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Article

Wave Function and Information

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Abstract: Two distinct measures of information, connected respectively to the amplitude and phase of the wave function of a particle, are proposed. There are relations between the time derivatives of these two measures and their gradients on the configuration space, which are equivalent to the wave equation. The information related to the amplitude measures the strength of the *potential* coupling of the particle (which is itself aspatial) with each volume of its configuration space, *i.e*. its tendency to participate in an interaction localized in a region of ordinary physical space corresponding to that volume. The information connected to the phase is that required to obtain the time evolution of the particle as a persistent entity starting from a random succession of bits. It can be considered as the information provided by conservation principles. The meaning of the so-called "quantum potential" in this context is briefly discussed.

Keywords: Information; nature of the wave function; Schrödinger equation; quantum particle; quantum potential

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1. Introduction

In this short communication we attempt to revisit the concept of the wave function of a quantum particle, proposing an entirely informational definition of it. We will do this by introducing two distinct measures of information, functions of the point and the instant, on the configurational space C of the particle, enlarged with the addition of the time coordinate t. These two measures are connected respectively to the amplitude and phase of the wave function. The information related to the amplitude measures the strength of the *potential* coupling of the particle (defined in aspatial terms) with each volume of its configurational space, *i.e*. its tendency to participate in an interaction localized in a region of ordinary physical space corresponding to that volume. It substantially coincides with the quantum entropy *for a pure state* introduced in [1].

The information connected to the phase is that required to convert the time evolution of the particle from a random succession of bits to a persistent state, in order to account for the existence of conserved quantities (spin, charge, momentum, etc.) associated with the free evolution of the particle.

These two measures of information become the components, respectively imaginary and real, of a complex information. The well known wave equation for the non-relativistic scalar particle (Schrödinger equation) is then rewritten as a relation between the time derivative and the spatial gradient of this complex information, the latter defined as a row vector. In this new form, the wave equation appears as a complex (vectorial) generalization of the ordinary Hamilton-Jacobi equation, with the addition of a term of divergence of the spatial gradient. In particular, the divergence of the quantum entropy gradient is weighted by the reciprocal of this entropy; this weight constitutes a sort of "coupling constant" between each region of C and the particle (in itself aspatial), with respect to its possible localization in these regions. The term of the wave equation generated by this coupling is the so-called "quantum potential", which appears in the hydrodynamical representation of this equation [2].

This form of the dynamical equation, therefore, makes explicit the coupling, *in a potential sense*, of the quantum particle with each volume of its configuration space. This coupling is actualized when a quantum jump, induced by an interaction in a region of *ordinary* physical space corresponding to a given volume of C, localizes the particle in that volume.

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We want to underline that although, for reasons of simplicity, we will limit our considerations in this note to the case of a single particle, they are immediately generalizable to systems with any number of particles and configurational spaces of any dimensionality.

We will develop this note according to the following plan. In Section 2 we recall the essential notions of particle and interaction, underlining that the space-environment of the particle (configurational space) is not the same as that of interactions (ordinary physical space). The actual model is proposed in Section 3. Section 4 is divided into various subsections dedicated to the analysis of individual aspects of the model; the general sense is to show its continuity with the quantum formalism usually accepted and taught. In Section 5 we present the rewriting of the Schrödinger equation for a single non-relativistic scalar particle and discuss the meaning of the various terms that appear in it. In Section 6 we report some concluding remarks.

2. Particles and Interactions

In this communication we do not intend to delve into the problem of the ontology of quantum particles. For our purposes we will adopt a minimalist definition, according to which a quantum particle is the maximal set of physical quantities encoded in its wave function, which would be conserved if motion were free. This means that these quantities are compatible, and that in the absence of external forces they would be constants of motion with values definite or not depending on the initial conditions actually chosen. Energy, momentum, spin, isospin, etc. are examples of such quantities, which in systems with many interacting particles combine according to specific rules to give total conserved quantities. The spatial or spatiotemporal position cannot be included among these quantities because, even in the absence of external forces, it is not a constant of motion. As a consequence of this definition, the particle does not have a definite spatial position.

The aspatial packet of physical quantities that constitutes the particle is manifested as a whole in a single interaction event, in which the wave function of the particle is created or annihilated (and possibly replaced by a new wave function). This event, which constitutes a so-called "quantum jump", occurs in a single volume of *ordinary* space, at a definite instant. The simultaneous manifestation in different spatially separated volumes would be in fact incompatible with the local nature of the conservation principles. Let us consider for example the case of a particle A with momentum $\boldsymbol{P}$ which manifests itself in two spatially separated and distinct regions V_1, V_2 by means of two releases of momentum $\boldsymbol{p}_1$, $\boldsymbol{p}_2$ such that $\boldsymbol{P} = \boldsymbol{p}_1 + \boldsymbol{p}_2$. This would mean that, at the moment of the interaction, in the volume V_i, where i = 1 or 2, the impulse $\boldsymbol{P}$ would enter and the impulse $\boldsymbol{p}_i$ would exit. Within this volume there would therefore be the disappearance of the impulse $\boldsymbol{P} - \boldsymbol{p}_i$.

In other words, even though, according to our definition, the particle does not have a definite spatial position, it can nevertheless manifest itself integrally (as a whole) in a certain spatial region by means of a quantum jump induced by the interaction with other particles or systems. This means that ordinary space coordinates label possible interactions between particles, not some "position" actually occupied by the particle between two successive quantum jumps. Space is, in other words, the environment of interactions, *not* that of particles.

A special case is that of the negative interaction [3–5], *i.e.* the fact that an expected manifestation of the particle does not actually occur. Non-manifestation preserves the aspatial nature of the particle and with it the phase relation of its wave function. An example of negative interaction is offered by the particle crossing a double slit, made on an absorbing screen. The negative interaction with the screen annihilates the wave function of the incident particle and creates a new one, different from zero only in the two regions occupied by the slits. The new function preserves the phase relation with the old one. The phase relation between the two components transmitted by the two slits produces the well known self-interference effects downstream of the screen [6].

3. The Model

Let us consider a positive or zero real function $| \psi_0 |$ defined on the enlarged configurational space of a quantum system. We indicate with α the square root of the average value of the square of this function on a volume V of the configurational space:

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$$\alpha(V) = \sqrt{\left\langle |\psi_0|^2 \right\rangle_V} \tag{1}$$

We introduce two complex-valued functions $h_f(V)$, $h_b(V)$ defined by two distinct conditions. The first condition is that their sum is real and corresponds to the information acquired by ascertaining the localization of the quantum system in V:

$$h_f(V) + h_b(V) = -\log\left[(\alpha(V))^2\ V\right] = -\log|p(V)| \tag{2}$$

Eq. (2) is satisfied if $|\psi_0|^2$ is identified as the probability density on the configurational space C and:

$$\int_C |\psi_0|^2 dV = 1 \tag{3}$$

Indeed, in this case:

$$-\log[p(V)] = \log\left[\frac{\int_C |\psi_0|^2 dV}{(\alpha(V))^2 V}\right] = -\log\left[(\alpha(V))^2 V\right] \tag{4}$$

is the information expected for the localization event $C \to V$.

If there were no conservation principles, the time evolution of the system starting from an initial condition would be an entirely random, transient process with decreasing probability. The conditional information associated with the confirmation of the existence of the system at a given time t would therefore grow with t. Denoting as $p_V(t)$ the integral of the localization probability density over the entire configurational space, under the condition that at time 0 the system is localized within V, the information associated with the existence of the system at time t is defined as $-\log(p_V(t))$. After this premise, the second condition is that the differential $d(h_f(V) - h_b(V))/2i$, where i is the imaginary unit, represents in this case the increase undergone, in the time interval dt, by the information associated with the *existence* of the system.

The effect of the conservation principles is to add, in the same interval, an exactly opposite decrease of information $-\lambda$, so that the total change in information in the interval is zero. The total information is then conserved in t, and this ensures the conservation of the probability of existence, thus guaranteeing the persistence of the system at all times following the initial condition. We must therefore have:

$$d\left(\frac{h_f(V) - h_b(V)}{2i} - \lambda\right) = 0 \quad \Rightarrow \quad \frac{h_f(V) - h_b(V)}{2i} = \lambda(V) + \textit{constant} \tag{5}$$

The quantity λ is therefore defined up to an additive constant, which we will ignore in the following. From the conditions (2) and (5) it follows that, in the limit $V \to 0$ and therefore $\alpha(V) \to |\psi_0|$:

$$h_f = -\log\left(|\psi_0|\sqrt{V}\right) + i\lambda; \qquad h_b = -\log\left(|\psi_0|\sqrt{V}\right) - i\lambda \tag{6}$$

where λ is now a function of the point x in which V is contracted and the instant t. Therefore:

$$h_f + h_b = -\log\left(|\psi_0|^2 V\right) \tag{7}$$

It is then possible to define two functions of the point and the instant:

$$\psi_f = \frac{e^{-h_f}}{\sqrt{V}} = |\psi_0| e^{-i\lambda}; \qquad \psi_b = \frac{e^{-h_b}}{\sqrt{V}} = |\psi_0| e^{+i\lambda} \tag{8}$$

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which are identifiable with the "forward" and "backward" wave functions of the quantum system, solutions respectively of the retarded and advanced Schrödinger equation. We note that, as a consequence of the relations (6), the functions (8) do not depend on V; they only depend on point and instant. Eqs. (8) provide an informational interpretation of the wave function.

4. Remarks

4.1. Born Rule

Let us consider the transition $\psi \to a_1\psi_1$, with:

$$\psi = \sum_i a_i \psi_i; \qquad \langle \psi_i | \psi_j \rangle = \delta_{ij} \tag{9}$$

We assume that ψ is normalized to 1 on C. Before the transition we have:

$$\left(h_{f,0} + h_{f,0}\right) = -\log\left[\left(\alpha(V)\right)^2 V\right]; \qquad \alpha(V) = \sqrt{\left\langle |\psi|^2 \right\rangle_V} \tag{10}$$

After the transition we have:

$$\left(h_{f,1} + h_{f,1}\right) = -\log\left[\left(\beta(V)\right)^2 V\right]; \qquad \beta(V) = \sqrt{\left\langle |a_1\psi_1|^2 \right\rangle_V} \tag{11}$$

Therefore the information acquired with the transition is:

$$\left(h_{f,1} + h_{f,1}\right) - \left(h_{f,0} + h_{f,0}\right) = \log\left[\frac{(\alpha(V))^2}{(\beta(V))^2}\right] \tag{12}$$

In the limit $V \to C$ one has $\alpha^2 \to 1/V$, $\beta^2 \to |a_1|^2/V$, and then:

$$\left(h_{f,1} + h_{f,1}\right) - \left(h_{f,0} + h_{f,0}\right) \to -\log\left[|a_1|^2\right] \tag{13}$$

Eq. (13) identifies $|a_1|^2$ as the conditional transition probability. This identification constitutes the well-known Born rule.

4.2. Existential Information

In the absence of conservation principles it should be:

$$d\left(\frac{h_f(V) - h_b(V)}{2i}\right) = -d\log p_V(t) \tag{14}$$

where $p_V(t)$ would be the probability of existence of the system somewhere at time t, conditioned by the presence of the system within the volume V at time 0. From (5) it follows that (14) equals $d\lambda$, then $p_V(t) = p_V(0)\exp[-\lambda(V)] = \exp[-\lambda(V)]$. In fact, the probability that the system is somewhere in C at time 0 is by construction 1, because at that instant the system is in V; therefore is $p_V(0) = 1$. In the limit $V \to 0$ this relation becomes $p_{V\to 0}(t) = \exp[-\lambda(x, t)]$, where x is the point in which V is contracted. In the same limit:

$$\frac{d}{dt}\left(\frac{h_f(V) - h_b(V)}{2i}\right) = -\frac{d}{dt}\log p_{V\to 0}(t) = -\frac{\dot{p}_{V\to 0}}{p_{V\to 0}} = \dot{\lambda}(x,t) \tag{15}$$

If the system is stationary and admits a wave function:

$$\psi = |\psi(x)|e^{-i\omega t} \tag{16}$$

where x is the generic point on the configuration space and ω is a real number independent on that point and on time, then $\omega = \lambda/t$ from (8). Furthermore, from Planck's law we have $\omega = E/\hbar$, where E is the total energy of the system. Therefore $\lambda = Et/\hbar$ and $p_{V\to 0}(t) = \exp(-Et/\hbar)$. This last expression is the same one that would be obtained by applying the Wick rotation $t \to -it$ to the phase factor in (16) [7].

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In addition, the expression (15) equates $\omega = E/\hbar$. The information added in the interval $(0, t)$ is nothing else than the de Broglie phase λ and the Planck constant h sizes the bit of this information, as evidenced by the relation $p_{V\to 0}(t) = \exp(-Et/\hbar)$, that identifies this bit as $\hbar\ln 2$. The quantization of the information of existence in time then takes the well known form of the uncertainty principle $(Et)_{min} \approx h$.

4.3. Compatibility with Quantum Mechanical Rules

As we have seen, it is not generally possible to ascribe a position to the particle. It is the discontinuous transition of the particle from one wave function to another (quantum jump) that is localized. It is localized exactly in time, partially (depending on the diffusion of the outgoing wave packet) in space. The problem can be made quantitative as follows. Let us first observe that from the relations already seen:

$$\psi = \sum_i a_i \psi_i \tag{17}$$

$$Prob(\psi \to \psi_i) = |a_i|^2 = \left| \int_C \psi \psi_i^* \, dV \right|^2 \tag{18}$$

If we make the further hypothesis of the existence of a linear Hermitian operator $\hat{O}$ such that:

$$\hat{O}\psi_i = o_i \psi_i; \qquad \hat{O} = \hat{O}^+ \tag{19}$$

then follows:

$$\left\langle \hat{O} \right\rangle_\psi \equiv \sum_i |a_i|^2 o_i = \langle \psi \mid \hat{O} \mid \psi \rangle \tag{20}$$

In this sense it is possible to associate the operator $\hat{O}$ with a physical quantity having a spectrum $\{o_i, p(o_i) = |a_i|^2\}$. If this quantity is the energy ($\hat{O} = \hat{H}$), *i.e.* the time rate of information of existence, a stationary state:

$$\psi = |\psi_0| e^{-i\omega t} \tag{21}$$

must be an eigenfunction of $\hat{H}$. This is only possible if $\hat{H} = i\hbar\partial_t$. In such a case the eigenvalue is $\hbar\omega$, in accordance with Planck's law. The relativistic transformation of the four-momentum $(E/c, 0) \to (E'/c, \boldsymbol{p})$ then implies the transformation between operators: $(i\hbar\partial_t/c, 0) \to (i\hbar\partial_{t'}/c, -i\hbar\nabla_x)$, from which the impulse operator $p = -i\hbar\nabla_x$ is obtained.

It follows that the energy of a non-relativistic material point subject to the potential V takes on the operatorial form:

$$E = \frac{p^2}{2m} + V \;\to\; \hat{H} = i\hbar\partial_t = \frac{(-i\hbar\nabla_x)^2}{2m} + V \tag{22}$$

From (22) the equation of motion:

$$i\hbar\partial_t\psi = -\frac{\hbar^2}{2m}\nabla_x^2\psi + V\psi \tag{23}$$

follows, that we consider in the next Section.

5. Schrödinger equation

In this Section we use the notation of ref. [1], with the additional position $\hbar = 1$. We start from the equation that in that article defines quantum entropy (in the language of this article, the spatial localization information):

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$$S_Q = -\frac{1}{2}\log\rho \tag{24}$$

where $\rho = \exp(2R) = |\psi|^2$ is the probability density on the configurational space. We also indicate by S the *existential* information λ, defined in units $\hbar = 1$. It is then possible to introduce the complex energy:

$$\Xi = \partial_t S + i\partial_t S_Q \tag{25}$$

as time derivative of the complex information $S + iS_Q$. We can further define the momentum as the row vector:

$$\Sigma = \left(\nabla S;\ i\nabla S_Q\right) \tag{26}$$

The dynamical equation is the dispersion relation that connects the quantities (25), (26). Let us consider the simplest case: that of a scalar particle in a non-relativistic regime. The corresponding quantum dynamical equation is the Schrödinger equation (23). We can write it in the form:

$$\Xi = -\frac{1}{2m}\Sigma\begin{pmatrix}1 & 1\\ 1 & 0\end{pmatrix}\Sigma^{+} - V - \frac{1}{2m}D\,\Sigma^{+} \tag{27}$$

where:

$$D = \left(-i\nabla\cdot;\ \frac{i}{S_Q}\nabla\cdot\right) \tag{28}$$

it is a two-component divergence vector to which we will return later.

By substituting (25), (26) and (28) into (27) and developing, we have a complex scalar expression. By separating the real part of this expression from the imaginary one we have the two real equations:

$$-\partial_t S = \frac{(\nabla S)^2}{2m} - \frac{1}{2m}\frac{\Delta S_Q}{S_Q} + V \tag{29}$$

$$\partial_t S_Q + \frac{\nabla S\cdot\nabla S_Q}{m} - \frac{\Delta S}{2m} = 0 \tag{30}$$

The relation (29) is the Hamilton-Jacobi equation with the quantum corrector (so-called "quantum potential"); Eq. (30) is a rewriting of the continuity equation (in terms of ref. [1] it is $S_Q = -R$). Considered together, (29) and (30) are notoriously equivalent to the Schrödinger equation (23) with $\psi = \exp(R + iS)$ [2].

We now come to the physical meaning of the terms that appear on the right side of (27). The first term, quadratic in Σ, is manifestly a complex generalization of the expression for kinetic energy. Its real part is the kinetic energy commonly understood which, added to the potential V, provides the total *classical* energy distributed on the configurational space as a consequence of the "propagation of the particle". The imaginary part provides the second term of (30), which expresses the contribution of the coupling between the gradients of the two information S, S_Q to the temporal variation of S_Q.

The third term of (27) is a scalar product that measures the local inflow (or outflow) of momentum (26) into (from) the configurational space. The first addend of the scalar product is related to the S-momentum, the second addend is related to the S_Q-momentum. This latter is multiplied by the reciprocal of S_Q, which acts as a coupling constant, dependent on the point and the instant, to this contribution. It is in fact intuitive that the coupling will be greater where the particle localization density ρ is greater (and therefore S_Q is lower); it will instead be smaller where ρ is smaller (and therefore S_Q is larger).

The two addends of the scalar product give rise respectively to the third addend of (30), which measures the contribution of S to the temporal variation of S_Q, and to the quantum potential in (29).

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The latter constitutes the kinetic energy corrector derived from the inflow (outflow) of the momentum related to S_Q. This contribution represents an unknown effect in classical physics. In accordance with the aspatial nature of the particle, it is affected by variations in boundary conditions throughout the space, for example the opening or closing of a slit.

In [8] the wave function is modeled as the exchange of a pair of charges $Q^{\pm}$ between individual points in space and an extra-spatial actuator. It is possible to connect the two narratives through the following transformations, relating to non-normalized wave functions:

$$\mathrm{Re}(\psi_f) = \mathrm{Re}(\psi_b) = \frac{Q^+ + Q^-}{2}; \qquad \mathrm{Im}(\psi_f) = -\mathrm{Im}(\psi_b) = \frac{Q^+ - Q^-}{2} \tag{31}$$

Or:

$$|\psi_0| = \sqrt{\left(\frac{Q^+ + Q^-}{2}\right)^2 + \left(\frac{Q^+ - Q^-}{2}\right)^2} \tag{32}$$

$$tg(\lambda) = \frac{Q^+ - Q^-}{Q^+ + Q^-} \tag{33}$$

The derivation of the usual hydrodynamical representation (29), (30) of (23) starting from a notion of particle as an entirely delocalized entity demonstrates that it is not necessary to consider the so-called drift velocity:

$$\vec{v} = \frac{\nabla_x S}{m} = \frac{\hbar \nabla_x \lambda}{m} \tag{34}$$

as the speed of a corpuscle actually present on spacetime, in some way "guided" by ψ. Even putting aside the inevitable non-locality that this driving process would exhibit both in the case of multi-particle systems in the presence of entanglement and of single-particle systems (due to the non-local nature of the quantum potential), Eq.(34) cannot be associated with the trajectory of a charge.

It is easy to realize this by observing that, if this were the case, for the electron of the ground 1s state of atomic neutral hydrogen (nascent hydrogen) one should have $\vec{v} = 0$; that is, it should be at rest with respect to the nucleus. The single hydrogen atom should therefore possess an electric dipole moment $\approx e \cdot \hbar^2/me^2$, easily observable but never actually observed. This moment would be zero only if averaged over the directions of space, as it would be if the averaging operation were performed on many atoms. The zero value of the electric dipole moment of each single hydrogen atom instead confirms the standard quantum mechanical predictions, which do not involve corpuscles.

One could think of maintaining the concept of trajectory of a charge by hypothesizing the existence of a stochastic motion superposed on (34), able to rebuilding the 1s state as a temporal average [9]. In that case, the time average of the electric dipole moment of the single hydrogen atom would be zero. The problem with such a hypothesis, however, is that the velocity of the atomic electron would be then $\approx \alpha c \approx 10^8$ cm s^{-1}. The time it takes for the electron to cross the atomic radius ($\approx 10^{-8}$ cm) would be then $\approx 10^{-16}$ s. Current technology based on laser pulses having width of the order of an attosecond (10^{-18} s) permits the monitoring of the electronic motion with a time resolution a hundred times bigger [10]. Nonetheless, to our best knowledge, no reports of significant deviation of the electronic motion from the behavior expected on the basis of quantum mechanical predictions can be found in the relevant literature. Of course, it is possible to argue that such deviations occur below the currently accessible time scale. Note, however, that the attosecond scale is only two orders of magnitude higher than the Compton scale, on which the valence electron ceases to exist and the electron-positron field coupled to the electromagnetic field appears [11]. The residual space for a stochastic solution therefore appears to be very limited.

6. Conclusions

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In this note we propose a purely informational representation of both the wave function of a particle and the wave equation of which it is the solution. According to this proposal, two distinct measures of information appear, which can be considered respectively as the real and imaginary part of a *complex* information, and as such be connected to the amplitude and phase of the wave function. The imaginary part represents the information gained in a quantum jump that localizes the particle in a specific volume of its configurational space: the one corresponding to the region of ordinary space in which the interaction occurs. In this sense, it can be defined as the information linked to the spatial localization; it substantially coincides with the "quantum entropy" of ref. [1].

The real part represents the information provided by the conservation principles to guarantee the persistence of the particle during its propagation between two subsequent quantum jumps. In other words, it is the existential information necessary to guarantee the causal nature of that propagation interval, or the information contained in causality. This information is linked to the quantum phase and the action variable. From a foundational point of view, it appears relevant that causality is connected to the existence of the phase, and that the introduction of a corpuscle carrying the interaction charges is not required. This introduction, moreover, would seem to be dissonant with some aspects of known physics, as argued in Section 5. On the other hand, the connection between causality and phase wave allows us to account in a natural way for the self-interference effects highlighted by experiments such as that of double slit.

The quantum phase is therefore a consequence of the aspatial nature of the particle, which "lives" in its own configurational space different from the ordinary physical space of our perception. The coordinates of the latter label not the possible positions of the particle, but the positions of the interactions in which it can participate. Only when the particle is projected onto a portion of its configurational space by an interaction that occurs in a region of ordinary space corresponding to that portion, it becomes "present" in that region. And this presence is completely ephemeral, because it is limited to the sole moment of the interaction.

The two terms, real and imaginary, of the complex information are dynamically coupled by the evolution equations. The "quantum potential", corrector of the kinetic energy in the hydrodynamical representation of the wave equation, expresses part of the action of the imaginary term on the real one. It is not associated with some force acting on some "corpuscle", and simply describes the dynamical relationship between causality and coupling of the particle with space. This relationship is clearly exhibited in experiments in which the particle incides on an absorbing screen, on which one or more slits have been made. The cancellation of the wave function on the screen except in the areas corresponding to the slits is the informational translation of the fact that no exchange of conserved quantities constituting the particle has occurred with the screen; consequently, the causal propagation of these quantities (*i.e.* the propagation of the phase wave) continues only at the slits. This implies that the localization information is reshaped on the configuration space, so as to provide a non-zero wave amplitude only at the slits. While the non-transfer of impulse, spin etc. to the screen represents an objective physical fact, the reshaping of the amplitude - *i.e.* the infamous "collapse of the wave function" - necessary to limit the causal propagation of quantities only to the spatial regions occupied by the slits, belongs to the informational sphere, as the generation of a new initial condition on the propagation of the particle [12]. The same mechanism works in the case of an impact on the screen; since the exchange of conserved quantities occurs at the point of impact, those same quantities can no longer be exchanged elsewhere for the reasons seen in Section 2. It follows that the position information, as a function of the point, is reshaped in such a way as to guarantee the cancellation of the amplitude at all points of the configurational space other than the point of impact. It should be noted that the overall phenomenon thus defined involves the single experimental run, and does not represent a purely statistical effect on the set of initial preparations of the micro-system.

In conclusion, we note that the real part of the complex information refers to a causal chain in the enlarged configuration space, which connects two actual interactions, while the imaginary part refers to the possible localizations in ordinary space. Actual interactions and localizations are synonymous with quantum jumps associated with micro-interactions, which represent objective physical facts in terms exemplified by the multiple slit screen experience. The information measures

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here introduced are therefore relative to physical facts, as it seems to us they should be in a physical theory, and do not constitute a primary layer of reality. The proposed approach therefore does not appear functional in circumventing the ontological problem through "it from bit" strategies [13].

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