Original Paper

Quantum Jumps and Electrodynamical Description

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Abstract: The customary description of radiation processes provided by Quantum Electrodynamics (QED) allows the quantitative derivation of many physical observables, in line with experiments. This extraordinary empirical success, however, leaves open the problem of the ontology of these processes. We identify these with the discontinuities of the evolution of the quantum state of the source, the so-called quantum jumps (QJ). Adopting a time-symmetrical view of the QJ borrowed from the transactional approach, the phenomena of radiation emission and absorption by an electron acquire an adynamic aspect, associated with their emergence from an atemporal background. The QJ activates the progressive generation of the electron timeline, along which its asymptotic state evolves. This causation process is of the formal type, and its dynamic "shadow" on the time domain is constituted by an interval during which the electron is self-interacting. Instead, in the absence of further interaction with external fields the asymptotic state is "on shell" *i.e.* not self-interacting. These ideas are used to constraint the value of the fine structure constant and of the cosmological constant, and to illustrate some less-known properties of electroweak decays.

Keywords: Fine structure constant, quantum jump, cosmological constant, mass-lifetimes duality

1. Introduction

The photon-electron interaction vertex is one of the first topics presented in any standard course on Quantum Electrodynamics (QED) and this might lead one to believe that there is nothing actually new to add on this subject. In our opinion, however, the conventional treatment of the interaction between the electromagnetic field and the electron, based on the perturbative expansion of their time evolution operator, does not cast enough light on an important aspect of radiation processes. The evolution operator is unitary but the radiation emission and absorption events (*e.g.* the quantum jumps of an atom) are represented by non-unitary projection operators. Such events, on the other hand, constitute an ascertained physical reality (here we limit ourseles to recall the "historic" articles [1,2]) and one may wonder whether and up to what point the QED provides a suitable description of these. This question is an *avatar* of the long-standing problem of quantum discontinuity, the best-known and most controversial aspect of which is the collapse of the wave function in Quantum Mechanics. The quantum formalism describes the discontinuity through Von Neumann's projection postulate [3], whose relation with the unitary evolution of state is as yet unclear. In section 2 we argue in favour of the need to identify the collapse of the wave function with the physical phenomenon represented by the quantum jump (QJ); this phenomenon, in turn, is identified, in the context which we propose to examine in this article, with the discontinuous change of the quantum state of an individual electron due to its coupling with the electromagnetic field. The structure of this event in time domain is described in section 3, through a suitable implementation of the projection postulate; in this section the correspondence of this description with the conventional formalism of Feynman paths is also presented. In section 4 the problem of the determination of the value of the fine structure constant α is re-examined, in the light of the description put forward in the preceding section; in particular, a physical justification of the algorithm suggested by de Vries several years ago [4] is proposed. This argument, in the light of the present level of knowledge, must be taken as a pure hypothesis, as is the greater part of the content of this article.

We interpret the QJ as a concomitant localization of the electron and the photon in time, *i.e.* as a non-local conversion process of trans-temporal entities into events localized on the time domain. On this basis it is possible to infer relations between the properties of the radiation processes and the geometry of spacetime on a cosmological scale. These relations are discussed in section 5. The formalism on which these relations are based can be generalized to a different context, that of decay of unstable particles. This is done in Section 6 where a not widely known property of these processes is presented. In Section 7 some possible connections with the yet unclear nature of the Higgs field are sketched. Finally, some concluding remarks are presented.

2. Quantum jumps

In quantum mechanics, the time evolution of the state vector of a system is normally continuous and unitary, but punctuated with discontinuous "jumps". These discontinuities are of two types: quantum jumps caused by coupling with external fields or systems (historically introduced by Bohr in his model of the hydrogen atom) and reduction of the wave packet associated with the observation of the system. Formally, both discontinuities are represented by the action of a convenient projection operator on the Hilbert space of the system state vectors.

In accordance with the point of view we adopt in this work, there is no difference between these two processes: the decay of a radioactive nucleus is both the quantum jump that leads the nucleus from the initial to the final state and the collapse of its state vector induced by the emission of decay products that are detectable by a distant observer (*e.g.* a gamma photon). This identification implies that the reduction of the state vector is an objective phenomenon not induced by the information on the system gained by an observer and determined solely by the interaction of the nucleus with the field responsible for the transition. However, a mechanism remains to be identified that is the basis for this discontinuous and non-unitary (non-Hamiltonian) aspect of the interaction. This physical mechanism, which is not described by the customary quantum mechanical formalism, must reproduce the projection on the final state of the transition, according to the "projection postulate" introduced by Von Neumann in 1932 [3].

We have proposed elsewhere [5,6,7,8] a minimal solution based on a literal translation, in physical terms, of the projection operator $|q\rangle\langle q|$ on the state q. With reference to elementary particles (leptons and hadrons), the idea is the following. The $\langle q|$ section of the projector is interpreted as a "shutdown" of the $|q\rangle$ component of the incident wavefunction or as the halt of its (forward) evolution in laboratory external time; the $|q\rangle$ section is seen as the "reactivation" of this evolution. It is also possible to see, symmetrically, the $|q\rangle$ section of the projector as the halt of the (backward) evolution of the conjugate wavefunction $\langle q|$ in laboratory external time; thus the $\langle q|$ section is the reactivation of this evolution. In laboratory external time the break interval in both cases is reduced to an instant; in this time, in other words, the quantum jump has no duration. This statement is consistent with experimental data available from direct observation of quantum jumps [1,2].

The quantum jump, therefore, is the set made up of the state vector mapping to a "timeless" background and its inverse. This double passage must preserve the information contained in the state vector; this information, therefore, must be codified, in the intermediate background condition, in a non-dynamic form. In this work we are not interested in the intermediate condition, or in the mapping which links it to the time evolution of the particle state. These details are described in the cited works, particularly [5]. Instead, what we are interested to evidence is that such mapping originates the time phase factor of the particle. Letting τ indicate the proper time of the particle (measured in the laboratory) and setting the QJ instant in $\tau = 0$, the mapping generates a "retarded" phase factor $\exp(iMc^2\tau/\hbar)$ for $\tau > 0$, and an "advanced" phase factor $\exp(-iMc^2\tau/\hbar)$ for $\tau < 0$. In these expressions, M represents the rest mass of the particle and c and $\hbar$ have the customary meaning. The QJ presents, therefore, a time-symmetrical structure, in accordance with the transactional approach [9,10,11,12]; the retarded phase factor is associated with the $|q>$ component of the $|q>< q|$ projector on the final state of the particle, while the advanced factor is associated with the $\langle q|$ component.

In this unconventional implementation of the Von Neumann projection postulate, the "atemporal" background actually possesses a complex internal time $\tau'+i\tau''$ of its own, distinct from laboratory external time τ [5-8]. For $\tau \neq 0$ a correspondence exists between the two times, in the sense that τ is the arc of the circumference having radius θ_0 on the complex plan $\tau'+i\tau''$, centred in $0+i0$. The "*chronon*" θ_0 is a property of the background that is independent on the particle, and thus an universal constant; numerically, it is given by the ratio of the classical radius of the electron and the speed of light in the vacuum [13]. Thus, the genesis of external time is of an essentially topological nature: the circumference is a one-dimensional closed domain whose generic point, associated with an angle φ, admits infinite recurrences $\varphi \pm 2k\pi$ with $k = 0, 1, 2,...$. These recurrences guarantee an *open* external time τ such that $\tau/\theta_0 = (\varphi \pm 2k\pi)/2\pi$, while the background complex time (precursor of laboratory external time) does not enjoy this property.

The outgoing state $|q>\rangle$ from the QJ represents the initial condition of the subsequent forward time evolution of the particle. Its conjugate $\langle\ |q>$ represents the final condition of the preceding forward evolution (or the initial condition on the backward evolution). In this sense, these are *asymptotic* states which, in the present description, exist for every value of τ, therefore also for$|\tau| \leq$

$\hbar/Mc^2$. If their following evolution is free (*i.e.* in the absence of any subsequent interaction), these asymptotic states are *on shell*. How is the existence of on shell asymptotic states reconciled with QED and its virtual processes?

3. QJs and virtual processes

As we have seen, τ and φ are linked by a relation that for the recurrence $k = 0$ takes the form:

$$\frac{\tau}{\theta_0} = \frac{\varphi}{2\pi} \tag{1}$$

where $\theta_0 = e^2/mc^3$ (m is the electron rest mass and the others symbols have their usual meaning) and the quantum jump corresponds to the instant $\tau = 0$, $\varphi = 0$. The relationship (1) applies to the asymptotic state (which we assume to be *on shell*); note, however, that in the range $\tau \in [0, \theta_0]$ (or $\tau \in [-\theta_0,0]$) the circumference on the complex time plan has not yet been completed, so the electron does not yet have its proper timeline along which the asymptotic state evolves. The arc on the circumference of the complex time plan represents, in appropriate units, the action associated with the asymptotic state in the corresponding "external" time interval. We can therefore assume that in the external time interval $\tau \in [-\theta_0/2,+\theta_0/2]$ the electron exists simultaneously in two versions, one described by its asymptotic state (which does not exchange action with the background), the other interacting with the background. To generate the proper timeline of the electron, the r.m.s value of the action exchanged by electron with the background must vary with continuity from $-\pi$ to $+\pi$; if this occurs, the recurrences of the points of the circumference thus completed will generate a real line which will be the proper timeline of the electron. If the circumference is not completed, this line cannot be generated (there are not enough points). To complete a revolution of the circumference a r.m.s. action $mc^2\theta_0 = e^2/c$ must be exchanged in the interaction associated with the QJ. If we indicate the energy exchanged in the interaction as ΔE, this action will be exchanged in a time f such that:

$$\Delta E = \frac{mc^2\theta_0}{f} \tag{2}$$

However, this is not the time in which the energy ΔE is in effect exchanged. This time, instead, in accordance with the Heisenberg principle, is $\tau = \hbar/\Delta E$. The relation between τ and f is obtained immediately by substituting the expression of τ into equation (2), and it is:

$$\tau = \frac{\hbar f}{mc^2\theta_0} \tag{3}$$

The temporal localization of a particle of mass M requires that the background exchange with the field associated with the particle a localization energy equal to $\pm Mc^2$, where the plus sign is associated with the creation of the retarded outgoing state (annihilation of the advanced incoming state), while the negative sign is associated with the creation of the advanced outgoing state (annihilation of the retarded incoming state). This exchange is nothing other than the creation of the de Broglie phase factor discussed in the preceding section. The total energy exchanged by the field with the background is clearly zero, because the two contributions cancel each other out. This means that the energy carried by the fields is conserved in an interaction; for example, the creation of new particles takes place through the conversion of energy released by other kinetic or annihilation processes.

Eq. (3) expresses the laboratory-measured duration of the interaction in external time (proper time of the particle), if the energy exchanged in the course of the interaction is ΔE. Strictly speaking, this energy is understood to be exchanged among the various fields associated with the various interacting particles. But we can apply the same concept to the exchange between the field associated with a given particle and the background. In this case $\Delta E = Mc^2$ and therefore one has from eq. (2) for the electron ($M = m$) the relation $f = \theta_0$. By substituting this relation into eq. (3) one has

$$\tau = \hbar/mc^2. \tag{4}$$

This is the duration (clearly finite) of the coupling of the background with the electron field and it must not be confused with the duration of the quantum jump which, instead, is instantaneous. We note that the interval $\hbar/mc^2$ within which the circumference is completed contains $1/\alpha$ full turns of the "asymptotic" phase angle φ, where $\alpha = e^2/\hbar c$ is the fine structure constant. In this sense, this constant represents the intensity of the electromagnetic coupling of the electron, or the probability of the electron-photon vertex.

These distinctions between the asymptotic state of the electron and its physical condition in the self-interaction interval centred on the QJ are also valid for any particle of mass M other than the electron. In this case one has:

$$\tau = \frac{\hbar}{\Delta E} = \frac{\hbar}{\frac{Mc^2\theta_0}{f}} = \frac{\hbar f}{Mc^2\frac{e^2}{mc^3}} = \frac{\alpha^{-1} fm}{M} \leq \frac{\alpha^{-1}\theta_0 m}{M} = \frac{\hbar}{mc^2}\frac{m}{M} = \frac{\hbar}{Mc^2} \tag{5}$$

When f varies from 0 to θ_0, τ covers the entire self-interaction interval having extension $\hbar/Mc^2$. This self-interaction interval associated with the QJ is defined when the asymptotic states leaving the QJ, relative to the two components of the von Neumann projector, are free. However, even the case of an asymptotic state of virtually interacting electrons occurs; this is, for example, the situation of the electrons of an atomic orbital which continually exchange virtual photons with the nucleus. This case is usually studied with the conventional methods of QED. Moreover, the single electron-photon vertex considered in this paper is not an actual physical process, because it does not meet the proper conditions on the four-momentum. A real QJ consists of two or more charge-photon vertices connected by a virtual fermionic or photonic propagator. The scale of the maximum spatiotemporal separation of each pair of vertices is then defined by $\hbar/m_q c^2$, where $m_{|q>}$is the mass of the exchanged quantum (m for the electron, 0 for the photon).

With these concepts in mind, we can now introduce the analogue of (1) for the version of the electron interacting with the background. We first denote with χ the action exchanged from this version of the electron with the background in the interval $[\tau - T, \tau + T]$, where $T = \hbar/mc^2$ ($T = \hbar/Mc^2$ for a particle of mass M). χ will be expressed in units $\hbar$. We postulate that $\chi/2^{1/2}$ is a random variable with mean zero and variance:

$$\frac{|\tau|}{T} = \left\langle \left(\frac{\chi}{\sqrt{2}} \right)^2 \right\rangle \tag{6}$$

on whose probability density we will not make hypotheses (although a Gaussian density appears reasonable). The (6) is the analogue of (1). It should be borne in mind that although the variance of the random variable χ depends on τ, we are not defining a stochastic process $\chi(\tau)$. Statistics on the height of individuals resident in a certain region may evolve over time as a result of migratory flows, but this does not lead to a time evolution in the height of a specific individual. Moreover, as seen in (5), the action values considered are less or nearly equal to Planck h action, and hence the "second version" of the electron is actually constituted by the virtual processes that accompany the manifestation of the "first version" in QJ. We are thus claiming that the value of χ is not defined or that the individual instances of χ are counterfactual. Only the averages on these values have physical sense, and is the probability density on the basis of which these averages are executed that depends on τ, not χ. The "second version" of the electron is described in QED from the complex of radiative corrections to the segment of the electronic line which includes the coupling vertex with an external photon. We note that what is isolated when, with the renormalization procedure, the "free" electron propagation is subtracted is precisely the contribution of these corrections . Specifically, the (6) can also be written in the form:

$$\left\langle \left(\frac{\chi c T}{\sqrt{2}} \right)^2 \right\rangle = 2D|\tau| \; . \tag{7}$$

which is the equation of a Brownian motion with diffusion coefficient $D = c^2T/2 = \hbar/2M$ for a generic particle, while $D = \hbar/2m$ for the electron. Let us now denote with $A(\tau)$ the action exchanged from the "second version" of the particle with the background, in the interval between the instants $\tau = 0$ and τ, expressed in units $\hbar$. The same considerations seen for χ apply to this random variable. The definition of χ takes the form:

$$\frac{\chi}{\sqrt{2}} = \frac{A(\tau + T) - A(\tau - T)}{\sqrt{2}} \tag{8}$$

Posing $y_1 = A(\tau - T)cT$ and $y_2 = A(\tau + T)cT$ respectively, we obtain:

$$\left(\frac{\chi}{\sqrt{2}} \right)^2 = \frac{1}{\hbar} \frac{M}{2} \frac{(y_2 - y_1)^2}{T} \tag{9}$$

which is equal in form to an Euclidean action for a free particle of mass M. The function:

$$\exp\left(-\left\langle\left(\frac{\chi}{\sqrt{2}}\right)^2\right\rangle\right) = \exp\left(-\frac{|\tau|}{T}\right) \tag{10}$$

thus represents a path integral performed on a single "bin" of duration T of a single path. We interpret this integral as the amplitude of the process represented by the "second version" of the particle. That is, the complex of the virtual phenomena associated with the QJ and which, in other words, represent its footprint on temporal dominion.

In transactional terms, (10) can be interpreted by saying that in addition to the retarded and anticipated components of the asymptotic state (represented by the wave function ψ and its complex conjugate ψ^* respectively), even two evanescent "tails" of amplitude exp(- $|\tau|$ /T), respectively retarded and advanced, with maximum in correspondence of the QJ (τ = 0) appear. These tails represent transient virtual processes. The origin of these transient phenomena is the localization of the electron on the temporal domain, i.e. the completion of the first recurrence at time $f = \theta_0$ and the genesis of the temporal line τ along which the asymptotic state evolves. The completion of the first recurrence, that is, the occurrence of the event $|\chi| = \pi$, can be understood in the statistical sense as the occurrence of the condition:

$$\left\langle\left(\frac{\chi}{\sqrt{2}}\right)^2\right\rangle = \left(\frac{\pi}{\sqrt{2}}\right)^2 = \frac{\pi^2}{2} \quad \Rightarrow \quad \exp\left(-\left\langle\left(\frac{\chi}{\sqrt{2}}\right)^2\right\rangle\right) = \exp\left(-\frac{\pi^2}{2}\right) \tag{11}$$

It is possible that this amplitude constrains the value of the fine structure constant α, as we see in the next section.

4. Complex time and the de Vries algorithm

As we have seen in the previous section, the virtual effects that survive the renormalization are those related to the exchange of action between the electron and the background in the temporal neighborhood of the QJ. In the conventional QED description this exchange becomes the self-interaction of the electron through the emission and the re-absorption of virtual photons, with all possible radiative corrections of higher order. In practice, the interval $\tau \in [-\theta_0,+\theta_0]$, centered on the QJ occurring in τ = 0, is included within k pairs of "virtual" pseudo-events, each consisting of the emission of a virtual photon and its reabsorption (figure 1).

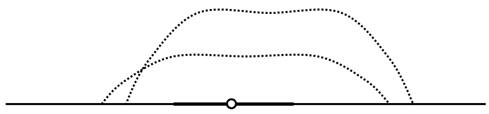


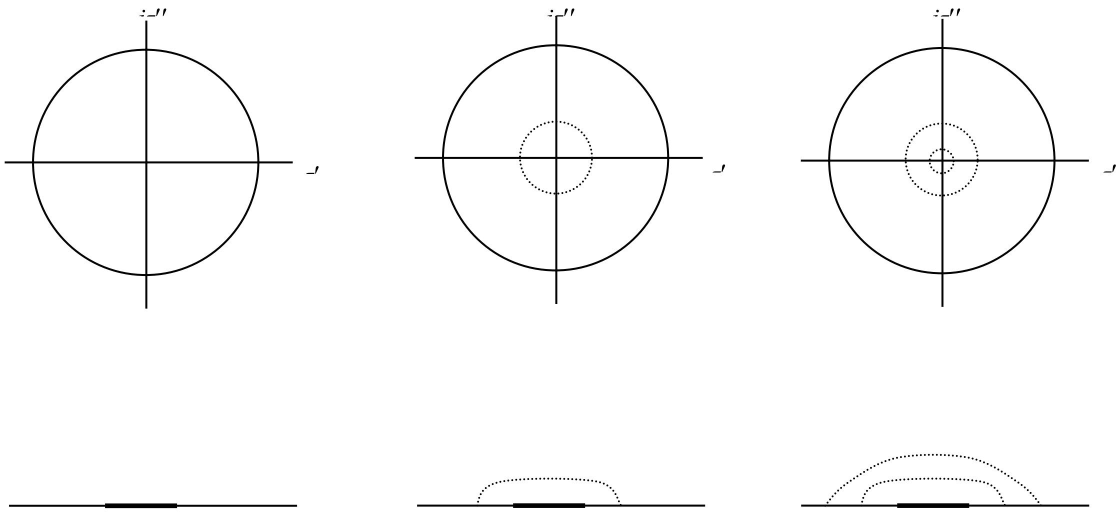
Figure 1; The θ_0-neighborhood of a QJ (induced by the action of external fields in τ = 0) is sorrounded by k pairs of virtual photons emissions and reabsorption

The set of these emissions and re-absorptions (with all the relative radiative corrections of higher order) is what we called the "second version" of the electron. It exists at the same time of the "first version", which consists of the retarded and anticipated components of the electron asymptotic state leaving the QJ.

Let us now look at this structure from the perspective of the complex time plan $\tau'+i\tau''$. The asymptotic state is represented, on this plan, by the points of the circumference of radius θ_0 and by their infinite recurrences. The action related to an arc of this circumference, expressed in $\hbar$ units, is proportional to the arc and the proportionality factor is $\alpha/2\pi$, as is immediately seen by multiplying and dividing the first member of (1) for mc^2. This action is the action of the asymptotic state, evaluated in the rest frame of reference of the electron. The action χ that we described in the previous section is related to an arc of circumference which is, in this case, a random variable with density dependent on τ. These actions connected to the angular part of $\tau'+i\tau''$ (with a fixed value of the modulus equal to θ_0) can be traced back, as we have seen, to a conventional description.

However, $\tau'+i\tau''$ is a complex number and therefore includes both a phase and a module. Consequently, we have two actions: one (the usual one) associated with the phase, that is, the arc on the circumference; the other connected to the module, that is to the radius of the circumference. This second action will appear in processes in which the radius of the circumference change on τ. In general, indeed, the two actions will be mutually convertible. It is therefore natural to associate these conversion processes with virtual photon emissions and reabsorptions. The "modular" action expresses the distance of the electron from the origin $0 + i0$ of the plan of the complex time, which corresponds to a circumference of null radius and thus to a condition of absolute immobility over time. This kind of "timeless vacuum" does not exist in the conventional QED description, as it does not exist in it the "modular" action of processes that reconnect that "vacuum" to the ordinary dynamic state.

Let us consider the interval $[-\theta_0,+\theta_0]$ of the variable τ represented in figure 1, where the instant $\tau = 0$ represents the QJ. Obviously $[-\theta_0,+\theta_0] = [-\theta_0,0] \cup [0,+\theta_0]$ and each of these two intervals is represented by the 0-th recurrence of the circumference of radius θ_0 on the complex time plan. The phase action associated with this recurrence is $mc^2\theta_0 = e^2/c = \alpha\hbar$ i.e. α, in $\hbar$ units. The ratio of the circumference radius to the circumference length is $1/2\pi$, so that the modular action associated with the 0-th recurrence will be $\alpha(1/2\pi) = \alpha/2\pi$. We can assume that when the interval $[0,+\theta_0]$ ($[-\theta_0,0]$) is included within k=1 pairs of virtual photons emissions/reabsorptions (see figure 1) this modular action is converted into the phase action of a circumference, concentric to the previous, whose length is equal to $1/2\pi$ times the length of the previous circumference. In other terms, the length of this inner circumference equates the radius of the outer circumference. Thus, the diagram with k = 1 pairs of emissions/reabsorptions is represented, on the complex plan, by the two circumferences of figure 2.2.



1. α 2. $\alpha(1+\frac{\alpha}{2\pi})$ 3. $\alpha\left[1+\frac{\alpha}{2\pi}\left(1+\frac{\alpha}{(2\pi)^2}\right)\right]$

Figure 2; Representation, on the complex time plan, of the self-interaction induced by the QJ.

The procedure, at this point, can be iterated. The phase action of the inner circumference was the modular action of the outer circumference, and therefore it amounts to $\alpha/2\pi$. The modular action of the inner circumference is given by the product of this action for 1/2π, ie $\alpha/(2\pi)^2$. This action can be converted into the phase action of a third internal circumference inside the other two and concentric to them; The set of these three circumferences will represent the interval $[0,+\theta_0]$ ($[-\theta_0,0]$) surrounded by k = 2 pairs of emissions/reabsorptions (figure 2.3). In summary, with k pairs we will have a contribution $\alpha/(2\pi)^k$ that is composed with the previous ones. The total action in units $\hbar$ will therefore be expressed by the terms in the series shown in figure 2. Thus, the total action (in units $\hbar$) associated with each of the two intervals $[0,+\theta_0]$, $[-\theta_0,0]$ is expressed by the "perturbative" series:

$$\Gamma(\alpha) = 1+\frac{\alpha}{(2\pi)^0}\left\{1+\frac{\alpha}{(2\pi)^1}\left[1+\frac{\alpha}{(2\pi)^2}\left(1+\frac{\alpha}{(2\pi)^3}\cdots\right)\right]\right\} = \qquad (12)$$

$$= 1 + \alpha + \alpha^2/2\pi + \alpha^3/(2\pi)^3 + \alpha^4/(2\pi)^6 + \alpha^5/(2\pi)^{10} + \alpha^6/(2\pi)^{15} + \ldots\ .$$

The function $\Gamma(\alpha)$ can be interpreted as the coupling constant for the process consisting of the generation of the interval $[0,+\theta_0]$ ($[-\theta_0,0]$) surrounded by infinite loops of virtual photons. Therefore, the product $[\Gamma(\alpha)]^2$ of the functions $\Gamma(\alpha)$ relative to the two intervals $[0,+\theta_0]$, $[-\theta_0,0]$ measures the strength α' of the electron coupling with the external field in the QJ. However, this strength must be further attenuated by a factor $\exp(-\pi^2/2)$ equal to the probability of closing the 0-th recurrence.

Otherwise, the electron timeline would not form, and the electron could not be localized on it at the instant corresponding to the QJ. Then:

$$\alpha' = [\Gamma(\alpha)]^2 \exp(-\pi^2/2) \ . \tag{13}$$

In fact, this is nothing but the fraction of action $\hbar$ (made available by the other fields that converge in the interaction vertex) associated with the completion of the first cycle, because the activation of the subsequent recurrences of the cycle (in both directions of external time) is then automatic. But, as we can see from equation $mc^2\theta_0 = \alpha\hbar$, this fraction is α. In other words $\alpha' = \alpha$, *i.e.*:

$$\alpha = [\Gamma(\alpha)]^2 \exp(-\pi^2/2) \ . \tag{14}$$

This is the relation put forward by de Vries [4] and, clearly, it establishes the value of α. In accordance with de Vries' procedure, this value can be found by iteration, by imposing an arbitrary initial value of α (say, between 0 and 1) and applying the iteration scheme [4]:

$$\begin{array}{ll} \text{step 1} & \alpha' = [\Gamma(\alpha)]^2 \exp(-\pi^2/2) \\ \text{step 2} & \alpha' \rightarrow \alpha \\ \text{step 3} & \text{go to step 1 .} \end{array} \tag{15}$$

The result is quite in agreement with the most recent CODATA report:

CODATA 2014 (source: NIST)	7.297 352 5664(17)	$\times 10^{-3}$
Hans de Vries	7.297 352 5686	$\times 10^{-3}$

If the derivation conjectured in this section is correct, the value of the fine structure constant in the limit of zero transferred momentum is connected with the completion of the first cycle which induces the entire electron timeline. In the following section we shall examine this latter aspect in greater detail; it clearly entails a deep connection between the QJ and the large-scale geometry of spacetime in which it occurs, i.e. a direct relation between particle physics and cosmology.

5. The electron and the cosmos

Now we come back to the exponential "tails" introduced in section 3 and more specifically to the particle self-interaction interval of duration $\hbar/Mc^2$, where M is the mass of the particle. As we have seen, in this interval the particle localization in the time domain occurs, in correspondence of a quantum leap. Since the duration of this interval is finite (while the QJ is instantaneous) this localization takes place gradually, in the sense that if $P = 1/t$ is the localization probability of the electron in the unit of time, this probability increases with the module of τ. It will vary from a minimum value of $1/T_0$ at $\tau = 0$ (i.e, at the QJ) to a maximum value at the end of the interval $[0, \hbar/Mc^2]$ (or at the beginning of $[-\hbar/Mc^2, 0]$). We can consider this process as exponential, as the tail is exponential. Therefore, without any loss of generality we can introduce sub-intervals of duration $\theta = \hbar/Mc^2n$, with n positive real, in each of which the value of P doubles (i.e. the value of t is halved). We have the obvious relations:

$$n = \frac{\hbar}{Mc^2}\frac{1}{\theta}, \tag{16}$$

$$T_0 = 2^n\theta \quad . \tag{17}$$

From these we obtain:

$$\frac{\hbar}{Mc^2T_0} = \frac{n}{2^n} \tag{18}$$

For $k = \tau/\theta \leq n$ it will be, in general:

$$t/\theta = (T_0/\theta)2^{-k} \tag{19}$$

where $t = \theta$ for $k = n$. The (19) can be rewritten as:

$$-\log_2\left(\frac{t}{T_0}\right) = k = \frac{|\tau|}{\theta} \tag{20}$$

Eq. (20) makes evident the connection between τ and the information about the localization of the particle in the unit time interval. It should be noted that at the end of the interval $T = \hbar/Mc^2$ the duration t does not vanish; it reaches a finite value $T_0/2^{T/\theta}$ identified with $\theta = \hbar/Mc^2n$. From (17) we then reobtain $n = T/\theta$, that is the (16).

The maximum possible value for θ is the chronon θ_0, and in this case the maximum possible value for n is given by the minimum value for M. As is known, the lighter elementary particle is the electron whose mass is m (if neutrinos, which we do not deal here, are neglected; they are created by weak interactions in oscillating superpositions of mass eigenstates). For the electron we have, from (16), $n = 1/\alpha$ if $\theta = \theta_0$. Replacing these values in (17) gives $T_0 = t_0$ with:

$$t_0 = 2^{1/\alpha}\theta_0 \tag{21}$$

Equation (21) shows that t_0 is independent of cosmic time; this suggests that t_0 can be a de Sitter time, that is, the chronological distance of the QJ from the two sheets ($\tau = -t_0$ and $\tau = +t_0$) of a de Sitter horizon, which is invariant with respect to the spacetime position of the QJ. This conjecture can be tested numerically. Since $2^{1/\alpha} \approx 10^{41}$ and the chronon is approximately equal to 10^{-23} s, the result $t_0 \approx 10^{18}$ s is of the order of the age of the Universe and its interpretation as de Sitter time provides the correct order of the density of dark energy: $3/(ct_0)^2 \approx 10^{-56}$ cm^{-2}. For the compatibility of the existence of a de Sitter time and big bang cosmology, please see reference [14].

If this reasoning is correct, a deep connection exists, therefore, between the appearance of the electric charges in the time domain, the extent of this domain and current issues in cosmology, such as the origin of the cosmological constant. Equation (16) was initially put forward by Sternglass [15]; its connection with the holographic paradigm is discussed in ref. [16]. One ought to bear in mind that the electron in eq. (21) does not play any privileged role in the definition of the cosmological constant compared to other particles. Both α and θ_0 are universal constants (parameters of the background) and the mass of the electron is linked to them by the relation $\theta_0 = \alpha\hbar/mc^2$.

6. A digression on unstable particles

A classic problem of atomic physics is: what drives one atom to decay spontaneously when in an excited level? The standard answer is constituted by the "vacuum fluctuations" and is motivated by the fact that it is the zero point term of the electromagnetic Hamiltonian to mediate these transitions. However, we must remember that a quantum jump emits a de Broglie phase wave in both temporal directions, as we saw in the previous sections. A process initiated by a quantum jump (in our case, the creation of the excited state) and terminated by a quantum jump (the atomic transition to the lower level) thus forms a single four-dimensional block. The decay process will inevitably start if a lower, free level is available; in this case, its transition amplitude contains the zero point term (see ref. [12] for a general discussion of this topic). In this phenomenon, only the asymptotic states coming out of the two QJs are involved. More precisely, the "transactional handshake" [11] between the retarded state coming out of the first QJ and the advanced state coming out of the second QJ is relevant here. However, even the "tails" play a role.

In fact, in addition to the irreducible complexity of the decay, owing to its four-dimensionality, one must also consider the role of the self-interaction interval of the decaying system. The typical time scale of the “dialogue” between the QJ that produces the unstable state and that one related to its decay is the mean lifetime of the unstable state. Instead, the typical time scale of the localization of the decaying system in the time domain is, as we have seen, $\hbar/Mc^2$ where M is the state mass. Here we shall examine the role of this interval in the decay processes of elementary particles. The probability that an unstable particle of mass M, with $Mc^2 = z\hbar/\theta_0$, is not yet decayed at the time θ_0/z after its creation is expressed by:

$$\exp[-\frac{(\theta_0/z)}{\tau_{mean}}] = 2^{-\frac{\theta_0}{z\tau_{mean}\ln 2}} \tag{22}$$

where τ_{mean} is the particle mean lifetime. The information associated with this fact is therefore $\theta_0/z\tau_{mean}\ln 2 = \theta_0/zT_h = \hbar/Mc^2T_h$, where T_h is the decay half-life. Let us consider the index n (not necessarily integer) defined by the equation:

$$\frac{\hbar}{Mc^2T_h} = \frac{n}{2^n} \tag{23}$$

Eq. (23) coincides with eq. (18) if one identifies T_0 with the half-life of the particle and n with the number of θ-intervals included in its self-interaction interval. The systematic study of nuclei and particles decays using this index was carried out by several authors two decades ago [17-21]. We note that equation (23) can be rewritten as the pair of equations (17) and:

$$\theta = \frac{\theta_0}{zn} \tag{24}$$

The similarity of this formalism with that one introduced in section 5 must not hide the differences: the left hand of equation (23) contains no more the maximum extension of the timeline accessible to the particle, but its half-life. For example, equation (23) formally becomes the equation (21) posing in it $M = m$ (electron mass) and $n = 1/\alpha$. But in the case of the electron, which is a stable particle, is actually $T_h = \infty$ and then, from equation (23), $n = \infty$.

The index n allows the definition of a not so widely known property of the decays with $\tau_{mean} > \hbar/mc^2$, where m is the electron mass. That is, decays whose duration is longer than both θ_0 and the time interval $\hbar/mc^2$. Decays mediated by the strong interaction, for which $T_h \approx \theta_0$, are therefore excluded and only electromagnetic and weak decays are considered.

The decays complying with this rule are not many and are exhaustively listed in Table I, sorted for decreasing values of n. We have the neutron taking first place, whose value n appears isolated (n = 96.09), probably owing to the exceptionally long half-life of this particle. The weak decays of leptons and hadrons then follow, with values of n between 44 and 64. We then have the electromagnetic decay of the neutral pion (n = 28.33) and all the other hadronic electromagnetic decays with values of n between 18 and 23. It is evident from Table 1 that the values of n of weak decays are subdivided into mutually very close groups, to each of which the same progressive integer number l can therefore be attributed. The following law thus appears satisfied with considerable accuracy:

$$n = n_{\max} - \sigma l \tag{25}$$

where $n_{max} = 72$ and $\sigma = 4$. It is possible that a similar law is valid for hadronic electromagnetic decays, but the subdivision of the values of n less than 22 into groups that can be associated with a same index l shows some ambiguities and it is not possible to draw any definite conclusion. In Table I we show a possible grouping which would lead to a law of the same type as eq. (25) with $n_{max} = 44$ and $\sigma = 2$.

Equation (25) describes a regularity of the index n which, as can be seen clearly from eq. (23) by means of which it is calculated, depends both on the *M parameter* of the particle and on its *interaction property* T_h. Our opinion is that this regularity is not of dynamic origin, *i.e.* connected with the dynamic causality that is usual in physics, expressed in the customary Lagrangian or Hamiltonian language. Instead, we believe that it is a regularity of the formal causation process through which the interaction vertex associated with the decay becomes manifest in the external time domain by emerging from the atemporal background. In the preceding sections we have analyzed certain details of this process, such as the appearance of a self-interaction interval in correspondence of a QJ. During this interval, the intrinsic transtemporality of the radiation or decay process is extinguished and the asymptotic state emerges. As is clearly seen from eq. (19), eq. (25) can be rewritten in the form:

$$\frac{T_{l+1}}{\theta_{l+1}} = 2^{-\sigma}\frac{T_l}{\theta_l} \quad (26)$$

In other words, the number of θ-intervals at the instant of the QJ associated with the decay of a state having index l+1 (*i.e.* T_{l+1}/θ_{l+1}) is a $2^{-\sigma}$ fraction of the one associated with a state having index l (*i.e.* T_l/θ_l) and this fraction is constant across the entire group of weak (electromagnetic?) interactions, regardless of whether it is leptons or hadrons that are decaying. Alternatively, one can take the binary logarithm of the two members of eq. (26). Since $\log_2(T_h/\theta)$ is the information associated with the choice of a specific θ-interval among all those (assumed to be equiprobable) at the instant of the QJ, eq. (26) states that by varying the l index by +1, this information decreases of σ.

Table I. Particle decays. Data from ref. [17].

	Particle	Mass (MeV)	Width (MeV)	Width/Mass	n	l	$n + \sigma l$
1	n	9.40E+03	7.43E-24	1.14E-27	96.09	1	
2	μ	1.06E+03	3.00E-15	4.08E-18	63.76	2	71.76
3	K_{0L}	4.98E+03	1.27E-13	3.68E-17	60.51	3	72.51
4	$K^{\pm}$	4.94E+03	5.33E-13	1.56E-16	58.38	4	74.38
5	$\pi^{\pm}$	1.40E+03	2.53E-13	2.61E-16	57.61	4	73.61
6	Ξ^0	1.31E+04	2.27E-11	2.50E-15	54.27	5	74.27
7	Λ	1.12E+04	2.50E-11	3.22E-15	53.90	5	73.9
8	Ξ^-	1.32E+04	4.02E-11	4.39E-15	53.44	5	73.44
9	Σ^-	1.20E+04	4.46E-11	5.36E-15	53.14	5	73.14
10	Ω	1.67E+04	8.02E-11	6.93E-15	52.76	5	72.76
11	Σ^+	1.19E+04	8.25E-11	1.00E-14	52.22	5	72.22
12	K_{0S}	4.98E+03	7.38E-11	2.14E-14	51.09	5	71.09
13	$B_{\pm}$	5.28E+04	4.28E-09	1.17E-13	48.56	6	72.56
14	B_0	5.28E+04	4.39E-09	1.20E-13	48.52	6	72.52
15	B_{0S}	5.38E+04	4.92E-09	1.32E-13	48.38	6	72.38
16	Λ_{0b}	5.64E+04	6.16E-09	1.58E-13	48.12	6	72.12
17	$D^{\pm}$	1.87E+04	6.24E-09	4.82E-13	46.46	7	74.46
18	$D^{\pm}_s$	1.97E+04	1.41E-08	1.03E-12	45.32	7	73.32
19	Ξ^+_c	2.47E+04	1.88E-08	1.10E-12	45.23	7	73.23
20	D_0	1.86E+04	1.59E-08	1.23E-12	45.06	7	73.06
21	τ	1.78E+04	2.23E-08	1.81E-12	44.48	7	72.48
22	Λ^+_c	2.29E+04	3.30E-08	2.08E-12	44.28	7	72.28
23	π^o	1.35E+03	7.85E-05	8.39E-08	28.33	8	
24	η	5.47E+03	1.20E-02	3.17E-06	22.77	10	42.77

25	γ(3S)	1.04E+05	2.63E-01	3.65E-06	22.56	11	44.56
26	γ(2S)	1.00E+05	4.40E-01	6.35E-06	21.70	11	43.7
27	γ(1S)	9.46E+04	5.25E-01	8.01E-06	21.34	11	43.34
28	Σ^0	1.19E+04	8.91E-02	1.08E-05	20.88	12	44.88
29	J/ψ(1S)	3.10E+04	8.80E-01	4.10E-05	18.80	13	44.8

7. Some reflections on the nature of the Higgs field

One can ask what the Higgs field φ really is and the reason for it is not vanishing in the vacuum. It is necessary to consider that so far this field has been studied in the context of QFT and therefore of the unitary evolution of field operators. But, to our knowledge, no inquiry has ever been made about the relationship between the Higgs field and the discontinuities of that evolution, namely the QJ. We can assume that actually the particle centres of charge (the single lepton or quarks if the considered particle is a hadron) are not coupled with the field $\varphi = \varphi(x_\mu)$ ($\mu = 0,1,2,3$) but rather with the field:

$$\xi(x_\mu, \tau, T) = \varphi(x_\mu)\left\{[1-\Theta(\tau)] + \Theta(\tau)\exp\left[-|\tau|/T\right]\right\} \tag{27}$$

$$\xi(x_\mu, \tau, T) = \varphi(x_\mu)\left\{\Theta(\tau) + [1-\Theta(\tau)]\exp\left[-|\tau|/T\right]\right\} \tag{28}$$

Let's now explain the symbols. First, $\Theta(x) = 1$ for $x \geq 0$; $\Theta(x) = 0$ for $x < 0$. The time interval between the present moment (x_0) and the quantum jump to which the particle quantum state undergoes, measured in the rest frame of reference of the particle to which the centres of charge belong, is denoted as τ. It should be noted that the coordinate x_0 and τ are independent variables. The parameter T is connected to the particle mass M through the relation:

$$T = \frac{\hbar}{Mc^2} \tag{29}$$

We formulate this hypothesis in the context of the transactional interpretation, which see the QJ as a simultaneous emission of the particle wave function ψ towards the future of the QJ ($\tau > 0$) and of the conjugate wave function ψ^* towards the past ($\tau < 0$); the latter actually represents the absorbed component of the particle field [9-12]. The (27) represents the field coupled to the centres of charge associated with ψ^* while (28) represents the field coupled to the centres of charge associated with ψ.
Let us now look at the physical meaning of the hypothesis. The (27) becomes $\xi = \varphi$ before the jump (i.e. for $\tau < 0$), while $\xi = \varphi\exp(-\tau/T)$ after the jump ($\tau > 0$), where the exponential factor is the same of (10). For (28) we have instead the mirror situation $\xi = \varphi\exp(\tau/T)$ for $\tau < 0$, while $\xi = \varphi$ for $\tau > 0$. Therefore, in conclusion, the coupling of the centres of charge with ξ coincides with the usual one with φ, except for the appearance of exponential tails of ξ of duration $\approx T$ around $\tau = 0$. In the first tail, related to the absorbed wave function ψ^*, the coupling vanishes and the centres return to the "original" condition of gauge invariance. Instead, this coupling is reset in the second tail relative to the emitted wave function ψ, starting from the gauge invariance condition.

From this it is understood that the Higgs field φ, autonomous and independent of the specific particle, is in fact the limit case of the field ξ dependent on the specific particle. The tails of ξ in correspondence with a discontinuity in the evolution of the quantum state of the particle *are* the particle, which is actually localized on the temporal domain. This field manifests itself when a massive particle undergoes a quantum jump. Operating with the energy operator on (27) and on (28) respectively we find:

$$i\hbar\partial_{|\tau|}\xi \ = \ \begin{cases} i\hbar\partial_{|\tau|} \ = \ 0 \quad for \quad \tau < 0 \\ i\hbar\partial_{|\tau|} \ \exp(-|\tau|/T) \ = \ (-i\hbar/T)\xi \quad for \quad \tau \geq 0 \end{cases} \tag{30}$$

$$-i\hbar\partial_{|\tau|}\xi \ = \ \begin{cases} -i\hbar\partial_{|\tau|} \ \exp(-|\tau|/T) \ = \ (i\hbar/T)\xi \quad for \quad \tau < 0 \\ -i\hbar\partial_{|\tau|} \ = \ 0 \quad for \quad \tau \geq 0 \end{cases} \tag{31}$$

The "absorbed" energy $-i\hbar/T$ and the "emitted" energy $+i\hbar/T$ add up to zero, as it must be given the impossibility of net exchanges of energy with the vacuum. They are imaginary, and thus define the line width of a transient consisting of the particle that contains the centres of charge. This result conforms to the notion of particles as events rather than objects. The localization energy Mc^2 is conveyed by ψ^* and ψ respectively, and is exchanged with the vacuum as described elsewhere [5].

From what we have said there exist, for $\tau > 0$, centres of charge associated with the asymptotic state ψ regularly coupled with φ as well as centres of charge associated with ψ^* whose coupling with φ is evanescent. For $\tau < 0$ there is a mirror situation with centres of charge associated with the asymptotic state ψ^* regularly coupled with φ together with centres of charge associated with ψ whose coupling with φ is evanescent. Of course, the net charge is conveyed by asymptotic states so that the total charge of the centres of charge associated with tails must be zero for each value of τ. The charges whose coupling with φ is evanescent are therefore the virtual ones that in the QFT description dress the net charges conveyed by the asymptotic states. With this we have that the perturbative effects are limited in this description to a range of extension $\approx T$ around $\tau = 0$ and do not affect the asymptotic states (if these latter are free). In other words, this description seems to correspond approximately to QFT *after* performing the renormalization procedure, with the consequent subtraction of free propagation diagrams. As can be seen, the coupling described by (27), (28) represents at the same time: 1) the localization of the particle in the temporal domain; 2) the self-interaction of the particle induced by its real interaction with the external world represented by the QJ; 3) the coupling of the particle centres of charge with the Higgs field.

In case of particles containing a single centre of charge (leptons) the coupling constant with the Higgs field, multiplied by the expectation value in the vacuum of this latter, is the mass of the particle while the time constant T of (27), (28) is the inverse of that mass. In the case of quarks, the first quantity is the inverse (in natural units) of the Compton length of the quark while T, which is the same for all quarks of the same hadron, is the inverse of the hadron mass. All these considerations assume a free asymptotic state ψ, although this restriction is not necessary. The asymptotic state can also contain virtual interactions, such as in the case of an electron in a stationary atomic orbital, which exchanges virtual photons with the nucleus.

At this point we can come back to the initial question of this section, that is, the true nature of the Higgs field. The product of the coupling constant of a given centre of charge with the expectation value of the Higgs field in vacuum is the inverse (in natural units) of the standard Compton length of that centre. The (27),(28) say that this length ranges from infinity at $\tau = \pm\infty$ (complete delocalization of the centre) to its standard value at $\tau = 0$, that is at the QJ. The inverse if this length decays in τ with a constant which is the inverse (in natural units) of the mass of the particle to which the centre of charge belongs. The suppression/reset of this inverse is manifested in the form of exponential tails in (27), (28), and in the actualization of an asymptotic state for the particle that contains the centres of charge. When an amount of energy equal to that of coupling between the centres of charge of a particle and the expectation value of the Higgs field is made available in the QJ, that particle may appear as a virtual transient phenomenon. Its actual creation requires that energy equal to the mass of the particle is available. It is therefore likely that the energy ε of the fluctuations of the Higgs field is the inverse, in natural units, of the shortest Compton length of the pair constituted by a centre of charge and its anti-centre. This "limit" Compton length will then be the smallest value attributable to the radius associated with the localization of a particle.

The centre of charge with the shortest Compton length is the quark top; the inverse of its Compton length amounts to $M_0 \approx 170$ GeV and the double of this value is 340 GeV. In accordance with our interpretation, the value of ε is estimated to be 346 GeV. It is also noteworthy that the quark top does not form hadrons, which support the hypothesis that it is placed precisely at the extreme limit beyond which the particle formation is no longer possible (or very difficult).

8. Conclusions

In this article we have examined a possible ontology of the electron-photon vertex, attempting to recover, from the perspective we propose, the customary description in terms of virtual processes. Firstly, the role of actions e^2/c and h in the temporal localization of an electric charge is highlighted. This localization takes place in the form of a *quantum jump*, seen as an objective physical process that coincides with the collapse (retrocollapse) of the wavefunction of the charge-carrying elementary particle. This process is always due to an interaction (possibly negative) with other fields or particles, and represents a non-Hamiltonian property of the interaction, expressed by an appropriate self-conjugate projection operator. As a special case, in the quantum jump the number of particles of a certain type appearing on the time domain can vary; this leads to the well-known creations/annihilations of quanta described by quantum field theory.

Secondly, the external time domain ("laboratory time") in which the charge is localized is not pre-existent to this localization but is coemergent with it. This leads to a simple correlation between cosmology (manifestation of the particle timeline) and the localization of the particle in the here-now. Particularly, the existence is suggested of a de Sitter radius in the Universe that is compatible with the density of dark energy obtained from observations (cosmological constant).

The generation of the timeline of a particle is triggered by a process of emission or absorption, and is progressive. It occurs in a finite time (while the QJ is instantaneous) during which the particle self-interacts. Instead, in the absence of further interactions with external fields the asymptotic state is not self-interacting (it is "on shell"). The self-interaction related to the emission or absorption vertex represents a constraint on the value of the fine structure constant in accordance with an algorithm suggested years ago by de Vries as a simple mathematical curiosity.

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