The wave-particle duality of photons

On realism, causality and locality

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1. The new paradigm

In my classical view, a full description of the surrounding nature must be based on the three pillars of mechanical materialism - causality, realism and locality; therefore, we should be able to build and use models that have all these basic features for any elementary particle and for any known interaction. Consequently, the well-known particles of "light" - the photons - must also have a simple description based on these premises, to which we have to add a precise definition of the collateral wave concept. Once the granular level and its special mechanics have appeared and caused a paradigm shift within the quantum field, both materialism and determinism may come back to their normal positions.

But which is the actual connection between waves and particles in this larger framework, and are all these new explanations consistent with the uncertainty concept of quantum mechanics? This opens an old debate of quantum physics, which has big philosophical implications, but some clear answers are really needed in this field governed by fuzziness. For example, is the position of a particle correctly described by the wavefunction, being given as density of probability? Is a particle "real" all the time, having a well-defined position in space and an exact speed, even if it is not observed? Does the observational limitation impose these probabilistic laws, while the reality is clear and deterministic at the quantum level?

And what exactly is this entity named photon, which behaves sometimes as a wave and sometimes as a particle? Does it have intrinsic properties all the time, or this depends on whether a certain measurement is performed or not?

Continuing this subject, we may also wonder if the actual quantum mechanics can completely describe reality by using the generalized wave-particle duality and the wavefunction formalism. Moreover, does the retro-causality really exist? Does the future influence the past - as some lab experiments seem to show? Also, is the quantum nonlocality a real phenomenon or there are some theoretical and experimental errors involved? Do all quantum systems have well-defined states prior to measurements or everything is uncertain and probabilistic at this dimensional level, as in the Copenhagen Interpretation? If the latter version holds true, could we bring (at least hypothetically) some order and determinism to this chaos-dominated realm by using a lot of supplemental (hidden) variables emerged from the granular level?

There are many simple and complex experiments that can be done with photons (such as the Double-slit experiment), all yielding strange results, raising questions regarding the wave or particle nature of light. Does the dual interpretation of this unusual behavior mean the photons are not well-defined until a measurement is carried out? So, which is the truth about photons and the other particles? Are they a part of one special, full of uncertainty micro-universe, very different from our clear and intuitive macrocosm? And can we really probe this universe, measuring some parameters, while its current status and the intrinsic characteristics remain unchanged?

2. Photons

Photons were described in my previous works as multilayer structures of low granular density (less dense than the elementary particles, but the value is higher than the average density of space). For these two reasons - low density value and distributed structure - it's difficult to assign a classical mass to photons, but they certainly carry a quantum of energy and may transfer it as mechanical impulse. All structural compact layers of photons are moving in a single direction, and this represents the global direction of travel; furthermore, the helicoidal shape of photons (a double helix - as it is shown in Figure 1, where the secondary helix is wrapped inside the blue tube) remains absolutely unchanged during propagation. Their granular layers are accurately duplicating the movement of the emitting particle during emission, and it's obvious that the amount of energy stored in a photon (and which may be transferred) depends on how these layers are distributed in time and space.

In other words, all generic photons are in fact granular concentrations of specific three-dimensional shape (helical); they have resulted from the distribution of the small electrophotons (as described in Gravity [3]) produced by a particle during its transition on various atomic energy levels or during annihilation processes. Photons provide an accurate copy, a "frozen" image of the trajectory followed by the emitting particle, containing its both precession and global movements; therefore, the granular distribution encodes all variations of mechanical energy that particle has experienced during emission.

2.1. Photons as particles

Prime Theory [1] and The Universe [2] introduced my first model of photons, assuming that these special particles have certain *physical structure* and *definite materiality*. They have a specific granular structure and travel at the maximum speed imposed by the local space. Their internal structure is *fixed* and remains practically unchanged during the uniform motion; however, some characteristics of photons may change in different mediums or in intense gravitational fields. Let be a normal photon **γ** (which contains two symmetrical parts), as shown in Figure 1, the upper picture. We may now reveal the correspondence between its physical characteristics and the magnitude of the associated quantities, in a classical approach (based on Maxwell's equations), where the generic photon will still be seen as a manifestation of the electromagnetic field.

The **velocity** of photons, **v**, is a vector quantity whose orientation corresponds to their direction of travel and whose value is normally equal to the speed of light in a vacuum, **c**. This is in fact the maximal value of the absolute speed for any material structure in our Universe, being set by the granular density of the local space. As the homogeneity of space is implicitly assumed (i.e. the lack of gravity) in addition to its perfect vacuum, all photons will have rectilinear trajectories.

The **electric field** is given by the sequence of unidirectional electrophotons (zero divergence) that are making up the body of the photon, i.e. by the variation in density of their granular layers (seen on the direction of propagation). This field is simply represented by the vector quantity **E**, whose magnitude has an averaged value that does not depend on the exact manner in which the precession movement was stored in those granular layers. The central graph from Figure 1 illustrates the approximative correspondence between the electric field intensity and the physical 3D model of the photon. A complete photon contains two halves (front and rear) and each half stores one semi-oscillation of the electric field, which means a variation in intensity from zero to a maximum and back to zero. The curvature of the emitting particle (i.e. the type of its electric charge) is not practically stored inside this spiral of electrophotons and therefore *we cannot give a certain sign* to the E-field; however, in order to keep the consistency and compatibility of this theoretical model, the first half (from the front) is considered positive and the second half is negative. Consequently, we may postulate that *there are no structural differences between the photons that are generated by particles and those generated by antiparticles* (for example by electrons and positrons). The electric field does not depend directly on the physical form of photons (a photon differs from another, even if they all have exactly the same frequency) or on their length; it actually depends on the *speed at which the granular density* **ρ** varies along the component layers (see the detail of the central graph depicted in Figure 1). We could show this direct proportionality by the following formula:

$$E(t) \sim \partial \rho \, / \, \partial t$$

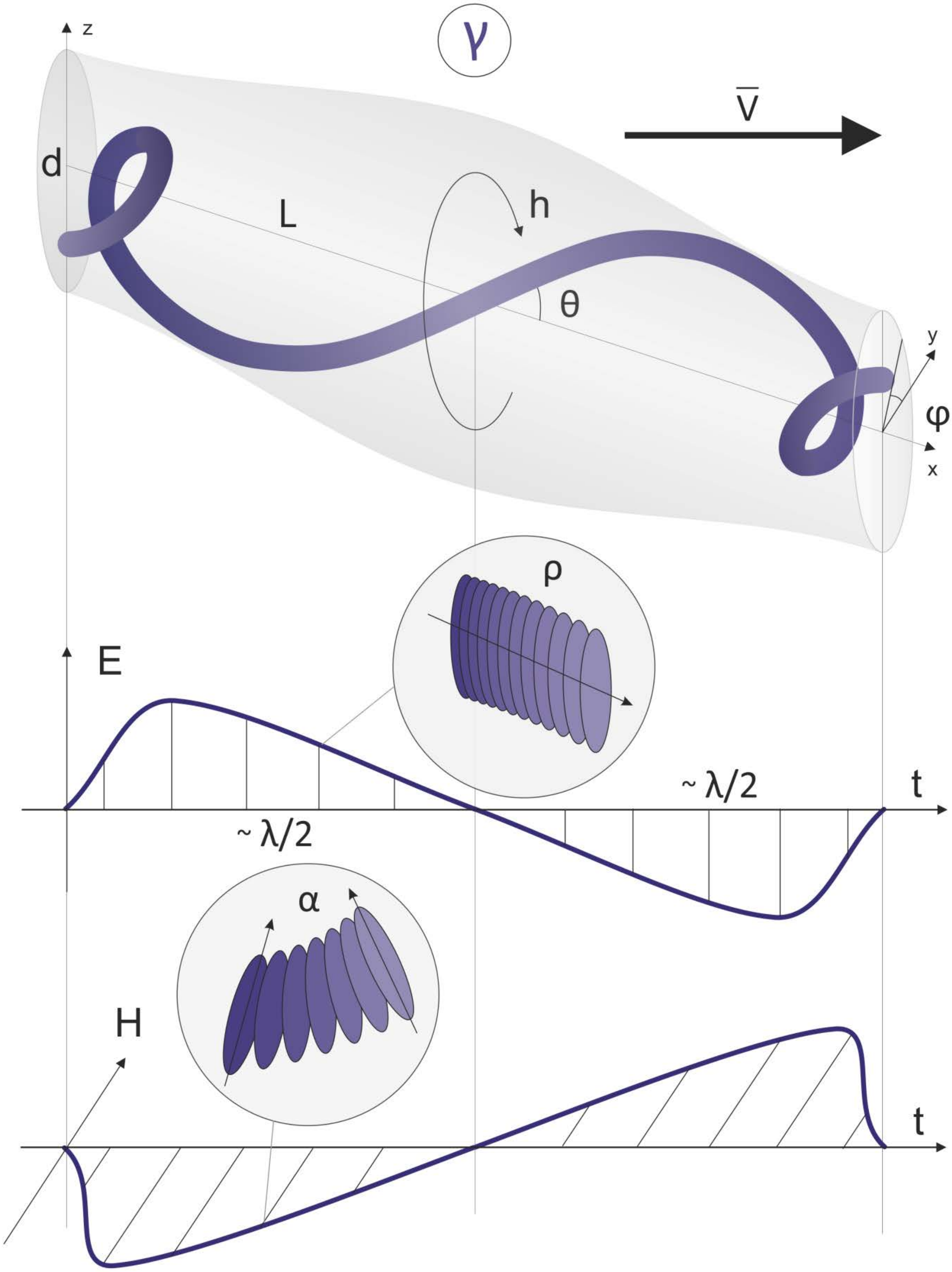

Figure 1 - *The physical shape of a photon*

The **magnetic field** is given by the variable orientation of the successive electrophotons constituting the photon's body. Each granular layer forms a certain angle with the global direction of travel, and the value of this angle changes in time (it decreases with the increase of granular density, as the granular layers accurately replicate the orientation of the particle's surface on the emission moments). As a vector quantity, the magnetic field is denoted by **H** (it can be seen in the bottom graph of Figure 1, where is a detail illustrating the variable orientation of granular layers) and its intensity is proportional to the variation of the angle:

$$H(t) \sim \partial \alpha / \partial t$$

Both E and H fields are therefore variable in time, and the only reason for this is the uniform movement in a certain direction of the whole structure of photons. Seen from the rest frame of these particles, the so-called "fields" do not vary at all; they become simple granular distributions within a larger structure - a fixed one, whose shape is not changing over time.

Going back to the physical phenomenon that has generated this photon, we may notice the strong correlation between the E and H fields during emission. Once the emitting electron accelerates, denser electrophotons will be generated and the angle of their internal layers increases (maximum 90 degrees relative to the direction of propagation); a similar phenomenon occurs when the electron slows down. The physical mechanism that lies behind the photon production leads to a simple connection between E and H, confirming all of *Maxwell's equations* - for example, the Maxwell - Faraday equation:

$$\nabla \times E = -\mu \, \partial H / \partial t$$

Seen as stationary granular formations, photons do not contain in fact electric and magnetic fields. If observed from another frame of reference (which may have a lower speed value, less than **c**), photons will dynamically display the "fields" hidden inside their sequences of granular layers. These fields now behave similarly to the usual electric and magnetic fields, as all of the photons practically preserve the original distribution of electrophotons that emerged from the emitting electron.

Moreover, we can never talk about an *independent, isolated magnetic field;* this type of field derives in fact from the electric one, which is based on the intrinsic movement of the charged particles. It represents the variation in orientation and position of all electrophotons that are coming out from a charged particle - of its electric field - which is transmitted at a distance and may exert an influence upon other electrically charged particles. Therefore, the magnetic field is only generated by the changes occurred in the electric field of charged particles - and this is the *real determinism*, the real correlation mechanism that allows photons to be created and which eventually leads to the well-known theoretical representation through those specific quantities and equations.

Remark. The actual variation of these fields (E and H) is not a perfect sinusoid, due to a presumed non-uniform variation of the particle's speed in the relativistic range; even if that particle would be uniformly accelerated, its mass does not vary linearly with speed. On the other hand, the sinusoidal-type solutions for E and H - seen together as an electromagnetic field - are just a good approximation of the physical reality, but they practically can describe very well this special particle called photon.

Photon polarization is fully determined by the physical shape and is given by the planes in which the granular oscillation manifests itself. The three-dimensional helical form of photons, as shown in the upper picture of Figure 1, expresses a *circularly polarized state.* Both E and H fields rotate along their oscillation intervals and this rotation reaches a certain angle in the end. If we consider the coordinate system XYZ (OX along an internal symmetry axis), we may identify the starting angle (to the axis OY) as an **initial phase φ** (not the one of the attached waves). There are left and right circular polarization states (depending on the clockwise rotation of the fields). This parameter of photons corresponds to the spin angular momentum - which is called **helicity** and is denoted by **h**; it characterizes the *circularly polarized photons* and its values are ± $\hbar$, expressing right-handed and respectively left-handed helicities. If the rotation angle of the E and H fields remains constant along the entire photon, there will be a single oscillation plane and this particular case will be called **linear polarization state**.

Note 1: The photon depicted in Figure 1 has *left circular polarization*, but this has to be seen in the opposite direction in case of absorption.

Note 2: The oscillations of both E and H fields were graphically represented in a single plane, identifying a linear polarization of another photon.

Note 3: There are incomplete photons, having incomplete field oscillations (whose initial and final phases are not directly given by the physical characteristics of their helical body, being stored in fact within photons' internal granular distribution).

Note 4: Photon's spin is associated with the *complete* "rotation" of the curved tube, which practically means two full oscillations of the granular density. This aspect actually quantifies the integer spin value, while the physical shape (helix's virtual direction of rotation) influences only the sign of the spin.

Photon's frequency ν (nu) is the most important parameter of the photon, a fundamental characteristic that also lies in its granular distribution. It indicates how "fast" the emitting particle has accelerated and oscillated during emission, i.e. the mechanical energy involved in this short-time process.

Photon's wavelength is also an important parameter, which is definitely connected to its physical form and to its corpuscular nature. Denoted by **λ** (lambda), it is associated to a certain space length that integrates *a full oscillation* of the electric field (or the distance between two crests). The wavelength is clearly linked with photon's frequency; if its frequency is higher (the oscillation has happened more quickly, within a shorter period), this leads to a smaller space extension of the granular structure. The two quantities are connected in this formula:

$$\mathbf{c = \nu \lambda}$$

where **c** is the speed of light in a vacuum.

Note 1: In an absolute perspective on their propagation, one of my previous articles (The size of our Universe [4]) explained why the photons coming from distant galaxies have a certain redshift (their wavelength is longer). This was caused by the speed of light, which has significantly increased over time; at a fundamental level, this increase is due to the lower granular density of space.

Note 2: The photon's shape, and hence its wavelength, are not directly depending on the medium's quantum fluctuations; these fluctuations will only lead to certain synchronization between the speed of photons and the local "absolute" (see [3]).

Note 3: The speed of photons traveling through various mediums and materials is lower than **c**, the speed of light in vacuum. This is not the consequence of some changes at granular level; it's just about a global delay of all the incoming photons, which is caused by the repetitive processes of atomic absorption and re-emission. The excited electrons are shortly re-emitting the absorbed photons, but this process takes some time - a duration that depends on their wavelengths. Therefore, the average propagation speed and the equivalent wavelength of the photons are significantly smaller in materials with a refractive index greater than 1, while their frequency (energy) remains virtually unchanged!

Note 4: Photons do not rotate during the free propagation. However, a point of their structure will apparently follow a curved path; for example, the top of the electric field vector will have a helical trajectory only if we take into consideration the uniform motion of the whole photon's body.

Mass, momentum and energy. We may consider photons as unitary bodies, although not all their component granules are adjacent. Their average granular density is greater than that of the empty space, even if some internal layers may have lower values. Therefore, a symbolic mass may be assigned to these special particles, given by the number of all their component granules (Gravity [3], Chapter 5). If we expand this concept of mass, as the ability of a body to transfer a certain momentum, a rest mass could be introduced - given by the scalar product between the symbolic mass and the value of a granular impulse. The directional mass, which means the mass a photon would show in a hypothetical interaction with larger particles, is identical to the rest mass (all of the granules have exactly the same direction of propagation).

However, the reality seems to be more complex, and we may better explain these things once we come to understand the way a photon is formed and what exactly is stored inside its granular structure. If an electrically charged particle speeds up and then slows down, many of the electrophotons it normally emits will be concentrated in a single direction. A certain amount of energy will be consumed within a certain period of time, and the exact value of energy depends on the range of particle's speeds: the initial, the maximum (let's say **c**) and the final ones. These speed values depend on the atomic orbitals of the emitting electrons, but in fact *their relativistic thresholds* are only counting. This thing automatically implies a precise *quantification* of the energy stored in photons, energy that is directly reflected by their frequency. The granular gradients in photon's structure accurately reproduce the path of the emitting particle and also its changes in speed and orientation. The photon absorption is a similar process, but it will take place in reverse order. When the electron from certain atomic orbital is hit by a photon, its precession and global movements are all changing and synchronizing due to the transfers of granular impulses. The electron's variations in speed (due to the additional energy it receives during absorption) are thus *identical* with those of the emitting particle in its potential field, between the thresholds we mentioned above. The amplitude of this oscillation is therefore almost constant, and what exactly discriminates the photon energy is the *period of this oscillation*, implicitly its frequency. It's easy to observe now the direct correlation between the physical length of photons and their wavelength, their energy in the end. As those cosmic photons have a certain redshift - i.e. an elongation, an increase in length - we can observe an apparent drop in energy, their actual frequency being lower (it is measured through absorption, at the current value of the speed of light **c**). The energy contained in photons, which was confirmed as mechanism and quantization since the first experiments on the photoelectric effect, is therefore correctly expressed by the well-known formula (**h** is the Planck's constant): $\mathbf{E = h\,\nu}$

The energy is not implicitly given by the amplitude of the magnetic and electric fields that are stored within the granular layers of photons; instead, it is directly proportional to the *rate* they varied between those two energy levels and spatial positions of the emitting particle. Quanta of energy are thus simply emitted, stored and then absorbed in all-or-nothing processes, but the reality seems to differ sometimes. As we have already seen, there are incomplete photons and also remains of photons; the absorption process, which may be shortly followed by re-emission, can also be partial. The surrounding space and the objects around us are continuously crossed by photons having a wide frequency spectrum, from Gamma and X-ray radiation to the visible one, infrared and radio waves. These photons - complete or not - are not "mixing" together, but their effects on particles may be composing in several ways; moreover, we must not forget the "noise" that is added to all these processes by the omnipresent quantum fluctuations.

Global momentum is that quantity conserved when a particle absorbs a photon. As that particle is part of an atom, which is part of a larger structure of atoms, its momentum varies and this difference will be transferred to the whole structure (while the granular layers of the absorbed photon will dissipate into the surrounding space). We have to notice the particle-like behavior of the photon, which has transferred only a discrete amount of energy during this interaction, a quantum.

The phase velocity. Both their physical structure and the conventional electromagnetic wave model of photons lead to a *sinusoidal-type* variation of the granular density and, consequently, of the associated electric field (which may be considered a plane wave). Therefore, the theoretical solutions that could satisfactorily reflect the entire evolution of these waves in time are the equations of this particular form:

$$E = E_0 \cos(\omega t - kx + \varphi_0)$$

ω - is the angular frequency (the rate of change of the phase)

φ_0 - the initial phase angle

K - the wave vector magnitude, $k = \omega/v$

v - phase velocity of the wave, the speed at which the phase propagates in space. In a normal medium, the phase of the frontal layers of photons - seen as spatial distribution, as well as the phase of the E and H fields - seen as attached waves, do not change during propagation, and therefore the phase velocity is constant, v = c.

2.2. Photons as waves

As three-dimensional structures of spiral form that uniformly propagate through space, photons are very similar to the sinusoidal mechanical waves. Regardless of the internal arrangement of their granular layers (the frozen image of the E and H fields), all photons may thus have this mechanical-like undulatory behavior. However, if two or more photon structures are overlapping at a given moment, there is no real composition of their internal fields. They will pass through each other and no interaction will occur (in accordance with their QM's boson attribute, photons can occupy the same space). Only their effects sum up in a particular manner, like the superposition of mechanical waves; given the physical similarity between the propagating photons (length, phase, frequency and wavelength) and the mechanical waves, the composition of continuous waves of photons will have similar equations and properties, varying with these parameters.

The Double-slit experiment, an old test in which photons of visible light are passing through a pair of closely spaced slits and then form an interference pattern - as some light waves originating from both slits would produce - is the simplest case showing the wave nature of light. Moreover, this type of experiment illustrates the same non-classic behavior for ordinary particles (the electrons, for example, which have an attached *de Broglie* wave); they are also interfering, following a possible path that is given as probability by their wavefunction. In accordance with a QM rule (the physicist *Max Born* has introduced it), particles will have a certain spatial probability distribution that depends on the existence of each slit and another one that results if particles are passing through both slits (pairs of slits in general)! This interference pattern would therefore be the result of the constructive or destructive composition of those waves (attached to particles and of the photons). However, which is the physical mechanism behind this superposition and self-interference that Max Born have postulated, and why the wave seems to follow all possible trajectories? And what would be the alternative explanation based on my granular model of photons?

3. The "Tree" Model

The main assumption of my model (as it was previously described in Chapter 2) is the granularity of the physical body, of the long and fixed helical structure of photons. Consequently, many characteristics of photons must be similar to those of the mechanical *waves* (manifested during propagation) and of the *particles* with mass (during their interactions with matter). These two sets of features are exclusively activated and the different behavior of photons, wave-like or particle-like, seems to depend on the particular type of experiment or measurement performed. Beyond this old quantum uncertainty, a photon must be something "real" at any moment, even when it is not observed. It's easy to presume that different interactions of photons with matter could determine some changes in their structure and their trajectories, and these changes could force a certain type of end result. Therefore, in order to include this shifting of shape and to justify the dual behavior - as part of the global QM's wave-particle dualism, my first model of photons must be completed with several inherent parameters.

3.1. Assumptions

As it was stated in Chapter 2.1., the granular density of the primary photon (which has not interacted yet with matter) has two peaks along the axial direction and these peaks are separated by a wide interval of very low density (the average density of space). Moreover, there are a few more assumptions and details we have to add to this model:

a) *The dual structure of the normal photons.*

A normal photon usually contains two distinct regions, **A** and **B**. *A* is the frontal region (on the wave's direction of propagation), followed at a certain distance by region *B* (as it was previously described in my books: Prime Theory [1] and The Universe [2], Chapter 5). This separation can be considered a hidden variable of the granular model.

Each of these two regions therefore includes a granular density maximum, and their spatial extent on the X-axis is proportional to half of the photon's wavelength (see Figure 2, where one primary photon is represented in a three-dimensional perspective as granular distribution). In the same way, each region ideally contains one complete semi-oscillation of the E and H fields (whose "sign" is not known yet).

Both regions of a complete photon have the same speed (c) and the same direction of propagation. However, in some special interactions, the two parts may separate and then move in different directions. These two components are not perfectly symmetrical to the center. With all that, the projections of these parts could generate some other general descriptions, like up/down or positive/negative (relative to a specific reference plane that includes the axial direction of photons). Considering their granular distribution, these two halves should have a different behavior during interactions. A is the *active* region; it accelerates an atomic electron and, in case of a "match", may trigger the absorption. The absorption process is completed by the *passive* region B, which can quickly push the electron into the new orbital.

b) *The real photons*

The tubular structure of a photon is not perfectly delimited in space, and its granular distribution extends in all section planes. Once an atomic electron enters this region, the capturing process starts and the electrically charged particle receives supplementary granular impulses, changing its movement in accordance with the photon's granular patterns. As in the case of the transparent materials with refractive index greater than 1, the electrons will shortly re-emit the photon (this phase delay depends on material and wavelength). This process repeats on many atoms; fragments of photons are thus superposing and this decreases the apparent wavelength of the new emitted photon and decreases its actual propagation speed in that material (phase velocity). Moreover, lots of partial "waves" will gather around the initial photon, each having a certain phase difference (a constant value for a particular material). Therefore, the photons of visible light are "multiplied" while passing through transparent materials, many of these real "clones" (granular layers that remained from the previous photons, not completely dispersed during the absorption) being added to them. Due to the phase delays, most of the clones are positioned in front of the real photons, increasing their size on both X and Y axes. As directions in space, the majority of these clones are parallel with the initial photon's direction of propagation, but we can assume a certain level of *divergence* that results from the change of momentum in some interactions.

This thing has two important implications:

(1) As a consequence of the interactions with matter, a newly born photon could immediately turn into a *real* photon - an extended granular structure that contains omnidirectional clones of the same frequency and phase (as shown in Figure 3a).

(2) This intricate structure from all around the primary photon increases in size during propagation and, at the same time, "loses" a number of clones because of dispersion (see Figure 3b). In time, the overlapping regions of the clones included in this network become smaller and smaller, and they will eventually lose contact with each other. Due to this separation process, the primary photon will be surrounded in the end only by the parallel clones (Figure 3c). The initial divergence and the final parallelism prevent all the clones coming from *a single source* to self-interfere. This configuration - a body and a chain of clones that precedes it - is probably the most common structure of photons in nature.

c) The extended functionality of the real photons

The real photon has the same energy as the primary one. Its additional clones are in fact the electrophotons remained from the previous processes of emission and absorption, granular bits that temporarily have the same direction and thus may form a "larger" photon (whose construction did not require any extra energy).

In principle, a real photon has the *same functionality* as a primary one, only its structure is bigger, with many extended "branches". The large numbers of chained clones (which are all in phase) allow the formation of such branches and give them a significant lifespan; in this way, all clones are in direct contact with the primary photon, "communicating" through this dense network of interlocked granular "tubes". For a short period of time, until a certain degree of granular dispersion is reached, *this solid structure will function as a whole (a single particle);* the size and distribution of its internal ramifications represent a new hidden variable of the model.

Under certain conditions, the frontal extension of a visible photon could reach many wavelengths in size (their physical equivalent), while its thickness could reach about one wavelength (before dispersion). If this photon moves freely again, its ramifications will only spread laterally; as all the clones have the same speed, its axial dimension will remain constant.

During the passage through specific regions, many clones will follow the contours and local geometry at the atomic level; they may create, depending on the wavelength, some special nodes - distinct sources that will emit other photon clones. These new groups of omnidirectional clones may *intersect* and *interfere* with the primary photon's group, creating different interference patterns, thickening or thinning the initial branches and producing secondary ones. Therefore, the constructive interference leads to the emergence of some *temporary branche*s (their high level of granular density makes them "solid" objects); due to the relatively long lifespan, we may definitely consider them *functional extensions* of the primary photon. These continuous extensions can serve as energy conduits; moreover, a photon may directly interact through one of them and transfer all its energy. The interaction propagates, as we already know, through the granules that exchange their elementary impulses; as many of the granules involved are already joined together, the overall speed of this "communication" process may exceed the **c** value.

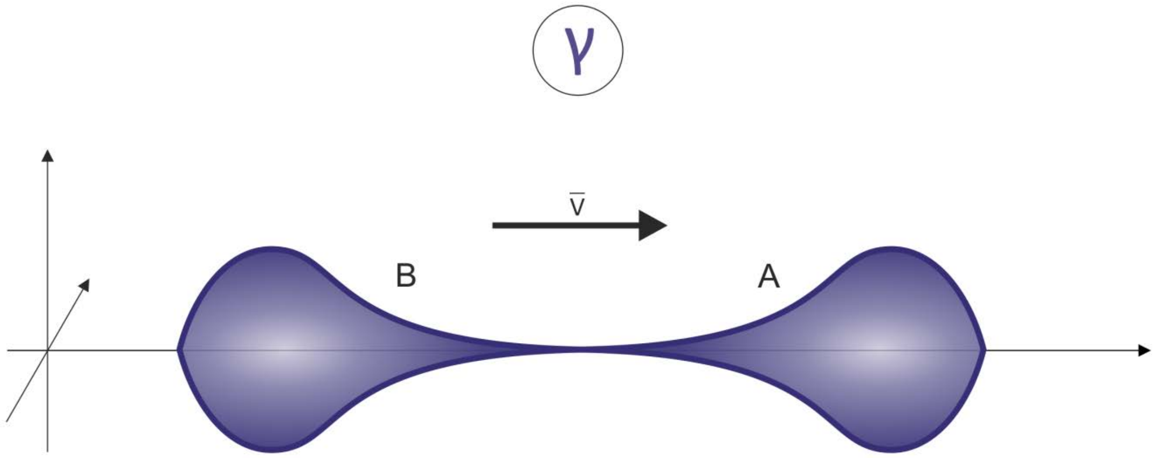

Figure 2 - *Generic representation of an ideal photon*

3.2. Explanations

There are two classic experiments made with visible light photons, both still suitable for new explanations and interpretations; they will be analyzed here from the perspective of the current quantum mechanics (and of the Pilot Wave alternative), respectively from that of granular mechanics (of the Tree Model).

a) The double-slit experiment (Young)

Richard Feynman: "The double-slit experiment has in it the heart of quantum mechanics. In reality, it contains the only mystery."

Stage 1. This simple setup is used at first, a source of monochromatic light (Laser L) and a screen S placed at some distance, as shown in Figure 4a - the upper picture. Light photons are emitted to the right and a bright spot may be seen in the exact place where they hit the screen. In this case, we could assume a certain position of each particle, somewhere on the straight line connecting the source and the bright spot (even the photons are not observed during the flight). The time and position uncertainty was not considered here.

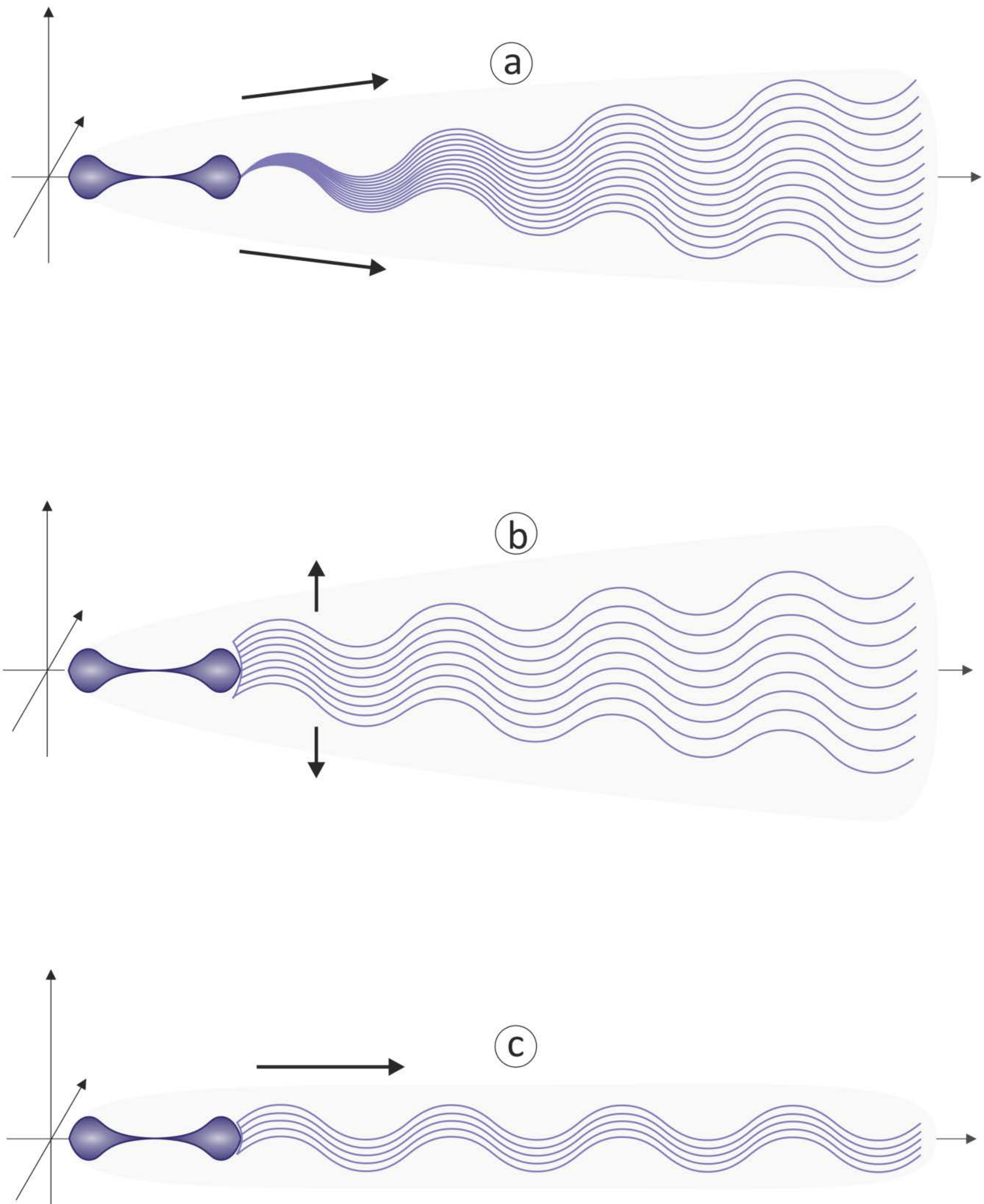

Figure 3 - *Various stages of a real photon formation*

Stage 2. An opaque board with a single slit (its width is about one wavelength) is now inserted on the trajectory of light. Things are quite similar; a bright smudge of light will appear in the same place, but the light is spread out on the horizontal direction and two faint side bands appeared due to diffraction. Apparently, neither the propagation, nor the behavior of photons were significantly affected during the passage through that narrow slit; some of the photons are deviating a little from the initial route, other ones are "going around" the obstacle and concentrate in some brighter areas on the screen (see Figure 4b).

Stage 3. The single-slit board is now replaced with another assembly that has two parallel slits, the distance between the slits being about the light's wavelength (Figure 4c). This changes all things fundamentally, the screen will show an interference pattern composed of multiple bands of light placed at certain distances - as two light waves coming from the slits would interfere. It should be noted one important aspect: when a single photon is emitted at a time, this interference pattern still appears. An obvious question arises immediately: which was the actual trajectory of each photon? A photon takes one of all the possible trajectories, following a wave that has interfered with itself? Moreover, how we may find out the exact slit a photon has passed through, *which way it has taken*?

Stage 4. In order to solve this mystery, the photon detector D is added in front of one slit (Figure 4d). Interestingly, the pattern formed on the screen disappears. Another legitimate question arises now, if the simple observation (a detector placed somewhere at the slits) sends a signal back and forces the photon to take one certain path of all the possible ones. And there are more general questions, beyond the classic dilemma *wave or particle*, all being related to some global issues such as realism, locality and causality in quantum systems with photons.

(**Quantum Mechanics**) First, what exactly are the photons - those bosons carrying the electromagnetic force - waves or particles? For now, we may assume that photons are particles; one photon is released, then it travels in straight line (Stage 1) and hits the screen. However, during the second and third stages of the experiment, light behaves differently, like a wave; it goes around obstacles and produces an interference (diffraction) pattern on the screen. As we try to find out which way a photon goes (Step 4), its particle-like nature is revealed once more. How can we explain all this? The type of measurement decides how the photons behave?

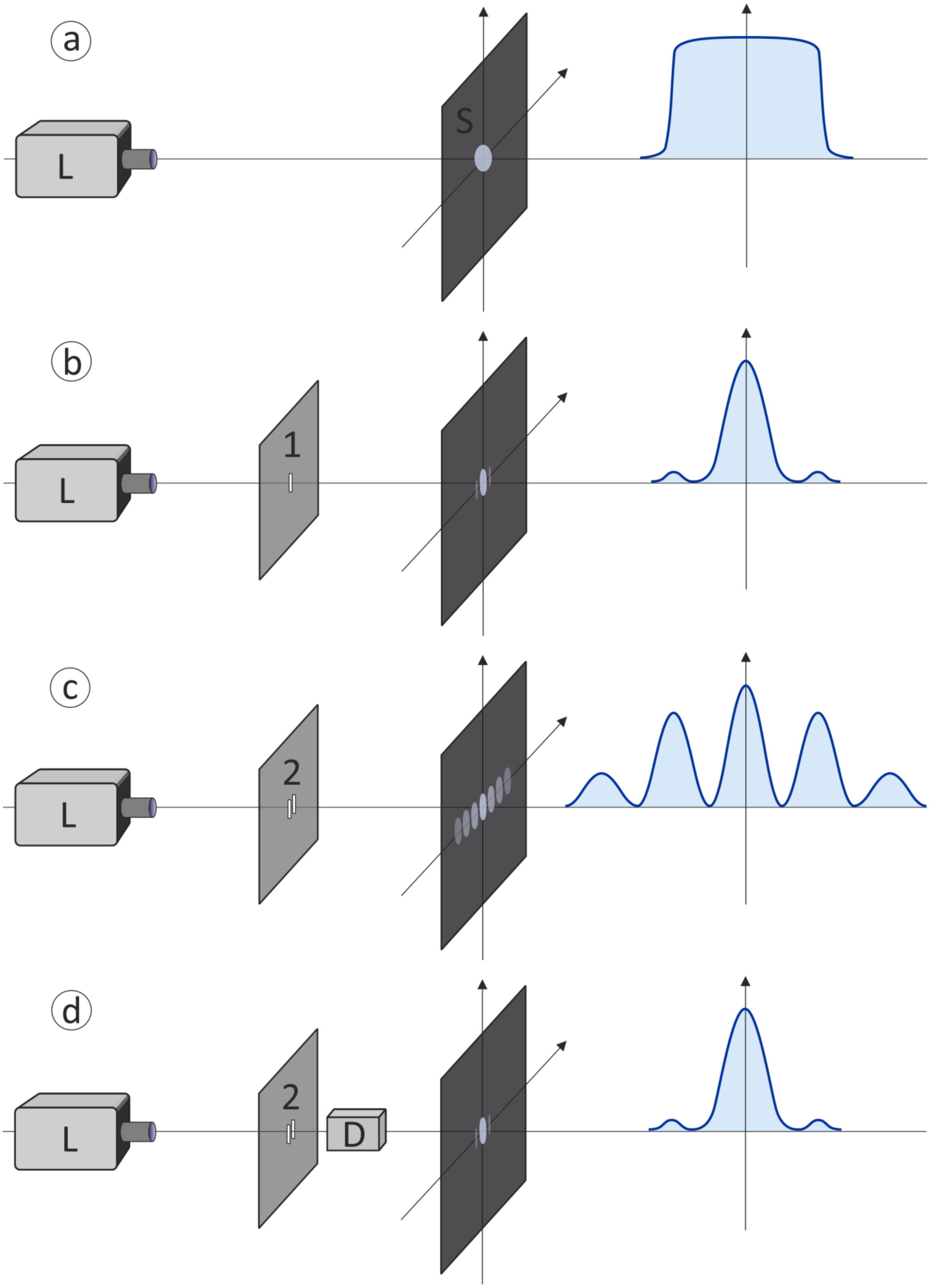

Figure 4 - *The double-slit experiment*

Taking the undulatory approach, we could simply start from the Huygens' Principle, which states that every point of a wave is a secondary source of spherical wavelets and the sum of these wavelets forms the wavefront. Different parts of the wave interfere while they take different routes toward the observer, generating interference fringe maxima and minima and proving in this way the clear wave character of the photons. Based on that, quantum mechanics has reached a much better explanation for interference, taking into account the fact that any particle - photons too - has an associated wave function. De Broglie theorized that each photon is guided by a *wavefunction*, following a path which is a random choice of one of many possible paths. In our experiment, these paths are determined by the concrete configuration and the component parts, while the wavefunction solutions will give them in the form of probabilities. As it was already mentioned, Max Born has introduced a rule telling that the probability distribution in this interference pattern results in fact from some interactions due to each slit individually and due to both of them together.

Another important principle must be enounced now: the Niels Bohr's *Principle of complementarity*, telling that the wave / particle aspects of any quantum object are mutually *exclusive* and the type of measurement actually determines which property is exposed.

This quantum experiment may be seen from a different angle. Considering a causal view of the whole process, we may find that once the uncertainty in position decreases when photons are passing through slits, their uncertainty in momentum (direction) will automatically increase - in accordance with the Heisenberg's *Uncertainty principle*.

Seemingly, all these fundamental principles and rules form a complete framework. Quantum mechanics thus offers perfect solutions, matching the experimental data. Any quantum object may be described by a wavefunction and this formalism has proved to work well. Therefore, the quantum realm seems to be profoundly probabilistic and we have certain limits in observing, probing and measuring all of its properties and parameters simultaneously.

However, something is missing here! What is hiding in fact behind the wave function? And how we may adapt the concept of wave in case of one photon, how exactly it splits in several waves and produce interference patterns? Its quantum of electromagnetic energy, the internal E and H fields are really dividing into smaller "parts"? Moreover, this randomness - which may be linked to its polymorphism - does not contain any bit of determinism? All of these questions are justified and they automatically lead us into another dimensional domain, where the real causes of the quantum phenomena must hide. The generalized probability could lie in a huge number of variable that are hidden in this subquantum realm, all having undefined values. Unfortunately, considering the uncertainty and the observational limitations we are facing, both causality and realism that would emerge from this granular level and would shape the quantum world might permanently remain beautiful theoretical speculations... Based on simple mechanical rules, the models built in this dimensional range can provide consistent and logical answers for our experiments with light; however, the objective barrier imposed by the discrete configuration of reality still cannot be avoided.

(**Granular Mechanics**) As we have already seen, a real photon has a certain granular distribution, occupying a very long cylindrical space whose diameter may be compared with one wavelength. The real photon contains, in general, a large number of primary photon's replica; we also know it behaves like a wave during propagation. When this granular entity tries to pass through a "narrow space", it automatically interacts with the peripheral atoms of the opaque material (dispersive or not). Consequently, their electrons will start to vibrate, the "rhythm" being imposed by the wave's frequency. The impulse received by the peripheral atoms will also propagate transversally as soliton and, depending on the barrier configuration, this vibration will reinforce the continuous emission of clones; moreover, some stationary waves will appear in this way. This particular complex process of synchronous vibration multiplies exponentially the number of clones, and more and more granular copies of the primary photon are re-emitted in all possible directions. We could compare this with an expansible *fluid* that spills all over the obstacle's surface; the clones with different phases continuously move and aggregate in wavelength-size groups, following the microscopic outline of the obstacle (Figure 5a). Depending on the wavelength and on the discontinuity represented by the slit, some distinct directions will quickly form; the clones moving on those directions are denser, they had a constructive interference (which means a temporary joining of the in-phase copies). Slits became in this way *clone replicators,* or *secondary sources* that multiply the incoming clones and emit copies in all directions. Groups of waves originating from these different sources may intersect and interfere on their way toward the screen, and this happens even if the primary photon did not pass yet through slits. If these thicker "branches" (which are more or less divergent) of the newly created network are still connected with the primary photon, they will become its virtual extensions, being able to directly interfere with an atomic electron. The entire photon energy - its quantum - may be transmitted through this dense granular channel (as through a solid) quasi-instantaneously (this speed was explained in Chapter 3.1, also the causality and the speed limit), and we may consider that the photon has already "hit" the screen. When the absorption process is complete, the primary photon (regardless of the position it reached) and the interacting branch will disintegrate, and all the inactive clones will eventually dissipate into space. If a continuous beam of photons is emitted, each photon will form random branches and a brighter self-interference pattern will be visible on the screen.

Due to the physical discontinuity, those slits have formed in fact two *independent sources* and their emitted waves may therefore combine and interfere (Figure 5b); some *new* channels were born in this way, new granular conduits for the photon energy. Things may be seen differently in both cases (single-slit and double-slit experiments): the primary photon has expanded and got extended functionality or it was simply multiplied by several clone sources. Anyway, it no longer makes sense to identify the exact slit a photon passed through, *which way* it followed. As its clones spread out in many directions (depending on the geometry and material characteristics), multiple granular channels were created and one of them has intermediated the action; therefore, the precise location of the primary photon at the absorption moment has no meaning at all.

If we try to observe the wave (which would imply absorption or at least new geometry for clones to follow) coming from one slit - seen as independent source, a certain granular channel will send back the "information" *this path is blocked* and that source will stop the emission on all directions (Figure 5c). The wave from the other source can no longer interfere; as in the single-slit experiment case, the interaction propagates through one of the already existing branches.

b) The delayed-choice experiment (Wheeler)

This experiment is based on the initial structure of the Mach-Zehnder interferometer, a few components being modified to prolong the trajectories of photons (in order to allow a "delayed" insertion of the second *Beam Splitter*). Figure 6 shows the simplified configuration of the apparatus and three distinct situations in which a photon seems to behave differently - as a particle when it takes a single path and as a wave when it splits and then interferes. This experiment is used in a particular manner, by choosing the type of measurement with certain delay (the presence of the secondary *beam splitter*). As the interference pattern still appears, one classical explanation would be the photon went "back in time" and "changed its character" from particle to wave... Or, a more realistic explanation would be a photon has no intrinsic properties until certain measurement is performed...

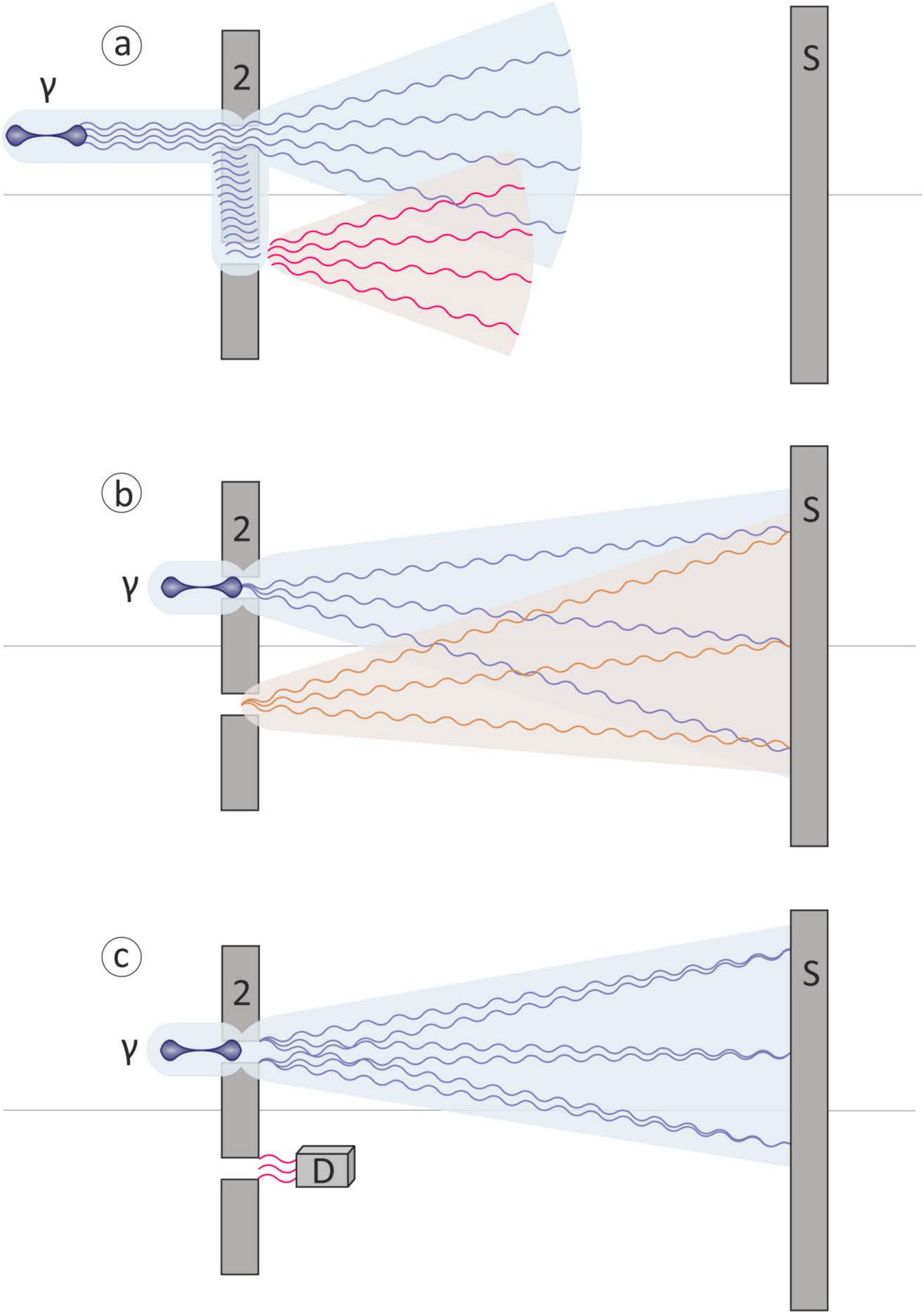

Figure 5 - *The interference patterns*

The experimental setup contains a monochromatic light source (the Laser L), two half-silvered mirrors (A and B), two normal mirrors (M1 and M2) and two photon detectors (D1 and D2). It has to be mentioned that the light source is specially configured to emit one photon at a time.

Case 1: The source L emits a photon that immediately reaches the BS A and then takes either Path 1 or Path 2, hitting one of the two detectors with 50% probability. In this first case, our photon behaved like a particle (Figure 6a).

Case 2: A visible photon behaves like a wave and goes on both ways, its wavelets interfering in BS B. The length of both paths is specially chosen to allow the constructive interference only on Path 1, and therefore that photon has a 100% probability of showing up in detector D1 (Figure 6b).

Case 3: This case is almost identical with the first one, just another beam splitter (BS B) is added; the second BS is activated at the last moment, after the photon would have already chosen one of the paths and apparently behaved as a particle. We have the same result: detector D1 will signal the presence of the photon (Figure 6c).

(**Quantum Mechanics**) Paradoxically, this simple experiment is not fully explained yet, even if we consider that the type of measurement could force the photon to act one way or the other. These results indicate retrocausality or the lack of local realism (the quantum objects would become real only upon measurement, as in Copenhagen Interpretation), both aspects being very difficult to accept.

A big step forward has been taken with the *Bohm's Interpretation* [5] of quantum mechanics, which restores the causality and the classical behavior of all particles. The *de Broglie-Bohm theory* (pilot wave) postulates that the position of any particle is defined by the wave function by a *guiding equation*. Unfortunately, the position of a certain particle depends on the positions of all the other particles in the universe, which means this theory is explicitly nonlocal and thus incompatible with special relativity. Anyway, it is perfectly capable of explaining the delayed-choice experiment.

We may consider the photon in our experiment as a particle that always has a definite position (which is a hidden variable); it also takes only one of the two possible routes, while the guiding wave goes through both paths. However, the wavefunction changes once we modify the global configuration (by adding the BS B, as in Case 3) and this happens faster than the speed of light. This interpretation, a deterministic and realistic alternative to standard quantum mechanics, provides the best results and explains very well the wave-particle duality revealed in the delayed-choice experiment.

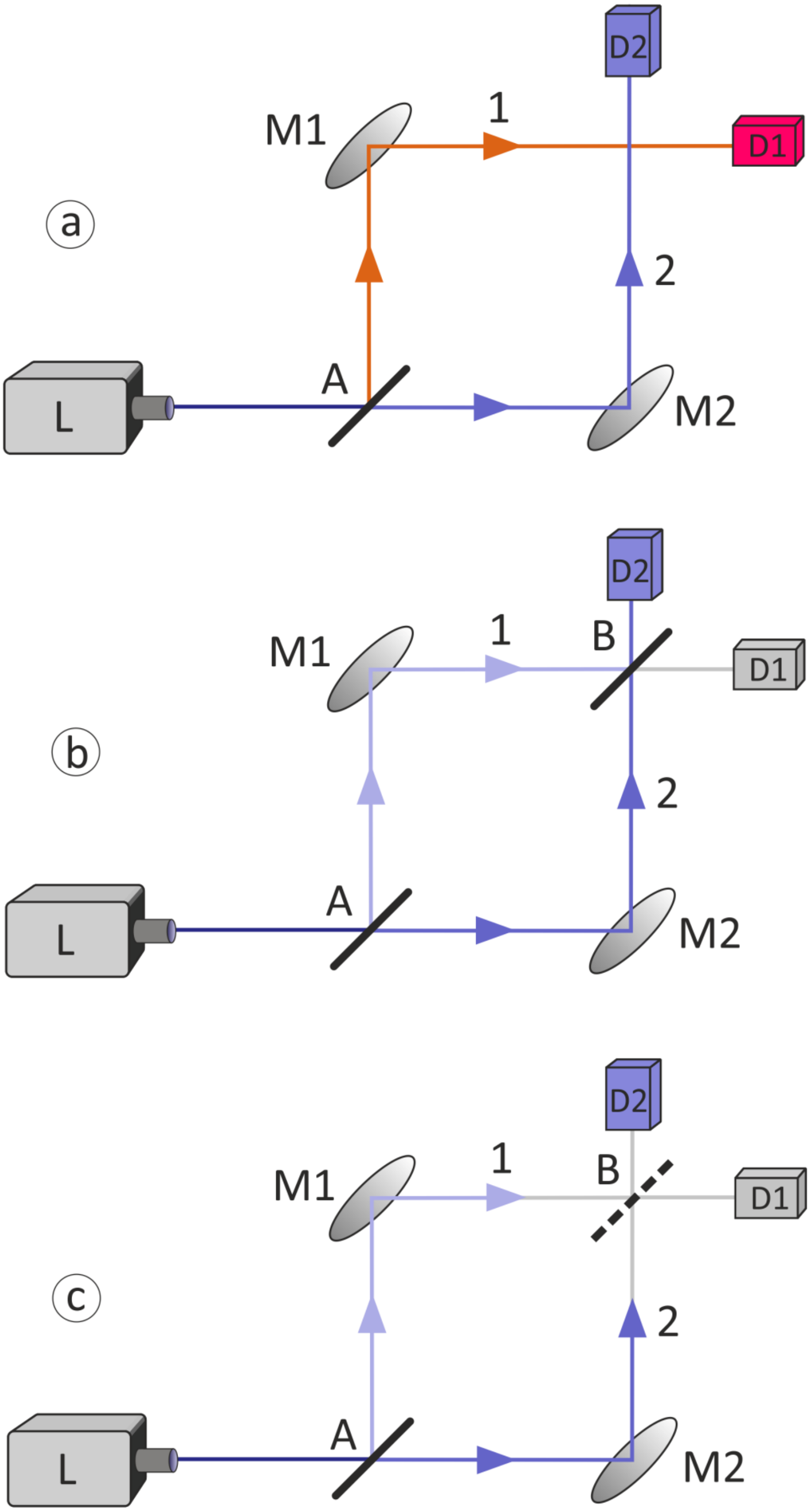

Figure 6 - *The delayed-choice experiment*

(**Granular Mechanics**) A photon is generated by the Laser L (Figure 6a) and it immediately reaches the BS A, where a lot of in-phase granular clones are emitted on both parallel and perpendicular directions. As in the previous experiment and for the same reasons, all these clones form granular waves that precede the photon (its speed decreases a little inside the splitter) and reinforce the already existing ones, extending the photon on each direction. These waves will therefore travel along both paths (the red and respectively blue rays), reflect in the mirrors and, crossing each other, will finally reach both detectors. The photon will take one of these routes, hitting one detector (probability is 50%); it seemed to show a particle-like behavior, but the primary and secondary granular waves were present all the way.

Case (b) includes another splitter, BS B; those two waves take both paths (1 and 2) and arrive at this second beam splitter, where more secondary waves will be emitted toward the detectors. They all will combine, interfering constructively only on the path to detector D2. This process creates two granular branches, a thicker (denser) one moving toward detector D2 and a thin one moving to detector D1; these branches have a long lifespan, a period long enough for the photon to arrive at BS B. Upon arrival, regardless of the route taken by photon (which now has no relevance), the interaction begins to propagate *through the thickest branch* and a certain atom of the detector D2 will be excited immediately. This detector will therefore signal 100% of the incoming photons.

The insertion (activation) of the splitter BS B is delayed in Case (c), it happens just after the photon would have passed the BS A - after it "would have chosen the path to take as particle". However, the granular waves have been already generated and they follow both ways, producing secondary waves and interfering at BS B. Obviously, the detector D2 will be activated for all of the emitted photons.

As the action of a photon is unique, we simply cannot find out which way it went; however, its interactions in various materials and the experiment type do reveal different behaviors, but in fact we are dealing with a single entity. It has a "real" configuration all the time, regardless of the path it takes.

4. Conclusion

There is a certain similarity between my model and *de Broglie-Bohm* theory ("Pilot Wave" [7]), as for the determinism, realism and the so-called "hidden variables" they both assume. However, the formalism of the *Pilot wave* should use a different description of the wavefunction and of its collapse, which must include all the changes of the actual waves traveling with a photon and the limited influence of its surroundings. The explanations for quantum nonlocality are based only on fundamental principles (already introduced by the Prime Theory [1] and The Universe [2] books), and my theoretical model above is thus fully compatible with the combined framework provided by the *Theory of relativity* and my *Theory of the absolute* ([2], Chapter 3). A lot of positive opinions are currently expressed about realism, along with some adaptations of the modern QM's formalism and with several experimental data that support it (as shown in [6]).

Defining characteristics of the Tree Model:

- Photons are granular entities with variable configurations; passing through various environments and materials, they *may extend in size by multiplication*, by adding numerous clones of the same frequency to their primary structures. These clones may interfere like the normal waves, creating denser formations on some directions - like the tree branches.
- This real photon has the *same functionality* as the primary one, only it can directly interact through one of the branches formed by the in-phase clones.
- The photon energy is transmitted via one of the *thicker branches* (randomly chosen) or via the parallel branch, if it is unique. The interaction may therefore be triggered by a frontal clone, even if the primary photon is not directly connected with the particle that absorbs it. As a final result of the interaction, that channel and the primary photon dissipate into space, as well as the remaining divergent clones.

Major implications of the Tree Model:

- The interaction of a photon with matter may actually happen before the "arrival" of its main body, and which way this part went through is no longer such an important information; however, the cause-effect relationship is not affected in any way, while *the retro-causality is not involved at all* - as we are talking about a single quantum entity!
- For the same reason, we can also talk about the *Principle of locality* when the real photons interact with matter. All divergent clones go along with the photon, but their density continuously decreases and, after a while, they can no longer form active branches; therefore, the surrounding space cannot be completely "probed" during this fixed period, and this *limits* its influence on the trajectory of photons - which are all determined *locally*.
- Photons are in fact *particles with wavy shapes,* whose spatial extent and inner structure may vary over time. The type of experiment will impose

what characteristic of photons is manifested upon measurement, but the wave/particle complementarity becomes a little artificial in the *tree model*'s context. We can therefore speak of *realism:* a photon may be observed or not, but it has a definite shape all the time.

Some of these implications may also refer to "classical" particles, such as the electrons, because they all have a wavy trajectory [1]. However, the observational uncertainty - an intrinsic feature of the quantum world - is always present; it cannot be avoided, no matter how "smart" is the experiment. There are hidden variables that cannot be measured and quantities that cannot be measured simultaneously. The quantum world has therefore some *absolute* secrets. Anyway, the exclusive wave or particle characteristic of photons has now become an observational particularity that is linked to the actual type of experiment being performed, not a real property that is changed by the measurement.

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