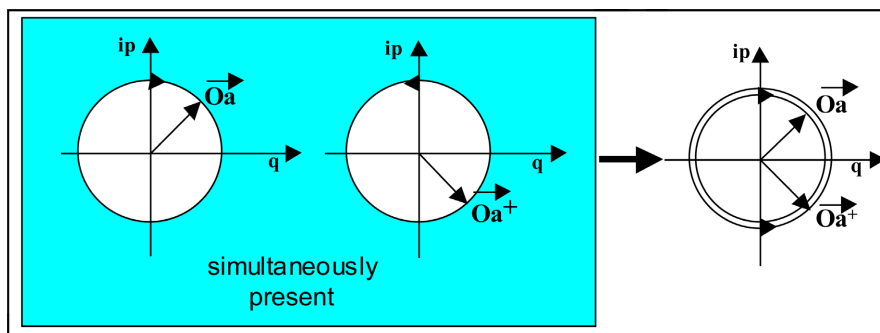


Figure 2. Phase vectors (\mathbf{Oa} , \mathbf{Oa}^+) simultaneously present.

The new physics could be the “*Quantum Mechanics*”, where the possible local states of a system can individually exist, but are experimentally complementary, or can also exist in a superposition state (non-locality). Let us recall that in analytical mechanics [8] to the two rotations of phase are associated two *fluxes* of phase ($(g_c(t), g_{\bar{c}}(t))$) with their respective Poisson operators and relative Poisson brackets (\bar{c} is clockwise, c is counterclockwise). Well, a difference between the two fluxes of phase (that is the difference ($\mathbf{Oa} \neq \mathbf{Oa}^+$)) would imply a *non-commutation* of the phase fluxes and therefore a non-zero value of their Poisson

bracket. If we then associate a physical quantity with an operator because experimentally observing and measuring perturbs the observed system and we admit the possibility of a non-local state Ψ of individual possibilities (eigenstates) or measurements (Ψ_k), then physics “changes” and instead of classical Poisson brackets we have commutators between operators. So, in quantum mechanics, see the Heisenberg’s representation, the Poisson brackets correspond to the commutators. It follows that the difference ($Oa \neq Oa^*$) must correspond to a commutation bracket relating to two operators (a, a^*), that is $[a, a^*] = (aa^* - a^*a) \neq 0$. Recall that the difference ($Oa \neq Oa^*$) is connected to the two eigenvalues ($\pm r$), now assumed to be observable. Therefore, the “new physics” admits the possibility of detecting the two rotation directions of the phase (classical physics does not) but this implies that the coordinates (a, a^*) become non-commutative operators and that there is the possibility of a non-local state in which the two rotation eigenvalues coexist. It follows, as far as quantum oscillators are concerned, we consider that the difference ($Oa \neq Oa^*$) is related to the commutation bracket (non-zero value) of the corresponding Hermitian operators (a, a^*), that is $[a, a^*] = 1$, and vice versa. Note that “vice versa” would mean that the entire physics of quantum oscillators is built on the possibility of detecting the direction of phase rotation. In conclusion, if we admit that QM is “true” we must admit that the two different directions of rotation of the phase assigned to a quantum oscillator (note that the energy is degenerate in these two eigenstates), can instead be detected, under certain conditions, and observed. The solutions of the motion equations in the phase plane of the quantum Hermitian operators (q, p) are the same as Equation (12), but with operators (q_{op}, p_{op}). In an adaptive oscillator, the solutions (see Equation (16)) for a quantum oscillator, expressed by operators, will be:

$$q(t) = q_{el}(0)\cos(\omega t) + q_{abs}(0)\sin(\omega t) \tag{20}$$

where q_{el} is the elastic component in phase with the external force, while q_{abs} has a phase delay of $\pi/2$ with respect to the external force. We remember that any oscillator has two components: elastic and inertial; therefore, we admit the following equivalence: $q_{abs} \equiv q_{inertial}$. It follows:

$$q(t) = q_{el}(0)\cos(\omega t) + q_{in}(0)\sin(\omega t) \tag{21}$$

This equation can also describe, as we have already mentioned, an oscillator belonging to a chain of coupled oscillators (field). We state that a quantum field oscillator should always be represented with two components. The graphic representation [6] [7] of the quantum oscillator with two components is, **Figure 3**:

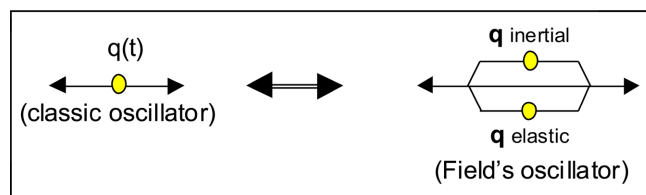


Figure 3. Field Quantum Oscillator at two components.

Recall that the quantum field Φ -field [3] is as a set of coupled quantum oscillators express by operators (a, a^\dagger):

$$\begin{aligned}\Phi(x_i, t) &= \left(\frac{1}{\sqrt{V}}\right) \sum_k q_k(t) e^{i(k \cdot x)} = \left(\frac{1}{\sqrt{V}}\right) \sum_k \left[\left(\sqrt{\frac{\hbar}{2\omega_k}}\right) (a_k + a_{-k}^\dagger) \right] e^{i(k \cdot x)} \\ \mathcal{E}_{(n_1, n_2, \dots, n_k)} &= \sum_k \left[\hbar \omega_k \left(n_k + \frac{1}{2} \right) \right], \quad P_{(n_1, n_2, \dots, n_k)} = \sum_k [\hbar k_k (n_k)]\end{aligned}\quad (22)$$

where $k_k = (2\pi/\lambda_k)$, $\omega_k = (v_\phi/k_k)$. Considering the Equations (18) and (19), we have [$q_t = q_0 \exp(\pm i\omega t)$, $p_t = p_0 \exp(\pm i\omega t)$] and resorting to the Euler's relations, easily one finds that:

$$\left\{ \begin{aligned} a_t &= \left(\sqrt{\frac{m\omega}{2\hbar}}\right) \left[q_0 e^{-i\omega t} + i \left(\frac{p_0}{m\omega}\right) e^{-i\omega t} \right] = k_q e^{-i\omega t} + i k_p e^{-i\omega t} = k_q e^{-i\omega t} + k_p e^{-i(\omega t - \pi/2)} \\ a_t^\dagger &= \left(\sqrt{\frac{m\omega}{2\hbar}}\right) \left[q_0 e^{i\omega t} - i \left(\frac{p_0}{m\omega}\right) e^{i\omega t} \right] = k_q e^{i\omega t} - i k_p e^{i\omega t} = k_q e^{i\omega t} + k_p e^{i(\omega t - \pi/2)} \end{aligned} \right\} \quad (23)$$

where it's [$q_0 = q(0)$, $p_0 = p(0)$] and

$$\left\{ \begin{aligned} k_q &= \left(\sqrt{\frac{m\omega}{2\hbar}}\right) q_0, \quad k_p = \left(\sqrt{\frac{1}{2m\hbar\omega}}\right) p_0 \\ [q_0, p_0] &= i\hbar, \quad [k_q k_p - k_p k_q] = \frac{i}{2}, \quad [a_0, a_0^\dagger] = 1 \end{aligned} \right\} \quad (24)$$

We thus note that the [(a, a^\dagger)] operators can be expressed by two components: elastic and inertial, see the Equation (21). We could then say that the operators [(a, a^\dagger)] will be expressed by the following equations, see Equation (23):

$$\left\{ \begin{aligned} a_t &= k_{(elastic)} e^{-i\omega t} + k_{(inertial)} e^{-i(\omega t - \pi/2)} \\ a_t^\dagger &= k_{(elastic)} e^{i\omega t} + k_{(inertial)} e^{i(\omega t - \pi/2)} \end{aligned} \right\} \quad (25)$$

We could then say that the operators (a, a^\dagger) will be expressed by the following equation (see Equation (25)):

$$\left\{ \begin{aligned} a_t &= a(t)_{elastic} + a(t)_{inertial} \equiv \mathbf{O}a \\ a_t^\dagger &= a^\dagger(t)_{elastic} + a^\dagger(t)_{inertial} \equiv \mathbf{O}a^\dagger \end{aligned} \right\} \Leftrightarrow \left\{ \begin{aligned} a_t &= a_{(el)} e^{-i\omega t} + a_{(in)} e^{-i(\omega t - \pi/2)} \\ a_t^\dagger &= a_{(el)}^\dagger e^{i\omega t} + a_{(in)}^\dagger e^{i(\omega t - \pi/2)} \end{aligned} \right\} \quad (26)$$

This is the generalization of the Equation (25). Let's duly observe that the elastic component has a phase delay of $\pi/2$, in comparison to the inertial one. Hereafter, we will resort to an oscillator with two components to describe a field oscillator associated with a particle, **Figure 4**.

The two descriptive circles of the oscillation in **Figure 4** and the doubling of the components of each quantization operator (a, a^\dagger) see [$(a_{el}, a_{el}^\dagger), (a_{in}, a_{in}^\dagger)$], lead us to describe a quantum field oscillator as a 2-dim. oscillator.

2.3. The Origin of the Commutation Bracket [a, a^\dagger] in QM

We return to the Equations (3), (4) and (6), which can be extended to any type of

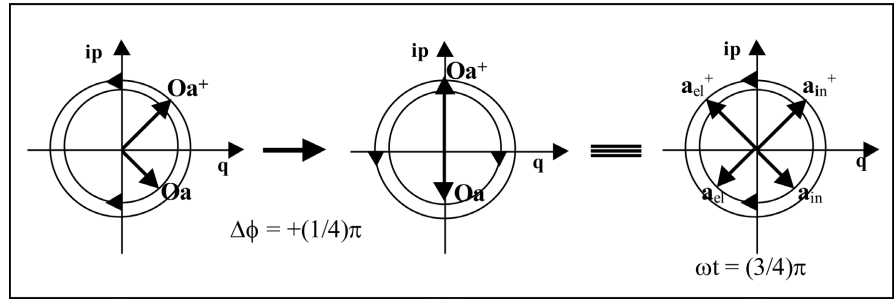


Figure 4. Representation of operators-vectors (a, a^*) with two components.

quantum oscillator. As we already said, Dirac [4] proposed the following relations for the (a, a^*) operators of a quantum oscillator, see the Equation (6):

$$\begin{cases} a = (\exp(i\varphi))(\sqrt{n}) \\ a^+ = (\sqrt{n})(\exp(-i\varphi)) \end{cases} \quad (27)$$

For Dirac, φ is the φ -operator of the phase angle (remember that (a, a^*) are operators). However, it's evident that this operator (φ) does not commute with the operators (H), (n), and (r), see the Equation (6): the phase angle [$\theta = \omega t$] is uncertain, if, instead, n' -eigenvalue of (n) is certain. Note that, if the oscillator energy (degenerate in an eigenvalue of (r)) is certain, then the phase is uncertain. As already demonstrated by us and by Susskind and Glogower [5], the Equation (27) leads to some contradictions, showing so that the phase must be seen as a physical variable but not as an operator. In Ref. [3], however, the functional operator (Φ) is proposed:

$$\Phi(\varphi) = \exp(i\varphi), \quad \Phi^+(\varphi) = \exp(-i\varphi) \quad (28)$$

Considering Fain [3] and our conjecture of the existence of an operator r , see Sects. 2.1 and 2.2, we can introduce the operator r into the function Φ , and have:

$$\begin{cases} a = (\Phi(r, \varphi))(\sqrt{n}) \\ a^+ = (\sqrt{n})(\Phi^+(r, \varphi)) \end{cases} \quad (29)$$

where r commutes whit Hamiltonian operator H and the function operator Φ consists in:

$$\Phi(r, \varphi) = \exp(ir\varphi), \quad \Phi^+(r, \varphi) = \exp(-ir\varphi) \quad (30)$$

From the Equations (11), (23) and (25) it is:

$$\begin{cases} a = (\Phi(r, \varphi))(\sqrt{n}) = [(e^{-ir\omega t})(k_{el} + ik_{in})] \\ a^+ = (\sqrt{n})\Phi^+(r, \varphi) = [(k_{el} - ik_{in})(e^{ir\omega t})] \end{cases} \quad (31)$$

But

$$\left\{ \begin{aligned} a^+ a &= n = (\sqrt{n})(\sqrt{n}) \\ a^+ a &= n = [(k_{el} - ik_{in})(e^{ir\omega t})][(e^{-ir\omega t})(k_{el} + ik_{in})] = (k_{el} - ik_{in})(k_{el} + ik_{in}) \end{aligned} \right\} \quad (32)$$

Note that the last equality (Equation 32(b)) implies a contradiction with the first one (Equation 32(a)) because it's $(k_{el} - ik_{in}) \neq (k_{el} + ik_{in})$. To avoid this contradiction, we recall the previous assumption, see **Figure 2**: the difference ($\mathbf{Oa} \neq \mathbf{Oa}^+$) between vectors ($\mathbf{Oa}, \mathbf{Oa}^+$) is implicitly contained in the commutator $[a, a^+]$ (non-zero value). Since the no commutation $[a, a^+]$ is a physical reality, then the difference ($|\mathbf{Oa}| \neq |\mathbf{Oa}^+|$) should be permissible. Vice versa if we physically admit the difference ($|\mathbf{Oa}| \neq |\mathbf{Oa}^+|$) as the existence of detect the two possible directions of phase rotation, then as consequence we have a commutator $[a, a^+] = 1$. This means that we can distinguish the norms of these operators, or we can distinguish the $(n)^{1/2}$ operator contained in (a) from that contained in (a^+) . Then we can conjecture the following form:

$$\left\{ \begin{array}{l} a = \Phi(r, \varphi)(\sqrt{n_+}) \\ \hat{a}^+ = (\sqrt{n_-})(\Phi^+(r, \varphi)) \end{array} \right\} \quad (33)$$

where it is

$$\sqrt{n_+} = (k_{el} + ik_{in}); \sqrt{n_-} = (k_{el} - ik_{in}) \quad (34)$$

with

$$\left\{ \begin{array}{l} \sqrt{n_+} \neq \sqrt{n_-} \\ (\sqrt{n_+})^+ = \sqrt{n_-} \Leftrightarrow (\sqrt{n_-})^+ = \sqrt{n_+} \end{array} \right\} \quad (35)$$

We'll have, for k operator, see the Equation (24):

$$(\sqrt{n_+})(\sqrt{n_-}) = (k_{el} + ik_{in})(k_{el} - ik_{in}) = (k_{el}^2 + k_{in}^2) - \left(\frac{1}{2}\right) \quad (36)$$

Thus, we find (by Equation (31) and Equation (33)) that:

$$\left\{ \begin{array}{l} a^+ a = [(k_{el})(e^{i\varphi}) - (ik_{in})(e^{i\varphi})][e^{-i\varphi}k_{el} + (ie^{-i\varphi})k_{in}] = [(\sqrt{n_+})(\sqrt{n_-})] \\ a^+ a = n \end{array} \right. \quad (37)$$

confirming that

$$n = [(\sqrt{n_+})(\sqrt{n_-})] \quad (38)$$

In this way, Equation (33) becomes:

$$\left\{ \begin{array}{l} a = (\Phi(r, \varphi))(\sqrt{n_+}) = [(e^{-i\varphi})(k_{el} + ik_{in})] \\ a^+ = (\sqrt{n_-})\Phi^+(r, \varphi) = [(k_{el} - ik_{in})(e^{i\varphi})] \end{array} \right. \quad (39)$$

A new Dirac's form of the (a, a^+) operators will be:

$$\left\{ \begin{array}{l} a = (\Phi(r, \varphi))(\sqrt{n_+}) = [(\Phi(r, \varphi))(k_{el}) + (\Phi(r, \varphi))(ik_{in})] = (a_{el} + a_{in}) \\ a^+ = (\sqrt{n_-})\Phi^+(r, \varphi) = [(k_{el})(\Phi^+(r, \varphi)) - (ik_{in})(\Phi^+(r, \varphi))] = (a_{el}^+ + a_{in}^+) \end{array} \right. \quad (40)$$

This form is valid also for fermionic operators (η, η^+) in Sect. 2.1. We have thus shown that the differences $\{[(\eta)_0 \neq (\eta)_+], [(\eta)_- \neq (\eta)_+]\}$ are given and are con-

connected to the Φ via the r -operator: $(\exp(i\mathbf{r}\omega t))$. Note that the (a, a^+) become complex operators, consisting of the operator Φ (with real norm $\rho = 1$) and the $(\sqrt{n_{\pm}})$ complex operator. Here, we point out that new form of the operators (a, a^+) contains one more piece (see the $(\sqrt{n_{\pm}})$) than the old form, Equation (27).

2.4. The Intrinsic Quantum Oscillator of Structure (IQuO)

Let us consider that a two-component quantum oscillator, see equations (17), (26) and (40), as also **Figure 3** and **Figure 4**, has the two components oscillating even in the vacuum state. Therefore, if the vacuum state is with energy $\varepsilon = 1/2\hbar\omega$, each component will have energy $\varepsilon = 1/4\hbar\omega$. We define “**full semi-quantum** (\bullet)” as the oscillating quantum with energy $\varepsilon = 1/2\hbar\omega$, and “**empty semi-quantum** (\circ)” as the quantum with energy $\varepsilon = 1/4\hbar\omega$ [6] [7]. In this case, we can have one quantum (\bullet) in way that:

$$\{(\bullet) = [(\bullet) + (\bullet)] \equiv (1\hbar\omega)\} \tag{41}$$

To better understand this last aspect, let’s consider the Schrödinger’s representation of a quantum oscillator, see **Figure 5** [10]:

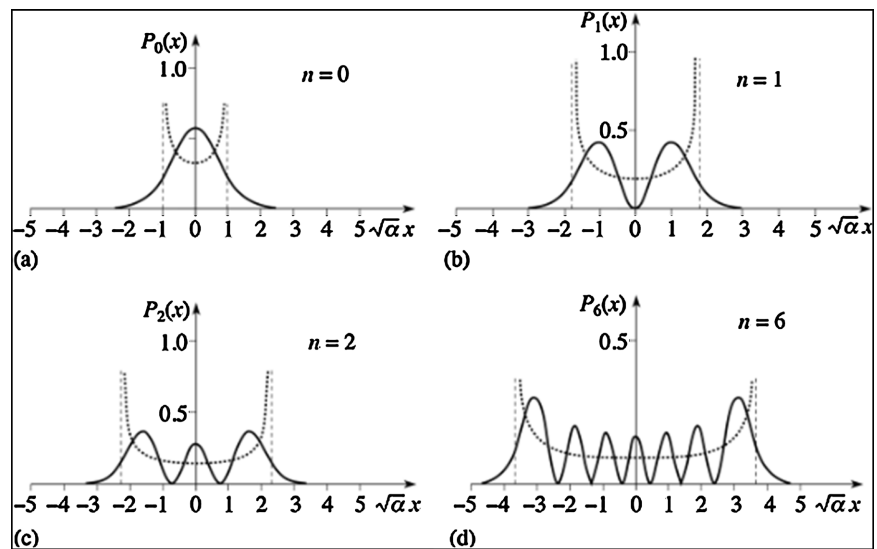


Figure 5. Probability function of quantum oscillator to varying of n quantum number.

The probability function $P_n(x)$ shows some peaks indicating where the energy quanta of the oscillation are most likely to be found at time t_0 . Then, we could conjecture that the peaks of $P_n(x)$ could represent the distinct parts (S_i) of the same quantum oscillator, each always with elastic characteristics and kinetic (inertial). The quantum oscillator is thus composed of $(n + 1)$ not-separable oscillating parts or “**sub-oscillators**” S_s , see **Figure 5**. We also believe that the presence of two or more oscillating components in an oscillator causes the “splitting” of its energy quanta into two energetic components in each sub-oscillators: this introduces the idea of “**semi-quanta**” (or singularly a “**semi-quantum**” (sq)). If $(n = 0)$, there is only one sub-oscillator with energy $(\varepsilon = 1/2\hbar\omega)$, then the two sq elastic and inertial

must each have an energy of $[(\varepsilon = 1/4\hbar\omega)]$. These relations are consistent with the actions of the operators (a, a^+) on the eigenvectors $|n\rangle$ of the operator (n) ; indeed, recall:

$$\begin{cases} a|n\rangle = (\sqrt{n})|n-1\rangle \\ a^+|n\rangle = (\sqrt{n+1})|n+1\rangle \end{cases} \quad (42)$$

With the H-Hamiltonian operator:

$$H = \left(a^+ a + \frac{1}{2} \right) \hbar\omega = \left(n + \frac{1}{2} \right) \hbar\omega \quad (43)$$

Recall that in any oscillator the energy ε is given as $(\varepsilon = U + K)$, where U is the potential energy or elastic, while K is the kinetic energy. Then, through the inverse of the two relations in Equation (18), we have, see also ref. [2]:

$$\begin{cases} U|n\rangle = \left(\frac{1}{2} m\omega^2 x^2 \right) |n\rangle = \left(\frac{1}{4} \hbar\omega \right)_U \left[a^2 + (a^+)^2 + a^+ a + a a^+ \right] |n\rangle \\ K|n\rangle = \left(\frac{p^2}{2m} \right) |n\rangle = \left(\frac{1}{4} \hbar\omega \right)_K \left[-a^2 - (a^+)^2 + a^+ a + a a^+ \right] |n\rangle \end{cases} \quad (44)$$

Note

$$\begin{cases} aa^+|n\rangle = a(\sqrt{n+1}|n+1\rangle) = \sqrt{n+1}(\sqrt{n+1})|n\rangle = (n+1)|n\rangle \\ a^+a|n\rangle = a^+(\sqrt{n}|n-1\rangle) = \sqrt{n}(\sqrt{n})|n\rangle = (n)|n\rangle \end{cases} \quad (45)$$

That is:

$$(a a^+ + a^+ a)|n\rangle = (n+1)|n\rangle + (n)|n\rangle = (2n+1)|n\rangle \quad (46)$$

So, we can calculate, by Equation (46), the value of the potential and kinetics energy in the $|0\rangle$ eigenstate:

$$\begin{cases} U|0\rangle = \left(\frac{1}{2} m\omega^2 x^2 \right) |0\rangle = \left(\frac{1}{4} \hbar\omega \right)_U \left[(a^+)^2 + 1 \right] |0\rangle \\ K|0\rangle = \left(\frac{p^2}{2m} \right) |0\rangle = \left(\frac{1}{4} \hbar\omega \right)_K \left[-(a^+)^2 + 1 \right] |0\rangle \end{cases} \quad (47)$$

Thus, the form of the Hamiltonian operator in $|0\rangle$ is found:

$$\hat{H}|0\rangle = U|0\rangle + K|0\rangle = \left(\frac{1}{4} \hbar\omega \right)_U |0\rangle + \left(\frac{1}{4} \hbar\omega \right)_K |0\rangle \quad (48)$$

In this way, in the empty state of quantum oscillator one demonstrates the existence of empty semi-quanta $sq(o)$ with energy $\varepsilon = 1/4\hbar\omega$. Looking at the Equation (48), one obtains, **Figure 6**.

We demonstrate by Equation (43) also that in $(n \neq 0)$ one has:

$$H|n\rangle = U|n\rangle + K|n\rangle = (2n+1) \left(\frac{1}{4} \hbar\omega \right)_U |n\rangle + (2n+1) \left(\frac{1}{4} \hbar\omega \right)_K |n\rangle \quad (49)$$

with eigenvalues in the eigenstate $\mathcal{S}(H,n)$ such that:

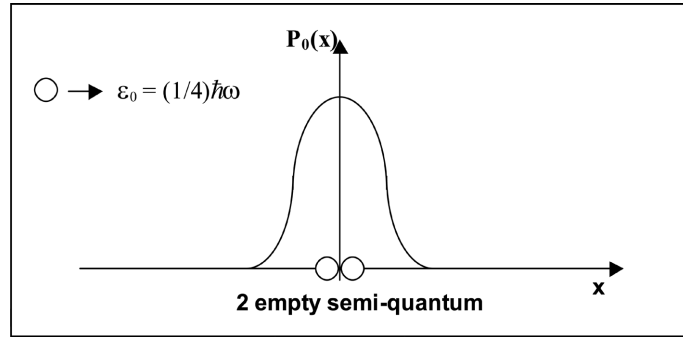


Figure 6. A sub-oscillator to $n = 0$.

$$\left[H_{(n)} \right]_{r'} = \left[U_{(n)} + K_{(n)} \right]_{r'} = \left[(2n+1) \left(\frac{1}{4} \hbar \omega \right)_U + (2n+1) \left(\frac{1}{4} \hbar \omega \right)_K \right]_{r'} \quad (50)$$

$$\begin{aligned} \left(H_{(n)} \right)_{r'} &= \left(U_{(n)} + K_{(n)} \right)_{r'} \\ &= \left[n \left(\left(\frac{1}{2} \hbar \omega \right)_U \right) + \left(\frac{1}{4} \hbar \omega \right)_U \right]_{r'} + \left[n \left(\left(\frac{1}{2} \hbar \omega \right)_K \right) + \left(\frac{1}{4} \hbar \omega \right)_K \right]_{r'} \end{aligned}$$

Here it is a further confirmation that in the quantum oscillator of field there are full semi-quanta and some empty semi-quanta. We denote by the acronym **IQuO** (Intrinsic **Q**uantum **O**scillator) an oscillator composed of sub-oscillators traversed by semi-quanta energy. We have, see **Figure 7**:

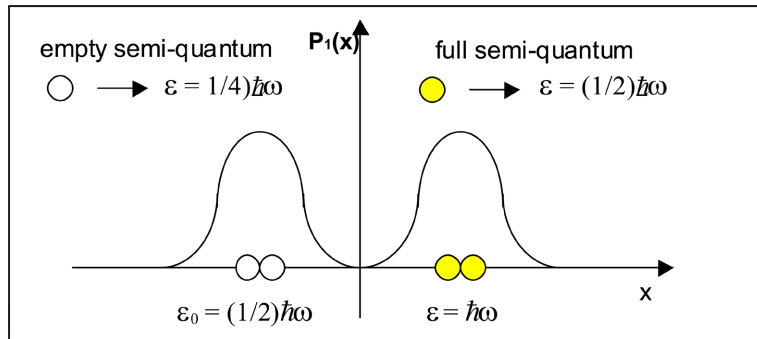


Figure 7. Two sub-oscillators in an oscillator to $n = 1$.

Even if the maximum potential energy and the maximum kinetic energy always have a constant value over time, the semi-quantum goes back and forth from a sub-oscillator to another.

2.5. The Geometric Representation of an IQuO

Now we can state the following correspondences:

$$\left\{ \begin{aligned} U &\equiv (\bullet + \circ) \\ K &\equiv (\bullet + \circ) \end{aligned} \right\} \Leftrightarrow \left\{ \Psi_{osc} \equiv \begin{pmatrix} Oa = Oa_{el} + Oa_{in} \\ Oa^+ = Oa_{el}^+ + Oa_{in}^+ \end{pmatrix} \right\} \quad (51)$$

$$\Leftrightarrow \left\{ \begin{aligned} a_{el} &\equiv U_{el}(\bullet) & a_{in} &\equiv K_{in}(\circ) \\ a_{el}^+ &\equiv U_{el}(\circ) & a_{in}^+ &\equiv K_{in}(\bullet) \end{aligned} \right\}$$

There is also the following equivalence (invariance for (o) \leftrightarrow (\bullet) change) between matrices:

$$\left\{ \left\{ \begin{array}{ll} a_{el} \equiv U_{el}(\bullet) & a_{in} \equiv K_{in}(o) \\ a_{el}^+ \equiv U_{el}(o) & a_{in}^+ \equiv K_{in}(\bullet) \end{array} \right\} \right\} \Leftrightarrow \left\{ \left\{ \begin{array}{ll} a_{el} \equiv U_{el}(o) & a_{in} \equiv K_{in}(\bullet) \\ a_{el}^+ \equiv U_{el}(\bullet) & a_{in}^+ \equiv K_{in}(o) \end{array} \right\} \right\} \quad (52)$$

Recall that the two sub-oscillators of the IQuO_(n=1) contain the $sq(\mathbf{o}, \bullet)$ which move following the oscillation vectors ($\mathbf{Oa}, \mathbf{Oa}^+$) and the corresponding components $\left[(a_{el}, a_{el}^+), (a_{in}, a_{in}^+) \right]$. We assign to each component of the operators (a, a^+) the “**semi-quantum operators**” $sq(\mathbf{o}, \bullet)$ with their respective elastic and inertial characteristics: $\left\{ \left[(a_{el}, a_{el}^+), (a_{in}, a_{in}^+) \right] \right\} \Leftrightarrow \left\{ \left[(\mathbf{o}_{el}, \bullet_{el}^+), (\bullet_{in}, \mathbf{o}_{in}^+) \right] \right\}$.

The projections of the operators $\left[(a_{el}, a_{el}^+), (a_{in}, a_{in}^+) \right]$ along the X-axis give us the position of the semi-quanta (\mathbf{o}, \bullet) along this axis. As for the (a, a^+) operators, by means of the Equation (53), we can set the following symbols:

$$\left\{ \left\{ \begin{array}{ll} a_{el} \equiv (\bullet)_{el} & a_{in} \equiv (o)_{in} \\ a_{el}^+ \equiv (o^+)_{el} & a_{in}^+ \equiv (\bullet^+)_{in} \end{array} \right\} \right\} \Leftrightarrow \left\{ \left\{ \begin{array}{ll} a_{el} \equiv (o)_{el} & a_{in} \equiv (\bullet)_{in} \\ a_{el}^+ \equiv (\hat{\bullet}^+)_{el} & a_{in}^+ \equiv (o^+)_{in} \end{array} \right\} \right\} \quad (53)$$

\mathbf{B}_1 -Matrix \mathbf{B}_2 -Matrix

where $((\mathbf{o}^+)_{eb}, (\mathbf{o}^+)_{in})$ are the creation operators of empty semi-quanta (with $\varepsilon = 1/4 \hbar \omega$), while $((\bullet^+)_{eb}, (\bullet^+)_{in})$ are the creation operators of full semi-quanta ($\varepsilon = 1/2 \hbar \omega$). Instead, $((\mathbf{o})_{eb}, (\mathbf{o})_{in})$ are annihilation operator of empty semi-quanta, while $((\bullet)_{eb}, (\bullet)_{in})$ are the annihilation operator of full semi-quanta. Precisely we have:

1) $(\bullet_{in}^+, \bullet_{el}^+)$ are creation operators of $sq(\bullet)$ (that is each creates an amount of energy ($\varepsilon = 1/2 \hbar \nu$) or fill an $sq(\mathbf{o})$ with the amount of energy ($\varepsilon = 1/4 \hbar \nu$), ($\mathbf{o} \rightarrow \bullet$))

2) $(\bullet_{in}, \bullet_{el})$ are annihilation operators of $sq(\bullet)$ (that is annihilate an energy quantity of ($\varepsilon = 1/2 \hbar \nu$) or empty $sq(\bullet)$ of the energy quantity ($\varepsilon = 1/4 \hbar \nu$) making it so empty, ($\bullet \rightarrow \mathbf{o}$))

3) $(\mathbf{o}_{in}^+, \mathbf{o}_{el}^+)$ are creation operators of empty $sq(\mathbf{o})$ (that is annihilate an energy quantity of ($\varepsilon = 1/2 \hbar \nu$) or empty a $sq(\bullet)$ of the energy quantity ($\varepsilon = 1/4 \hbar \nu$), ($\bullet \rightarrow \mathbf{o}$))

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

How are these last two operators interpreted? We remind you that in QM the annihilation op. (a) does not act in eigenstates $|n\rangle$ with $n = 0$. The same it happens to operators $(\mathbf{o}_{eb}, \mathbf{o}_{in})$. In an eigenstate of (\mathbf{r}) and (n), it will be (see Equation (25) and Equation (26)):

$$\left\{ \begin{array}{l} \mathbf{Oa}_{n,r'}^+(t) \equiv a_{n,r'}^+(t) = (\bullet^+)_{el}^{(n)} [\exp(ir'\omega t)] + (\mathbf{o}^+)_{in}^{(n)} [\exp(i(r'\omega t - \pi/2))] \\ \mathbf{Oa}_{n,r'}(t) \equiv a_{n,r'}(t) = (\mathbf{o})_{el}^{(n)} [\exp(-ir'\omega t)] + (\bullet)_{in}^{(n)} [\exp(-i(r'\omega t - \pi/2))] \end{array} \right\} \quad (54)$$

or equivalently

$$\left\{ \begin{array}{l} \mathbf{Oa}_{n,r'}^+(t) \equiv a_{n,r'}^+(t) = (\mathbf{o}^+)_{el}^{(n)} [\exp(ir'\omega t)] + (\bullet^+)_{in}^{(n)} [\exp(i(r'\omega t - \pi/2))] \\ \mathbf{Oa}_{n,r'}(t) \equiv a_{n,r'}(t) = (\bullet)_{el}^{(n)} [\exp(-ir'\omega t)] + (\mathbf{o})_{in}^{(n)} [\exp(-i(r'\omega t - \pi/2))] \end{array} \right\} \quad (55)$$

These mathematical relations give to us the mathematical form of the field oscillator called "IQuO". In an IQuO at first level ($n = 1$) it will be:

$$\begin{cases} a_{1,r'}^+(t) = (\bullet^+)_{el} [\exp(ir'\omega t)] + (o^+)_{in} [\exp(i(r'\omega t - \pi/2))] \\ a_{1,r'}^-(t) = (o)_{el} [\exp(-ir'\omega t)] + (\bullet)_{in} [\exp(-i(r'\omega t - \pi/2))] \end{cases} \quad (56)$$

With

$$\begin{aligned} (r)' = +1 &\Rightarrow \begin{bmatrix} [a_{el} = o_{el} \text{ (clockwise direction)}] \\ [a_{in} = \bullet_{in} \text{ (clockwise direction)}] \end{bmatrix} \\ (r)' = +1 &\Rightarrow \begin{bmatrix} [a_{el}^+ = \bullet_{el}^+ \text{ (anti-clockwise direction)}] \\ [a_{in}^+ = o_{in}^+ \text{ (anti-clockwise direction)}] \end{bmatrix} \end{aligned} \quad (57a)$$

$$\begin{aligned} (r)' = -1 &\Rightarrow \begin{bmatrix} [a_{el} = o_{el} \text{ (anti-clockwise direction)}] \\ [a_{in} = \bullet_{in} \text{ (anti-clockwise direction)}] \end{bmatrix} \\ (r)' = -1 &\Rightarrow \begin{bmatrix} [a_{el}^+ = \bullet_{el}^+ \text{ (clockwise direction)}] \\ [a_{in}^+ = o_{in}^+ \text{ (clockwise direction)}] \end{bmatrix} \end{aligned} \quad (57b)$$

Considering **Figure 4**, we could use the following representation (see Equation (56)) about an IQuO with ($r' = -1$) and phase angle of ($5\pi/4$), see also the Equation (57b), in **Figure 8**:

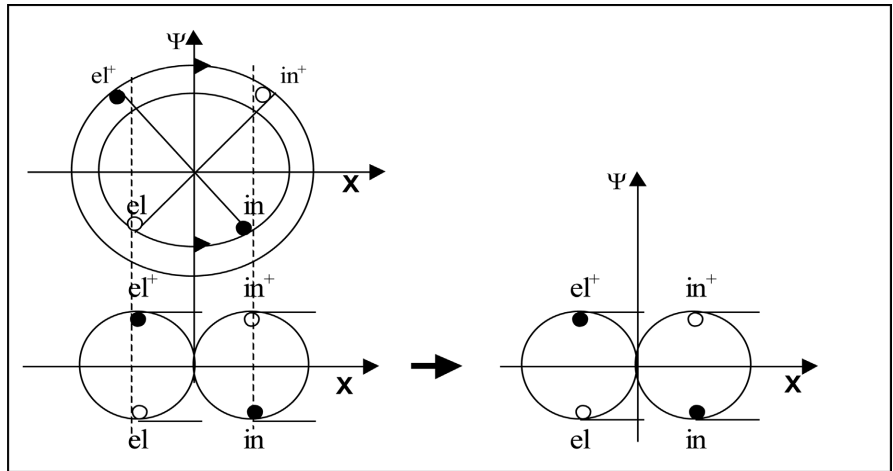


Figure 8. IQuO with eigenvalue $r' = -1$.

Note that by convention the positive angles increasing in anti-clock direction. This is the graphic representation of an IQuO, where $(\underline{o}_{el}, \underline{\bullet}_{in})$ is the pair with anti-clockwise rotation of the phase, while $(\bullet_{in}^+, \bullet_{el}^+)$ is the couple with clockwise rotation. This representation could be useful to represent a particle moving along the X axis, seeing this as a quantum moving along a line of coupled field-oscillators. Considering ($r' = \pm 1$), we will have **Figure 9**.

This is the graphic representation of an IQuO, where we will denote by $[(\underline{o}_{el}$

\bullet_{in} , $(\circ_{in}^+, \bullet_{el}^+)$ the pairs with anti-clockwise rotation of the phase, and by $[(\circ_{el}^+, \bullet_{in}^+), (\circ_{in}^+, \bullet_{el}^+)]$ the pairs with clockwise rotation. Looking **Figure 6** and **Figure 9**, and the Equation (56) with eigenvalue $r' = +1$, we set up the following representation, see **Figure 10**.

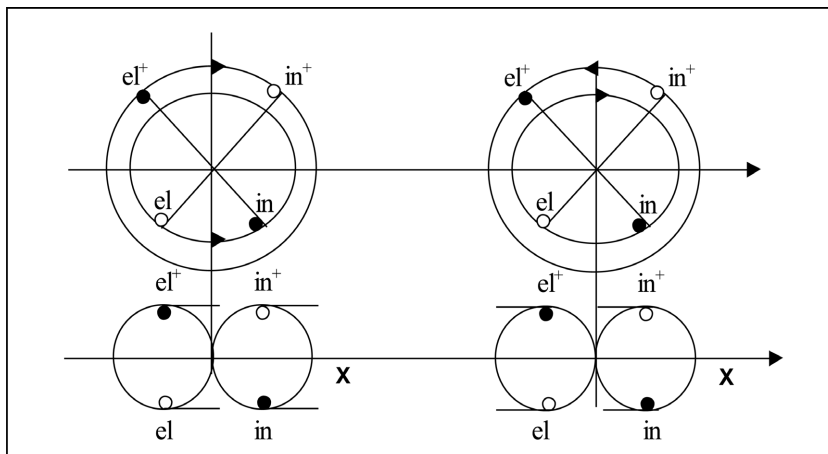


Figure 9. Two IQuO 2-dim. with phase rotation opposites ($\varphi = \omega t = 3\pi/4$), and different eigenvalues $r(\pm 1)$.

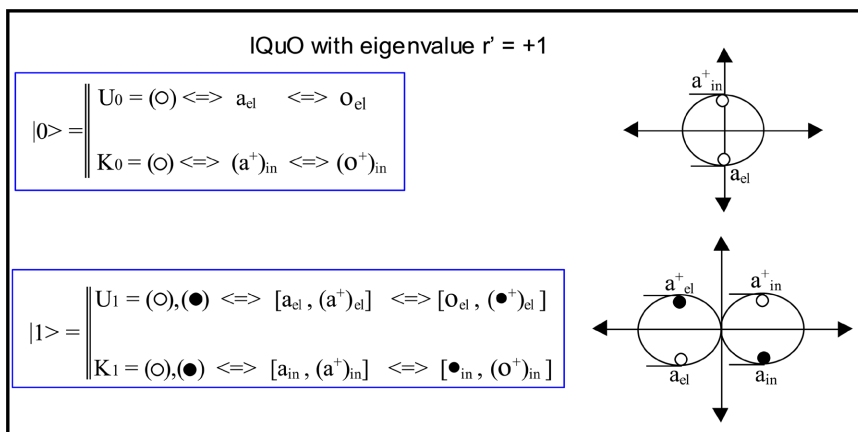


Figure 10. IQuO representation with eigenvalue ($n = 0, 1$).

Note that the two-component oscillator (forced oscillator of field) admits the presence of an internal degree of freedom, that is the phase rotation. This aspect is very important in the gauge fields' theory because this internal degree of freedom allows us of determine the origin of the sign of the electric charge [6] [7] and that of color [11] [12] by sub-oscillators, see the first image in **Figure 10**, correspondent to *gluons*. It is evident that an IQuO could not spontaneously change the r' eigenvalue, from $r' = +1$ to ($r' = -1$). We show (as an example) the first three possible configurations after those of the second image in **Figure 9**, of the IQuO during the phase change, with ($r' = +1$), see **Figure 11**.

In analogy with the classical oscillator, we project on the X-axis the motion of the quanta which represent the oscillator of **Figure 11**; we'll have, **Figure 12**.

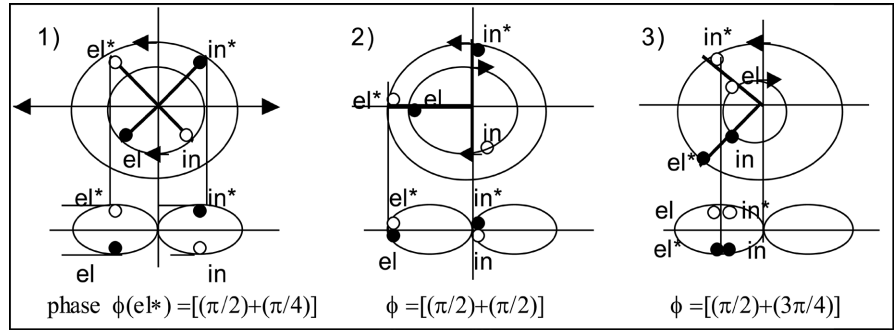


Figure 11. Three configurations of the oscillation of an IQuO.

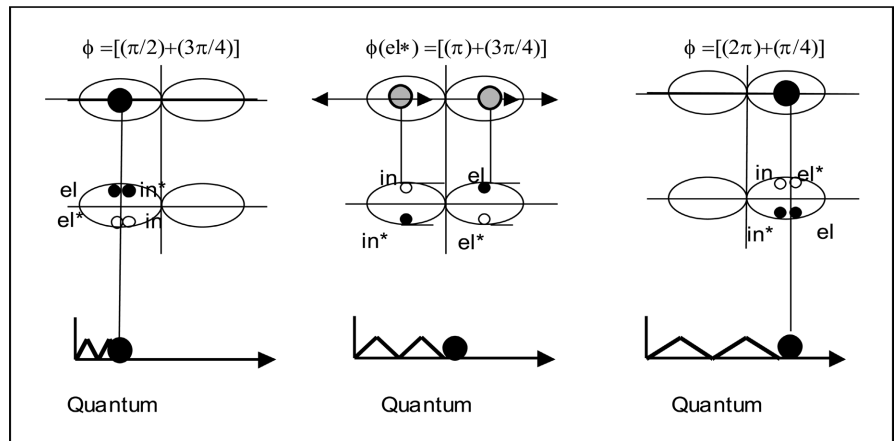


Figure 12. The oscillation of a “quantum” along X-axis.

Where the position of a “*quantum*” $[(\bullet, \bullet) \equiv (\bullet)]$ follows the law of probabilistic function $|\Psi_1(x)|^2$. We underline that in the $|r'\rangle$ eigenstate (local state) the phase is uncertain (that is the configuration is indefinite), see the Sect. 2.1. The non-local state of the phase involves that the transition instant of a semi-quantum from a sub-oscillator to other one is uncertain, even if the configurations during an unobserved oscillation follow each other in an orderly way, see **Figure 11**. Note, from **Figure 8**, that the projections of the op. of semi-quanta (\bullet, \bullet) along the X axis give us the position of the semi-quanta, $[sq(\bullet, \bullet)]$, along this axis and therefore the position of the quantum (\bullet, \bullet) , respect to two sub-oscillators, see **Figure 12**. In this figure, the upper image represents the oscillation of one quantum (\bullet) moving along the X-axis, between the two extreme points (x_1, x_2) ; the lower image represents an oscillator with its two sub-oscillators and the *sq* pairs (\bullet, \bullet) moving (see the arrow) along the X axis between the two points (x_1, x_2) . Note the *sq* are matched to their respective operators. Let us return to **Figure 9**; the image reads as follows:

- 1) the *sq* $(el^+(\bullet))$ moves in the +X direction with clockwise phase rotation; then, the $(\bullet)_{el}^+$ operator works by creating a *sq* (\bullet_{el}) in the +X direction
- 2) the *sq* $(el(\bullet))$ moves in the +X direction with counterclockwise phase rotation; then the $(\bullet)_{el}$ operator works by annihilating a *sq* (\bullet_{el}) in the +X direction, but this is equivalent to creating a *sq* (\bullet_{el}) in the +X direction

These two aspects give us the following equivalences:

$$\left[(\bullet)_{el}^+ \equiv (\underline{o})_{el} \right]_{+X}, \left[(\bullet)_{in}^+ \equiv (\underline{o})_{in} \right]_{+X}$$

This implies the equivalence of the matrices, see Equation (54), and, that is, during the oscillation the full sq(•) change with empty sq(o) and vice versa: $[(\bullet) \Leftrightarrow (\underline{o})]$.

2.6. The Matrix Representation of an IQuO

We define the $\Phi(B)$ -matrix associated with each configuration in **Figure 9**, see also the Equation (56):

$$\left[\Phi(B) \right]_{(r'=+1)} \equiv \left\{ \left[\begin{pmatrix} (a_{el})_{(cl)} & (a_{in})_{(cl)} \\ (a_{el}^+)_{(cl)} & (a_{in}^+)_{(cl)} \end{pmatrix} \Leftrightarrow \left[\begin{pmatrix} (o_{el})_{(cl)} & (\bullet_{in})_{(cl)} \\ (\bullet_{el}^+)_{(cl)} & (o_{in}^+)_{(cl)} \end{pmatrix} \equiv \left[\begin{pmatrix} (\bullet_{el})_{(cl)} & (o_{in})_{(cl)} \\ (o_{el}^+)_{(cl)} & (\bullet_{in}^+)_{(cl)} \end{pmatrix} \right] \right] \right\} \quad (58a)$$

$$\left[\Phi(B) \right]_{(r'=-1)} \equiv \left\{ \left[\begin{pmatrix} (a_{el})_{(cl)} & (a_{in})_{(cl)} \\ (a_{el}^+)_{(cl)} & (a_{in}^+)_{(cl)} \end{pmatrix} \Leftrightarrow \left[\begin{pmatrix} (o_{el})_{(cl)} & (\bullet_{in})_{(cl)} \\ (\bullet_{el}^+)_{(cl)} & (o_{in}^+)_{(cl)} \end{pmatrix} \equiv \left[\begin{pmatrix} (\bullet_{el})_{(cl)} & (o_{in})_{(cl)} \\ (o_{el}^+)_{(cl)} & (\bullet_{in}^+)_{(cl)} \end{pmatrix} \right] \right] \right\} \quad (58b)$$

where the *cl-index* indicates clockwise direction, and the *cl-index* indicates anti-clockwise direction. To the $\Phi(B)$ matrix we associate an IQuO of type B (B-IQuO). Using the properties of the (a, a^+) quantum operators (their commutators) and the properties of the Hamiltonian operator (H), we obtain the commutation brackets of the (\bullet, o) semi-quantum operators, as:

$$\begin{aligned} \text{I}^\circ \text{ case: } & \left[(\bullet_{el}^+)_{cl}, (o_{el})_{(cl)} \right] = 0; & \left[(\bullet_{in}^+)_{cl}, (o_{in})_{(cl)} \right] = 0 \\ \text{I}^\circ \text{ case: } & \left[(o_{el}^+)_{cl}, (\bullet_{el})_{(cl)} \right] = 0; & \left[(o_{in}^+)_{cl}, (\bullet_{in})_{(cl)} \right] = 0 \end{aligned} \quad (59)$$

Other reports on semi-quantum operators and their symmetry properties can be summarised by the following commutation brackets:

$$\begin{aligned} \text{I}^\circ \text{ case: } & \left[\bullet_{el}^+, o_{in} \right] = \frac{i}{2}; & \left[o_{el}^+, \bullet_{in} \right] = \frac{i}{2} \\ \text{II}^\circ \text{ case: } & \left[\bullet_{in}^+, o_{el} \right] = \frac{i}{2}; & \left[o_{in}^+, \bullet_{el} \right] = \frac{i}{2} \end{aligned} \quad (60a)$$

The other cases (see Appendix in ref. [6] [7]) derive from the property that any global exchange $(\bullet \leftrightarrow o)$ doesn't change the commutators of the (a, a^+) operators. Then it is:

$$\begin{aligned} \text{I}^\circ \text{ case: } & \left[\bullet_{el}^+, \bullet_{in} \right] = \frac{i}{2}; & \left[o_{el}, o_{in}^+ \right] = \frac{i}{2} \\ \text{II}^\circ \text{ case: } & \left[\bullet_{in}^+, \bullet_{el} \right] = \frac{i}{2}; & \left[o_{in}, o_{el}^+ \right] = \frac{i}{2} \end{aligned} \quad (60b)$$

The calculation of the commutation relations, Equation (60), is reported in ref. [6] [7].

3. The Coupling between Two Representative IQuO

3.1. The Reduction Process in the Coupling between Two Fields-Particles

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 in quantum field theory, the process of “*reduction*” of the wave function (collapse of the wave function) representing the field in interactions between particles. In this way, if the interaction between particles implies an exchange 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. The term precedes implies that $t_{reduction} < t_{int}$, that is the interaction process (exchange of energy quanta) occurs only if the reduction process has already occurred. This would mean that the reduction process is separate from the interaction process and that it takes place in a different way. In this first part, for reasons of organization of the arguments addressed in the article, we choose to briefly explain the reduction process, leaving the precise and detailed exposition to the second part of the article. We specify that the treatment of reduction and interaction processes will make use of wave physics of the fields, implicitly admitting the mathematical relations and demonstrations that express the wave phenomena referred to. On the reduction process, we will say:

- 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), each of them composed of coupled oscillators
- The reduction process manifests itself through reciprocal phase shifts (phase variation) between oscillators that couple themselves
- The reciprocal phase shifts between (I_1, I_2) propagate at the phase propagation velocity v_φ , as predicted by wave theory, along their respective belonging chains (C_1, C_2)
- The phase shifts are produced by exchanges of $sq(\bullet, \mathbf{o})$ between the field oscillators without, however, involving exchanges of “*integer*” quanta or pairs of $sq(\bullet, \bullet)$

This last aspect, very important, defines the reduction process as a “*non-dynamic action*”: the exchange (see **Figure 11**) of a pair (\bullet, \mathbf{o}) between two IQuO (I_1, I_2) does not imply the presence of interaction (!) between the two particles. We could mathematically formalise the reduction process by an **O_R -operator**. This

“*non-dynamic*” process of an \mathbf{O}_R reduction operator can manifest itself in two different ways:

- 1) Reduction to an eigenstate $|k_i\rangle$ relative to a k_i -mode of oscillation: $\mathbf{O}_R \equiv \mathbf{O}_k$
- 2) Reduction to a local eigenstate of the position $|x_i\rangle$: $\mathbf{O}_R \equiv \mathbf{O}_x$

In the first case, the action of a *reduction operator* \mathbf{O}_k will then only be focused on the operator q_k of Ψ in Equation (22), acting by phase shift $[\exp(-i\varphi_s)]$ on the q_{ki} oscillation mode, where $s \in (k_1 \dots k_n)$. So, the \mathbf{O}_k operator reduces the state vector Φ to an eigenstate Φ_s : $\mathbf{O}_k \Phi = \Phi_s$, where \mathbf{O}_k is a *projection operator* ($|k_i\rangle \langle k_i|$). We would like to point out that to stimulate an oscillation mode, one of the two oscillators (I_1, I_2) must “force” the other oscillator through exchanges of $sq(\bullet, \bullet)$ and not whole quanta, $sq(\bullet, \bullet)$. Note that the exchange of semi-quanta in the IQuO representation does not imply “dynamic action”. Recall [9] that to induce a mode of oscillation an external force must act:

- 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: $\varphi_{est}(x_i) = \varphi_k(x_i)$.

If the phase shifts are different from $[\exp(-i\Delta\varphi_s)]$, 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. This is because the discordant phase shifts upset the couplings of the field oscillators which pass to an “*indeterminate*” state of the oscillation modes, consistently with the axioms of quantum mechanics. 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. To a discordant phase shift action, we associate the *position operator* \mathbf{O}_x , that is ($|x_i\rangle \langle x_i|$).

In any type of reduction, at the end of this process there is an “*adaptation phase*” with a Δt_{adb} 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:

$$\Delta\varphi_1 = -\Delta\varphi_2 \quad (61)$$

and the phase shift will be expressed by the operator \mathbf{O}_φ (*phase shift action operator*), with $[\mathbf{O}_\varphi = [\exp(-i\Delta\varphi)]]$. To the phase shifts given by exchanges of semi-quanta $sq(\bullet, \bullet)$, not integers, occurring between the two IQuO (I_1, I_2), we will associate the operator \mathbf{O}_ε (*operator of semi-quanta exchange*) that it exchange the $sq(\bullet, \bullet)$ between two oscillators (I_1, I_2): $[sq_I(\bullet) \Leftrightarrow sq_2(\bullet), sq_2(\bullet) \Leftrightarrow sq_I(\bullet)]$. Note that the exchange of a pair $sq(\bullet, \bullet)$ can be given by the combination of two pair-exchange operators $\mathbf{O}_\varepsilon(sq(\bullet, \bullet))$, that is: $\mathbf{O}_\varepsilon(sq(\bullet, \bullet)) = \mathbf{O}_\varepsilon(sq(\bullet, \bullet)) \cdot \mathbf{O}_\varepsilon(sq(\bullet, \bullet))$. In this case, the operator \mathbf{O}_ε determines the exchange of a quantum (\bullet, \bullet) and is thus present in the dynamic phase of the interaction.

3.2. The Reduction Process in the Coupling between Two Fields-Particles

Let’s take two real scalar fields in the representation of the quantum operators (a ,

a^+) [3]:

$$\left\{ \begin{array}{l} \Phi_1 = \sum_k \varpi_k \left[\left(a_{1k} \left(e^{-i\hat{r}\omega_k t + \alpha} \right) + a_{1(-k)}^+ \left(e^{i\hat{r}\omega_k t + \alpha} \right) \right) \left(e^{ikx} \right) \right] \\ \Phi_2 = \sum_k \varpi_k \left[\left(a_{2k} \left(e^{-i\hat{r}\omega_k t + \beta} \right) + a_{2(-k)}^+ \left(e^{i\hat{r}\omega_k t + \beta} \right) \right) \left(e^{ikx} \right) \right] \end{array} \right\} \quad (62)$$

We denote by $(\Phi_1 \oplus \Phi_2)$ the coupling of two fields where the sign \oplus is the reciprocal action operation with components $\oplus \equiv (O_R, \oplus)$. O_R describes the *nondynamic* initial reduction phase while the \oplus sign indicates, after the reduction process, the *dynamic* coupling by exchanges of $sq(\bullet, \bullet)$ pairs between two IQuO (I_1, I_2) of two fields (Φ_1, Φ_2) . 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 $|r\rangle$ 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, 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:

$$\boxed{|\Phi\rangle_{(I_{QuO1}+I_{QuO2})} = |\Phi\rangle_{(1)} \oplus |\Phi\rangle_{(2)} \Rightarrow \left\{ \begin{array}{l} |\Phi(r' = \pm 1)\rangle_{(1)} \oplus |\Phi(r' = \pm 1)\rangle_{(2)} \\ |\Phi(r' = \pm 1)\rangle_{(1)} \oplus |\Phi(r' = \mp 1)\rangle_{(2)} \end{array} \right\} \quad (63)$$

The first combination in Equation (63) has a “non-zero eigenvalue” of the operator (r), while the second has a “zero eigenvalue”. Let us first examine the two possible combinations of the “zero eigenvalue” of (r):

$$\left(|\Phi_1(r' = \pm 1)\rangle \right) \oplus \left(|\Phi_2(r' = \mp 1)\rangle \right).$$

We consider a pair creation process. As we have already said, the coupling between two fields can occur at a given point (x) of the space between the two corresponding oscillators (I_1, I_2); therefore, 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 ($|x\rangle \langle x|$), makes k “*indeterminate*”, as if an inverse operator of O_k had been applied operator, 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 and therefore a single field 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 (I_1, I_2) can be described by initially considering a system of two fields (Φ_1, Φ_2) with a single moment k_0 . Recall in a pair creation the two exiting particles have the same energy and impulse $|k_x|$ and the same mass ($m_0 = \hbar\omega_0/c^2$). 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 (Φ_{1k}, Φ_{2k}) on which an operator O_x acts. We'll have (for simplicity one sets $\alpha = \beta$ in Equation (62)) from the Equation (63) that:

$$\left\{ \begin{array}{l} \Phi_{1x}(r' = -1) = \varpi_k \left(a_k e^{i\omega_k t} + a_k^+ e^{-i\omega_k t} \right) \left(e^{ikx} \right) \\ \Phi_{2x}(r' = +1) = \varpi_k \left(a_k e^{-i\omega_k t} + a_k^+ e^{i\omega_k t} \right) \left(e^{ikx} \right) \end{array} \right\}_{(k=k_x)} \quad (64)$$

At the end of this process with O_x there is an “*adaptation phase*” with a Δt_{ab} in which there are instantaneous reciprocal inductions of phase change (phase-shifting) between two IQuO (I_1, I_2)_x, where there is the relation $[\Delta\varphi_1 = -\Delta\varphi_2]$ with (see Equation (61), that is $|\varphi_1| = |\varphi_2| = \varphi$). This reduction process is operated by the operator $O_R = O_x$ to which a phase shift operator O_φ is corresponding:

$$O_\varphi = \begin{pmatrix} e^{i\varphi_1} & 0 \\ 0 & e^{i\varphi_2} \end{pmatrix} = \begin{pmatrix} e^{i\varphi} & 0 \\ 0 & e^{-i\varphi} \end{pmatrix} \tag{65}$$

The operator O_φ , 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 will 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:

$$(\Phi_{1k} \oplus \Phi_{2k}) = \left\{ \oplus_{O_\varphi} (\Phi_{1k}, \Phi_{2k}) \right\} = \left\{ \left[\Phi_{1k}, \cdot (O_\varphi \cdot \Phi_{2k}) \right]_{\oplus} \right\}$$

with O_φ operating to right than left. Remember that $\oplus \equiv (O_R, \oplus)$ 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 $sq(\bullet, o)$, 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 $O_R \equiv (O_\varepsilon, (O_\varphi)_x)$. Then, we will have:

$$\begin{aligned} \Phi_{1k} \oplus \Phi_{2k} &= \left\{ O_\varepsilon \cdot \left[\Phi_{1k} \cdot \left((O_\varphi)_x \cdot \Phi_{2k} \right) \right]_{\oplus} \right\} \\ &= \left\{ O_\varepsilon \cdot \left[\begin{pmatrix} \Phi_{1k} \\ 1 \end{pmatrix} \cdot \left[\begin{pmatrix} e^{i\varphi} & 0 \\ 0 & e^{-i\varphi} \end{pmatrix}_x \cdot \begin{pmatrix} 1 \\ \Phi_{2k} \end{pmatrix} \right] \right]_{\oplus} \right\} \\ &= \left\{ O_\varepsilon \cdot \left[\begin{pmatrix} \Phi_{1k} \\ 1 \end{pmatrix} \cdot \left[\begin{pmatrix} e^{i\varphi} \\ e^{-i\varphi} \Phi_{2k} \end{pmatrix}_x \right] \right]_{\oplus} \right\} \\ &= \left\{ O_\varepsilon \cdot \left[\Phi_{1k} e^{i\varphi} + e^{-i\varphi} \Phi_{2k} \right]_{\oplus} \right\} \end{aligned} \tag{66}$$

Omitting the index x . Where $\oplus \equiv (O_R, \oplus) = (O_R)_{\oplus}$. By of Equation (65), applying the Equation (66), we will then have, omitting ϖ_k :

$$\begin{aligned} &\Phi_{1k} \oplus_{(\varepsilon, \varphi)} \Phi_{2k} \\ &= \left\{ \left[\left(a_k e^{i\omega_k t} + a_k^+ e^{-i\omega_k t} \right) (e^{ikx}) \right] e^{i\varphi} + e^{-i\varphi} \left[\left(a_k e^{-i\omega_k t} + a_k^+ e^{i\omega_k t} \right) (e^{ikx}) \right] \right\}_{(O_\varepsilon, \oplus)} \\ &= \left\{ \left[\left(a_k (e^{i\omega_k t + i\varphi}) + a_k^+ (e^{-i\omega_k t + i\varphi}) \right) (e^{ikx}) \right] + \left[\left(a_k (e^{-i\omega_k t - i\varphi}) + a_k^+ (e^{i\omega_k t - i\varphi}) \right) (e^{ikx}) \right] \right\}_{(O_\varepsilon, \oplus)} \end{aligned} \tag{67}$$

Setting $|\varphi_1| = |\varphi_2| = (\pi/4)$, it follows, omitting the operation (O_ε, \oplus) :

$$\begin{aligned}
 \Phi_{1k} \oplus \Phi_{2k} &= \left[(a_k^+ (e^{i\varphi}) + a_k (e^{-i\varphi})) (e^{-i\omega_k t}) + (a_k (e^{i\varphi}) + a_k^+ (e^{-i\varphi})) (e^{i\omega_k t}) \right] (e^{ikx}) \\
 &= \left[(a_k^+ + a_k (e^{-2i\varphi})) (e^{i\varphi}) (e^{-i\omega_k t}) + (a_k + a_k^+ (e^{-2i\varphi})) (e^{i\varphi}) (e^{i\omega_k t}) \right] (e^{ikx}) \\
 &= (e^{i\varphi}) (e^{ikx}) \left\{ \left[(a_k^+ + a_k (e^{-2i\varphi})) (e^{-i\omega_k t}) \right] + \left[(a_k + a_k^+ (e^{-2i\varphi})) (e^{i\omega_k t}) \right] \right\} \\
 &= (e^{i\pi/4}) (e^{ikx}) \left\{ \left[(a_k^+ + a_k (e^{-i\pi/2})) (e^{-i\omega_k t}) \right] + \left[(a_k + a_k^+ (e^{-i\pi/2})) (e^{i\omega_k t}) \right] \right\}
 \end{aligned}$$

Recalling the Euler formula, it follows:

$$\begin{aligned}
 \Phi_{1k} \oplus \Phi_{2x} &= (e^{i\pi/4}) (e^{ikx}) \left\{ \left[(a_k^+ + a_k (e^{-i\pi/2})) (e^{-i\omega_k t}) \right] + \left[(a_k + a_k^+ (e^{-i\pi/2})) (e^{i\omega_k t}) \right] \right\} \\
 &= (e^{i\pi/4}) (e^{ikx}) \left\{ \left[(a_k^+ - ia_k) (e^{-i\omega_k t}) \right] + \left[(a_k - ia_k^+) (e^{i\omega_k t}) \right] \right\} \\
 &= (e^{-i\pi/4}) (e^{ikx}) \left\{ \left[(\alpha_k) (e^{-i\omega_k t}) \right] + \left[(\beta) (e^{i\omega_k t}) \right] \right\} \\
 &= \Psi_1(\alpha(t)) + \Psi_2(\beta(t))
 \end{aligned} \tag{68}$$

With

$$\left\{ \begin{aligned}
 \Psi(\alpha)_k &= (\alpha_k) (e^{-i\omega_k t}) = (a_k^+ - ia_k) (e^{-i\omega_k t}) = (a_k^+) (e^{-i\omega_k t}) - i(a_k) (e^{-i\omega_k t}) \\
 \Psi(\beta)_k &= (\beta_k) (e^{i\omega_k t}) = (a_k - ia_k^+) (e^{i\omega_k t}) = (a_k) (e^{i\omega_k t}) - i(\hat{a}_k^+) (e^{i\omega_k t})
 \end{aligned} \right\} \tag{69}$$

where the operator $[\alpha = (a^+ - ia)]$ is different from the operator $[\beta = (a - ia^+)]$. Note that the operators (α, β) are complexes, and α has the opposite direction of phase rotation to the operator β . An important result here is: the fields $(\Psi(\alpha), \Psi(\beta))$ are respectively expressed by IQuO with annihilation and creation operators (a, a^+) having the same direction of the phase rotation in α and β . The Hamiltonian operator H of the physical system is established, as usual, by the field operator and its conjugate (setting $\beta = \gamma^*$), thus obtaining [13] [14]:

$$H = \sum_{-\infty}^{+\infty} \hbar \omega_k \left(\alpha_k^+ \alpha_k + \gamma_k^+ \gamma_k + 1 \right) \tag{70}$$

The action of the operation \oplus 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 of the chain does not change the $|k\rangle$ mode, see the Equation (66). For complex fields, see Equation (69), the literature assigns an electric charge to this type of particle-field. We will prove the same for fields described by IQuO that is for oscillators with semi-quanta, see the fields $(\Psi(\alpha), \Psi(\beta))$ of Equation (69). Thus, we will demonstrate that the \oplus -operation would lead to complex fields having electric charge. Recalling the Equation (56):

$$\left\{ \begin{aligned}
 a_{1,r'}^+(t) &= (\bullet^+)_{el} e^{ir'\omega t} + (o^+)_{in} e^{i(r'\omega t - \pi/2)} = (\bullet^+)_{el} e^{-i\omega t} + (o^+)_{in} e^{-i\omega t} e^{i(-\pi/2)} = (\bullet^+)_{el} e^{-i\omega t} - i(o^+)_{in} e^{-i\omega t} \\
 a_{1,r'}(t) &= (o)_{el} e^{-ir'\omega t} + (\bullet)_{in} e^{-i(r'\omega t - \pi/2)} = (o)_{el} e^{i\omega t} + (\bullet)_{in} e^{i\omega t} e^{i(+\pi/2)} = (o)_{el} e^{i\omega t} + i(\bullet)_{in} e^{i\omega t}
 \end{aligned} \right. \tag{71}$$

and introducing inside the state functions $(\Psi(\alpha), \Psi(\beta))$, in a compatible way to the the operators of semi-quanta:

$\left\{ \left[\left(\bullet_{in}^+, \bullet_{el}^+ \right)_{(cl, \underline{cl})}, \left(o_{el}, \bullet_{in} \right)_{(cl, \underline{cl})} \right], \left[\left(\bullet_{in}^+, o_{el}^+ \right)_{(cl, \underline{cl})}, \left(\bullet_{el}, o_{in} \right)_{(cl, \underline{cl})} \right] \right\}$, where the notation (cl) indicates a rotation clockwise and (\underline{cl}) a rotation counterclockwise, we obtain:

$$\left\{ \begin{array}{l} \Psi(\alpha)_{cl} = \left[\left(a^+ \right) \left(e^{-i\omega t} \right) - i \left(a \right) \left(e^{-i\omega t} \right) \right]_{cl} = \left[\left(\left(\bullet_{el}^+ - i o_{in}^+ \right) - i \left(o_{el} + i \bullet_{in} \right) \right) e^{-i\omega t} \right]_{cl} \\ \Psi(\beta)_{\underline{cl}} = \left[a \left(e^{i\omega t} \right) - i a^+ \left(e^{i\omega t} \right) \right]_{\underline{cl}} = \left[\left(-i \left(\bullet_{el}^+ - i o_{in}^+ \right) + \left(o_{el} + i \bullet_{in} \right) \right) e^{i\omega t} \right]_{\underline{cl}} \end{array} \right\}$$

By this last equation, finally, we'll have the components of state vectors $(\Psi(\alpha), \Psi(\beta))$ in the sq -representation:

$$\left\{ \begin{array}{l} \Psi(\alpha)_{cl} = \left\{ \left[\left(\bullet_{el}^+ \right)_{cl} + \left(o_{in}^+ \right)_{cl} e^{i(-\pi/2)} \right] \left(e^{-i\omega t} \right), \left[\left(o_{el} \right)_{cl} e^{i(-\pi/2)} + \left(\bullet_{in} \right)_{cl} \right] \left(e^{-i\omega t} \right) \right\}_{cl} \\ \Psi(\beta)_{\underline{cl}} = \left\{ \left[\left(\bullet_{el}^+ \right)_{\underline{cl}} e^{i(-\pi/2)} + \left(o_{in}^+ \right)_{\underline{cl}} e^{i(\pi)} \right] \left(e^{i\omega t} \right), \left[\left(o_{el} \right)_{\underline{cl}} + \left(\bullet_{in} \right)_{\underline{cl}} e^{i(+\pi/2)} \right] \left(e^{i\omega t} \right) \right\}_{\underline{cl}} \end{array} \right\} \quad (72)$$

The graphic representation of the Equation (72) will be, see **Figure 9**, with $(\varphi = \omega t = 5\pi/4)$, see **Figure 13**:

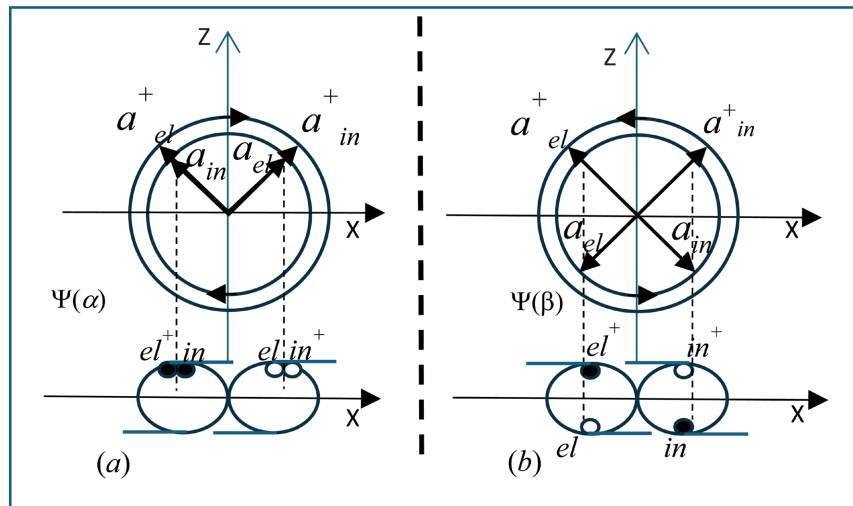


Figure 13. Two IQuO with equal operators in the phase rotation but with opposite rotations.

We define as “*mono-verse*” IQuO in the phase rotation the two (IQuO_{cl}, IQuO_{cl}). We point out that the IQuO_{cl} (**Figure 13(a)**) has not a “regular” shape, see the $\Psi(\alpha)$; compare this figure with **Figure 8**, where there is an IQuO with different operators (a, a^+) in the directions of phase rotation. Consequently, the IQuO_{cl} (**Figure 13(b)**) appears regular, see the $\Psi(\beta)$. It follows that: in the coupling $(\Phi_1 \oplus \Phi_2)$ there’s something missing: the presence of a particular field is required, that corrects the non-regular shape of an emergent mono-verse IQuO by means of appropriate phase shifts. This, as we know from the literature, occurs locally because the field in question operates local gauge transformations (phase shift) to make the interacting fields locally symmetrical: photon will be the correcting field, see QED [15]. The coupling mechanism $(\Phi_1 \oplus \Phi_2)$ can be greatly simplified by placing the two IQuO in the same initial configuration (see **Figure**

9). If we use the matrix form of the IQuO (Φ_1, Φ_2), see the Equation (58), we will have:

$$\left\{ \left((\Phi_1) \right) \equiv \left(\begin{array}{c} \left(\bullet_{1el}^+ e^{-i(5/4)\pi} + o_{1in}^+ e^{-i(7/4)\pi} \right)_{cl} \\ \left(o_{1el} e^{i(5/4)\pi} + \bullet_{1in} e^{i(7/4)\pi} \right)_{\underline{cl}} \end{array} \right) \left((\Phi_2) \right) \equiv \left(\begin{array}{c} \left(\bullet_{2el}^+ e^{i(3/4)\pi} + o_{2in}^+ e^{i(1/4)\pi} \right)_{\underline{cl}} \\ \left(o_{2el} e^{-i(3/4)\pi} + \bullet_{2in} e^{-i(1/4)\pi} \right)_{cl} \end{array} \right) \right\} \quad (73)$$

In the case of a perfect concordance between two IQuO (I_1, I_2) and thus of two fields (Φ_1, Φ_2), we can admit in an “ideal” way ($|\varphi_1| = |\varphi_2| = 0$). It follows a direct coupling without phase shifts O_φ , but with energy exchanges O_ε between the semi-quanta $\left[\left(\bullet_{2in} \longleftrightarrow o_{1in}^+ \right), \left(\bullet_{1in} \longleftrightarrow o_{2in}^+ \right) \right]$; in this case we will have the following expression:

$$\left(\Phi_1 \oplus \Phi_2 \right) = \left\{ \left(\begin{array}{c} \left(\bullet_{1el}^+ e^{-i(5/4)\pi} + o_{1in}^+ e^{-i(7/4)\pi} \right)_{cl} \\ \left(o_{1el} e^{i(5/4)\pi} + \bullet_{1in} e^{i(7/4)\pi} \right)_{\underline{cl}} \end{array} \right) \oplus \left(\begin{array}{c} \left(\bullet_{2el}^+ e^{i(3/4)\pi} + o_{2in}^+ e^{i(1/4)\pi} \right)_{\underline{cl}} \\ \left(o_{2el} e^{-i(3/4)\pi} + \bullet_{2in} e^{-i(1/4)\pi} \right)_{cl} \end{array} \right) \right\}_{O_\varepsilon} \quad (74)$$

$$= \left(\begin{array}{c} \left(\bullet_{1el}^+ e^{-i(5/4)\pi} + \bullet_{1in}^+ e^{-i(7/4)\pi} \right) \\ \left(o_{2el} e^{-i(3/4)\pi} + o_{2in} e^{-i(1/4)\pi} \right)_{cl} \end{array} \right) + \left(\begin{array}{c} \left(\bullet_{2el}^+ e^{i(3/4)\pi} + \bullet_{2in}^+ e^{i(1/4)\pi} \right) \\ \left(o_{1el} e^{i(5/4)\pi} + o_{1in} e^{i(7/4)\pi} \right)_{\underline{cl}} \end{array} \right)$$

Graphically it is, see **Figure 14**:

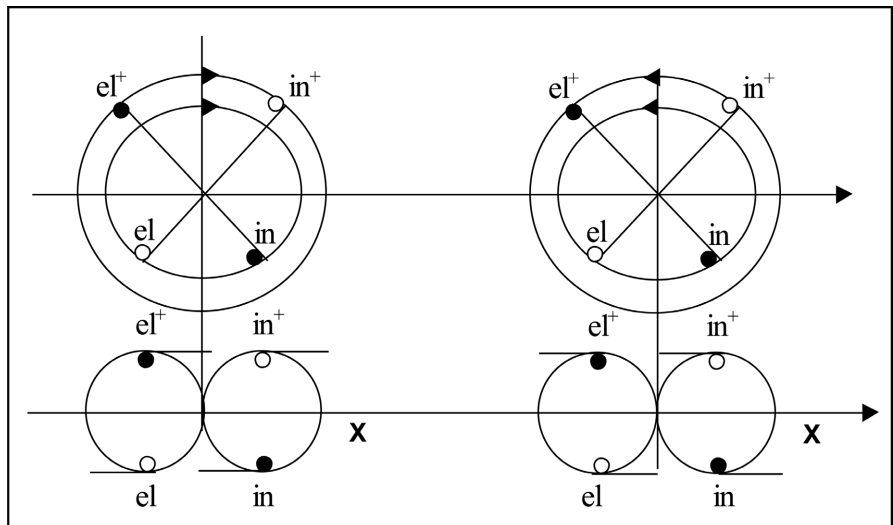


Figure 14. Two mono-verse IQuO in regular shape with opposite rotations of the phase.

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

Figure 9 indicates the presence of an IQuO with sq - operators having both directions of rotation of the phase: we indicate this type of IQuO as **B-IQuO**. Instead, **Figure 14** indicates the presence of a mono-verse IQuO, that is, with sq -operators having all the same direction of rotation of the phase: we indicate this type of IQuO as **F-IQuO**. Two important observations must be made.

The first observation.

As we have already mentioned in the previous section, in coupling ($\Phi_1 \oplus \Phi_2$)

it is necessary to insert a third Field Φ_φ operating phase shifts to make regular the mono-verse IQuO of **Figure 13(a)**. Note that the Field Φ_φ must be a B-IQuO. Then, a possibility would be a coupling with a third $\Phi_{\varphi I}$ -IQuO, such that one of the two (Ψ_i) of **Figure 13**, acquires a regular shape at the expense of the third (Φ_φ). It can be argued that for every F- IQuO with irregular shape, there must be an external field Φ_φ which, acting locally on the phase φ of Ψ_F , regulates its IQuO shape. The opposite can also happen, namely, an external field Φ_φ could alter the regular shape of a Ψ_F -IQuO. We would therefore say that around the field Ψ_F there is always a Φ_φ - acting field, which induces changes in phase and configuration in it. Note in **Figure 13(a)**, that if the Φ_φ field induces a phase shift of ($\varphi = -\pi$), on the Ψ_{cl} then the IQuO_{cl} becomes regular, see the second image in **Figure 14**. This phase shift without energy exchange between the sq does not alter the dynamic state of the field Ψ_{cl} which thus remains unchanged. As it is well known, the Φ_φ field is a gauge field and the transformation induced by it is called “*gauge transformation*”. We also know the fields Φ_φ act on electrically charged particles-fields. Therefore, we can consider the hypothesis of associating the fields (Ψ_{cl}, Ψ_{cl}) with a sign ($\pm q$) of electric charge q connected to two directions of phase rotations: (Ψ_{cl}, Ψ_{cl}) \Leftrightarrow ($+q, -q$). It should also be remembered that if we want regularly shaped mono-verse fields it is necessary to associate them with a Φ_φ field. This, as we know from the literature, is analogous to the description in QED where every electric charge is “dressed” by virtual photon fields [16].

The second observation.

Note that in **Figure 9**, the two pairs of sq $\left[(\underline{o}_{el}, \underline{\bullet}_{in}), (\underline{o}_{in}^+, \underline{\bullet}_{el}^+) \right]$ see the first image in **Figure 9** and see the second image in **Figure 9** the two pairs of sq $\left[(\underline{o}_{el}, \underline{\bullet}_{in}), (\underline{o}_{in}^+, \underline{\bullet}_{el}^+) \right]$, act in “**agreement**”, in the same direction of propagation along the X axis (see the projection along X-axis), and coherently, since they satisfy the equivalence relations, see the Equation (54), which are independent by direction of phase rotation: $\left[(\underline{\bullet}_{in}, \underline{\bullet}_{el}) \equiv (\underline{o}_{in}^+, \underline{o}_{el}^+) \right]$ and $\left[(\underline{o}_{el}, \underline{o}_{in}) \equiv (\underline{\bullet}_{el}^+, \underline{\bullet}_{in}^+) \right]$, see also the Sect. 2.5. In fact, see **Figure 9**, if the operator $\left(\underline{\bullet}_{el}^+ \right)_{+X}$ creates a full sq (\bullet) of elastic energy at the point x in the +X direction also $(\underline{o}_{el})_{+X}$ annihilating an empty sq (o) of elastic energy in the point x in the +X direction, actually creates an sq full (\bullet) of elastic energy, in the same +X direction, that is $\left(\underline{\bullet}_{el}^+ \right)_{-X} \equiv (\underline{o}_{el})_{+X}$. Now, instead in **Figure 14**, where the “mono-verso” phase rotation IQuOs appear, the sq -operators are “**discordant**”, act in opposite directions along the X axis of propagation, and are not coherent, that is $\left(\underline{\bullet}_{el}^+ \right)_{-X} \neq (\underline{o}_{el})_{+X}$. This makes “**antagonists**” the sq -operators of **Figure 14**. In fact, see the first image in **Figure 14**, if $\left(\underline{\bullet}_{el}^+ \right)_{+X}$ creates a full sq (\bullet_{el}) of elastic energy in the +X direction then we have a quantum (\bullet) going in direction +X, instead $(\underline{o}_{el})_{-X}$ annihilating an empty sq (o) of elastic energy in the direction -X, that is creates an sq full (\bullet) of elastic energy, in the -X direction: thus, we have that $\left(\underline{\bullet}_{el}^+ \right)_{+X} \neq (\underline{o}_{el})_{-X}$. We notice 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 the F³-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, that is of massive particles. Thus, it appears obvious that a particle would be represented by different species of IQuO constituents:

- 1) IQuO representative of the basic no-massive field oscillations in the different spatial planes (B-IQuO)
- 2) IQuO representative of “additional” coupling (massive) with electric charge (F-IQuO).

A first possibility to have additional couplings with no-discordant sq operators and mono-verse in a particle at IQuO, 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}) . This is because the diversification of the planes of oscillation re-establishes the coherence between the sq -operators, thus avoiding the opposition or discordance between the pair of sq of a -operator and that of a^+ . Therefore, we need to modify the form of F-IQuO to have a representation 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 the image in **Figure 4**; we will so have that a new IQuO, which we will indicate as F'-IQuO see **Figure 15**:

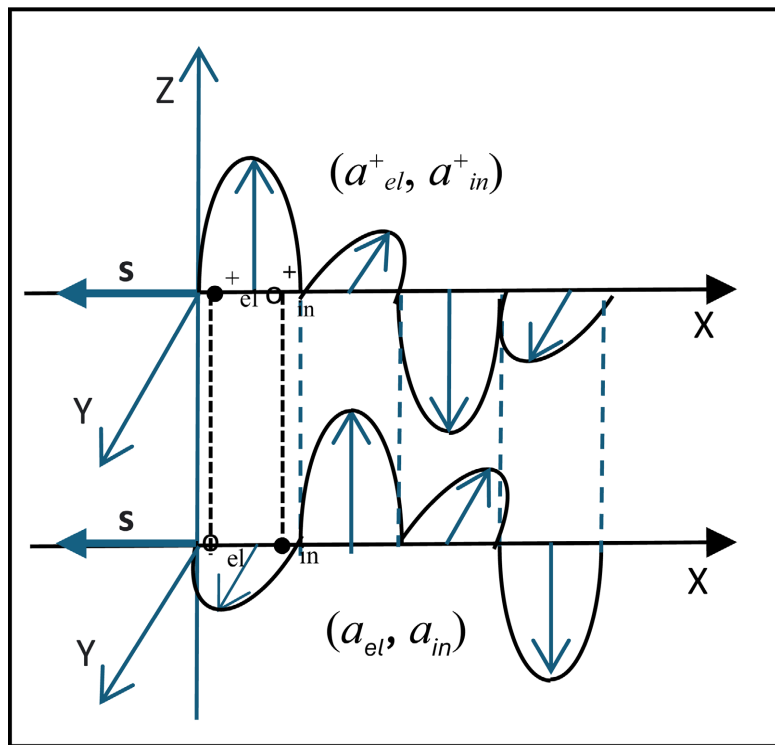


Figure 15. F-IQuO with “phase-shifted planes” between the a -operators and a^+ .

where \mathfrak{s} is the spin vector. The phase shift of the planes of oscillation implies, as we have already seen in ref. [17], the existence of a semi-integer spin, given that the wave function results with a period of 4π , see just **Figure 15**, as in *Fermions*.

It follows that we need to combine the B'-IQuO in such a way as to give rise to particles at IQuO as particles of fermion type. 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.

3.4. Direction of Phase Rotation and Sign of Electric Charge

Now, we prove that a Ψ field with a mono-verse IQuO has an electric charge Q with eigenvalue ($q = +1$, $q = -1$). We calculate the electric charge of the (Ψ_{cl}) field in the semi-quanta representation, however, changing the configuration of **Figure 14** to simplify the calculations:

$$\Psi_{cl} \equiv \left[\left(\bullet_{el}^+ e^{-i\pi} + \bullet_{in}^+ e^{-i3\pi/2} \right)_{cl} + \left(o_{el} e^{-i\pi/2} + o_{in} \right)_{cl} \right] \quad (75)$$

in matrix form:

$$\Psi_{cl} \equiv \begin{pmatrix} \left(o_{el} e^{-i\pi/2} + o_{in} \right)_{cl} \\ \left(\bullet_{el}^+ e^{-i\pi} + \bullet_{in}^+ e^{-i3\pi/2} \right)_{cl} \end{pmatrix} \quad (76)$$

this configuration is, obviously, the evolution over time of the configuration in **Figure 14**. The distribution of sq pairs of semi-quanta is not arbitrary, since, as will be shown later, the arrangement of the matrix elements is related to the direction of rotation of the phase. Well, this arrangement can be read by a gauge field Φ_φ (B-IQuO), which can thus read the sign of the electric charge from the direction of phase rotation. For the calculation of Q , it is also necessary to consider the Hermitian field Ψ^+ (in matrix) of Ψ in the Equation (76):

$$(\Psi_{cl})^+ \equiv \begin{pmatrix} \left(o_{el}^+ e^{i\pi/2} + o_{in}^+ \right)_{cl} \\ \left(\bullet_{el} e^{i\pi} + \bullet_{in}^{i3\pi/2} \right)_{cl} \end{pmatrix} \quad (77)$$

but we impose that the conjugation operation of Ψ contains the exchange ($\bullet \leftrightarrow o$) to keep the shape of the sq configuration unchanged. Therefore, we'll have:

$$(\Psi_{cl})^+ \equiv \begin{pmatrix} \left(\bullet_{el}^+ e^{i\pi/2} + \bullet_{in}^+ \right)_{cl} \\ \left(o_{el} e^{i\pi} + o_{in}^{i3\pi/2} \right)_{cl} \end{pmatrix} \quad (78)$$

Using the well-known definition of the electric charge [3] [15] and the commutation relations with semi-quanta (see Equation (60), and appendix in ref. [6] [7]) it then follows that:

$$\begin{aligned} Q_{cl} &= \int \left[\left((\Psi_{cl}^+) \right) \sigma_3 \left((\Psi_{cl}) \right) \right] dV \\ &= \int \begin{pmatrix} \left(\bullet_{el}^+ e^{i\pi/2} + \bullet_{in}^+ \right) \\ \left(o_{el} e^{i\pi} + o_{in}^{i3\pi/2} \right) \end{pmatrix} \begin{pmatrix} \left(o_{el} e^{-i\pi/2} + o_{in} \right) \\ - \left(\bullet_{el}^+ e^{-i\pi} + \bullet_{in}^+ e^{-i3\pi/2} \right) \end{pmatrix} dV \end{aligned} \quad (79)$$

where σ_3 is a Pauli's matrix. Let's consider the integrand of integral:

$$\begin{aligned}
 Q'_{cl} &= \left[\left(\left(\bullet_{el}^+ e^{i\pi/2} \right) + \bullet_{in}^+ \right) \left(o_{el} e^{-i\pi/2} + o_{in} \right) - \left(o_{el} e^{i\pi} + o_{in}^{i3\pi/2} \right) \left(\bullet_{el}^+ e^{-i\pi} + \bullet_{in}^+ e^{-i3\pi/2} \right) \right] \\
 &= \left(i \bullet_{el}^+ o_{in} - i \bullet_{el}^+ e^{-i\pi} o_{in}^{i3\pi/2} \right) + \left(\bullet_{in}^+ o_{el} e^{-i\pi/2} - \bullet_{in}^+ e^{-i3\pi/2} o_{el} e^{i\pi} \right) \\
 &= \left[\bullet_{el}^+, o_{el} \right] + \left[\bullet_{in}^+, o_{in} \right] + i \left[\bullet_{el}^+, o_{in} \right] + i \left[o_{el}, \bullet_{in}^+ \right] = -1
 \end{aligned}
 \tag{80}$$

Note that the numeric value is (-1) . This means that the value of the “electric charge” Q will be negative; therefore, we can say that an IQuO with a clockwise direction of phase rotation has a negative value of the physical quantity Q of the Ψ_{cl} field. An important observation is to be made: having immediately reduced the Ψ_{cl} of the field to a “point” where the IQuO (I_{cl}) is located, the integral of Equation (78) must be calculated between zero and λ , where λ is Compton wavelength of the particle as well as its spatial dimension coinciding with the oscillation amplitude of the IQuO (I_{cl}). This avoids problems of infinities in the calculation of the integral when applied to “point-like” particles. Now, we also calculate the sign of electric charge of the (Ψ_{cl}) regular IQuO. In matrix form it is:

$$\Psi_{cl} = \begin{pmatrix} \left(\bullet_{el}^+ e^{i\pi} + \bullet_{in}^+ e^{i\pi/2} \right)_{cl} \\ \left(o_{el} e^{-i\pi/2} + o_{in} \right)_{cl} \end{pmatrix}
 \tag{81}$$

Note that this matrix (Ψ_{cl}) is similar in form to the (Ψ_{cl})⁺ matrix of Equation (77) but with a different arrangement of the configuration angles; hence it is not (Ψ_{cl}) = (Ψ_{cl})⁺. Because of this diversity we could say that a photon distinguishes a particle from its antiparticle (!), because antimatter is not given by a simple “conjugation” operation on the wave function associated with matter. Thus, we will not have the following matrix:

$$\Psi_{cl} = \begin{pmatrix} \left(o_{el} e^{-i\pi/2} + o_{in} \right)_{cl} \\ \left(\bullet_{el}^+ e^{i\pi} + \bullet_{in}^+ e^{i\pi/2} \right)_{cl} \end{pmatrix}$$

Proceeding, it follows:

$$\begin{aligned}
 Q_{cl} &= \int \left[\left(\left(\Psi_{(+) }^+ \right) \right) \sigma_3 \left(\left(\Psi_{(+) } \right) \right) \right] dV \\
 &= \int \begin{pmatrix} \left(o_{el} e^{-i\pi} + o_{in} e^{-i\pi/2} \right) \\ \left(\bullet_{el}^+ e^{i\pi/2} + \bullet_{in}^+ \right) \end{pmatrix} \begin{pmatrix} \left(\bullet_{el}^+ e^{i\pi} + \bullet_{in}^+ e^{i\pi/2} \right) \\ - \left(o_{el} e^{-i\pi/2} + o_{in} \right) \end{pmatrix} dV \\
 &= \left[\left(o_{el} e^{-i\pi} + o_{in} e^{-i\pi/2} \right) \left(\bullet_{el}^+ e^{i\pi} + \bullet_{in}^+ e^{i\pi/2} \right) - \left(\bullet_{el}^+ e^{i\pi/2} + \bullet_{in}^+ \right) \left(o_{el} e^{-i\pi/2} + o_{in} \right) \right] \\
 &= o_{el} \bullet_{el}^+ + o_{el} \bullet_{in}^+ e^{-i\pi/2} + o_{in} \bullet_{el}^+ e^{i\pi/2} + o_{in} \bullet_{in}^+ - \bullet_{el}^+ o_{el} \\
 &\quad - \bullet_{el}^+ o_{in} e^{i\pi/2} - \bullet_{in}^+ o_{el} e^{-i\pi/2} - \bullet_{in}^+ o_{in} \\
 &= \left[o_{el}, \bullet_{el}^+ \right] + \left[o_{in}, \bullet_{in}^+ \right] + i \left[\bullet_{in}^+, o_{el} \right] + i \left[o_{in}, \bullet_{el}^+ \right] = +1
 \end{aligned}
 \tag{82}$$

Notice that, using the irregular form, see **Figure 13**, the same result is obtained. In fact, it is:

$$\begin{aligned}
Q_{el} &= \int \left[\left(\Psi_{(+)}^+ \right) \sigma_3 \left(\Psi_{(+)} \right) \right] dV \\
&= \left[\left(o_{el} e^{-i\pi} + o_{in} e^{-i\pi/2} \right) \left(\bullet_{el}^+ e^{i\pi} + \bullet_{in}^+ e^{i\pi/2} \right) - \left(\bullet_{el}^+ e^{-i\pi/2} + \bullet_{in}^+ e^{-i\pi} \right) \left(o_{el} e^{i\pi/2} + o_{in}^+ e^{i\pi} \right) \right] \quad (83) \\
&= \left[o_{el}, \bullet_{el}^+ \right] + \left[o_{in}, \bullet_{in}^+ \right] + i \left[\bullet_{in}^+, o_{el} \right] + i \left[o_{in}, \bullet_{el}^+ \right] = +1
\end{aligned}$$

This result tells us that the phase shift (operated by an external agent to regulate the IQuO), does not change the sign of the electric charge, which this corresponds to the gauge invariance of electromagnetic interactions. All this shows 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 $(\Phi_1 \oplus \Phi_2)$ coupling of two IQuO has generated two particles-IQuO with opposite electric charge (q): $(\Psi_{el})_{+1}$, $(\Psi_{el})_{-1}$. We have thus demonstrated that “*the (\pm) sign of the electric charge is related to the direction of the phase rotation of IQuO oscillation*”.

4. Conclusions

The IQuO model, by introducing the intrinsic quantum oscillator, revolutionizes our understanding of quantum mechanics and particle physics. Key points include:

- **Novel particle interpretation:** Particles may be viewed as coupling structures of IQuO, with a well-defined geometry
- **Explanation of electric charge origin:** The sign of the electric charge is correlated with the phase rotation direction of the IQuO, providing a fundamental explanation
- **Detailed description of interactions:** The coupling between IQuO of different fields allows for a precise description of interaction processes and particle creation
- **Consistency with the Standard Model:** The IQuO model is fully consistent with the Standard Model but complements it by explaining the origin of features such as the color charge of quarks
- **New descriptive paradigm:** The Geometric Particle Model (PGM) introduces a new perspective, treating particles as geometric structures with spatial dimensions [12] [18] [19].
- **Predictivity and coherence:** The IQuO model can predict and explain a wide range of phenomena, such as weak decays, pair creation, and particle interactions

An example of this geometric connection (see the PGM) is the golden ratio (where ϕ is the golden number): $\left\{ \left(\lambda_Z / \lambda_H \right) = \left[\phi^2 + 1 \right]^{1/2} / (2)^{1/2} = (1.345) \right\}$ which relates the Compton wavelengths λ (and thus the masses) of the Z-boson and the H-boson; hence, the mass of the Higgs boson in weak interactions is found to be:

$$m_H \approx (1.345)m_Z \approx (1.345)(91.2)\text{GeV}/c^2 \approx (123)\text{GeV}/c^2$$

Implications and Advantages of the IQuO Model:

- **Deeper understanding:** The IQuO model provides a more structured and intuitive view of the particle universe, allowing for the visualization of physical processes
- **Unification of theories:** The IQuO model has the potential to unify different theories, providing a unitary and coherent description of matter
- **New investigation tools:** The geometric representation of particles opens new perspectives for the development of new tools and models for studying particles
- **Explanations for unsolved phenomena:** The IQuO model could provide answers to open questions in particle physics, such as the origin of mass and the nature of dark matter

The IQuO model represents so a significant step forward in understanding the fundamental nature of matter. Its ability to explain a wide range of phenomena makes coherently and comprehensively it a promising tool for future research in particle physics.

Conflicts of Interest

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

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