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PHYSICAL PRINCIPLES IN REVEALING THE WORKING MECHANISMS OF BRAIN. PART I

BY

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Abstract. This work is addressed to a wide range of scientists who approach the research of the human brain from different points of view. Our main point is that no matter of the angle of approach in the brain research, a scientist has to be aware of the physical possibility of the brain functioning. We describe this possibility by modeling the brain as light. The essential physical property of this model is then fractality. It will be physically explained for the light itself and then applied as such to the brain. The main brain functions: the memory, acquiring information, and handling this information are then to be explained as scale transient fractal phenomena. This physical model is thereby useful in guiding any research on brain, no matter of its nature.

Keywords: neuron; light ray; universe; luxon; Madelung fluid; theory of interpretation; theory of holographic memory.

1. Introduction

In order to build up a physical understanding of the way in which the brain operates, our task with the present work is twofold: first, to consider

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critically what we can carry, from the fundamental physics at large, over to the specific physics of brain; secondly, with a proper selection thus done, to explain the basic functions of the brain, *i.e*. acquiring and handling *the information* and, more importantly, *the memory*. Useless to say, these two tasks are in fact heavily entangled with each other, so that our presentation follows them only as a general guidance: at any point of discourse we shall have in mind both the physics and the world of brain on equal footing.

Up to this point in our life the physics can be categorized as the science describing what we can perceive outside ourselves, *i.e*. the material universe. Transposed over to the brain *per se* or, in fact, to the nervous system at large, this science has created that part of anatomy of the brain which defines it as structured matter: gray matter, white matter, neurons, axons, dendrites and such. But this means dead matter, for here we have to do with the matter accessible to our senses, either in a mediated way, or directly. Once we need to describe the operational brain, we have to define it *as a universe*, for there is no other possibility, physically speaking: any invasive intervention destroys the very object of our study, transforming it into dead matter. From this moment on the trouble starts brewing, once we realize that this is not a physical universe as we know it. For, in case of a physical universe, the task of describing it is a lot easier: we have pretty much at our disposal, by our senses, the structural formations of matter representing the constitutive parts of the universe – atoms, molecules, planetary system, galaxy, metagalaxy, *etc*. – together with some of their possible connections, and their space and time scales' dependence. Thus, we can physically explain the constitution of the universe as a whole made out of some parts, specific to the scale of the universe. This is not the case for the living brain: it is a universe that cannot be studied but only from outside on both the accounts of *functionality* and *connectivity*. So one of the fundamental problems of physics becomes critical here: how do we define a universe in general? What is essential in such a description, as we know it from physics that can be carried over in the description of *any* universe? We have an answer to this question, and this answer provides a criterion of definition of brain itself as a universe. This definition, in turn, provides criteria of choice of the physical principles involved in the physics of brain, and their adaptations to this physics.

As a living universe, the brain produces and handles what we know physically – and even manage routinely, from a medical point of view – as *electric* and *magnetic fields*. Indeed, from a noninvasive point of view – the only way to preserve life during research – we have at our disposal for the study of brain two main methods, generated by the electrical nature of the brain activity. The first one – the *electro-encephalography* (EEG) – exploits the electrical activity of the brain, while the second – the *magneto-encephalography* (MEG) – exploits the magnetic activity of the brain. If we do not consider the magnetic field as 'invasive', then the *magnetic resonance imaging* (MRI) and *functional magnetic resonance imaging* (fMRI) can also count as valid methods of study under ‘noninvasive’ description. The experience generated by these methods has long produced pertinent general conclusions about the universe we call brain.

We can only infer that the electric and magnetic fields are involved in both the connectivity and the physical structure of the local neural populations, synchronized, as it were, in order to form structural constitutive units in the human brain. Concepts like ‘amount of synchrony’, ‘coherence’, ‘time series’ and so on, currently used in brain research, have a precise physical meaning. There seems to be no doubt that the physics is involved here through electrodynamics. However, according to the orthodox view on this very part of physics, such an application would mean that the fields are always considered as a consequence of some motion, and the induction phenomenon is orderly in the brain. We challenge this idea in a specific way, with the hope that there is also something positive in ‘statics’ rather than only in ‘kinematics’, or even ‘dynamics’: *electro-statics* and, above all, *magneto-statics*, properly handled, are liable to show a way to solution of functionality of the brain as a whole. We relate this statics to the *concept of phase*, and then attach to it the concepts listed above, and then some others to be presented here in due time.

1.1. The Strategy of Approach

The main point to be observed from the physics we have at our disposal thus far, is then its way to construct the image of the universe around us. The light, in any and all of its instances, is the essential element of this universe, allowing the explanation of its very structure. The light gives the *connections* in the universe, the light *stores* and *transmits the information* in the universe in the form of a *memory*, the light is the *epitome of interactions* between the fundamental structures of the universe. Most of these properties have been revealed based on the idea of confinement of light, experimentally realized long ago in the form of a Wien-Lummer enclosure, which made light into a thermodynamical system (Wien and Lummer, 1895). The research of this system was able to produce the quantum physics with all its consequences. Somewhere along this path, a fundamental property of light has been discovered: *the invariance with respect to dimensions of the Wien-Lummer enclosure*. This means that the light as a thermodynamical system has some special properties which are the same in microcosmos, at the scale of the laboratory, and in the universe at large, which thus becomes simply a Wien-Lummer box of a particular dimension.

The world of brain is naturally confined in such an enclosure: *the skull*. This is our starting point with the present research, but there is an essential difference with respect to the physical case of thermodynamic light that inspired us: *there is no scale transition here*. All skulls of human population have just about the same dimensions, so that the variation in dimensions can be only of a statistical nature. The problem then becomes apparently simpler: *describe those processes that are only statistically invariant*, in order to present the connectivity of the brain from a physical point of view. Then we find that the essential statistically invariant description of light, which can be safely translated into brain is the concept of *light ray*. The theory of light itself started with this concept in the first place, but we shall show here that the physics of brain adds more to it along the idea of a fundamental physical structure.

1.2. The Fundamental Constitutive Unit of Brain

The description of living brain should start from the functionality of its fundamental anatomical unit: *the neuron*. This will be taken here as one or more *tubes*, known as *dendrites* in the anatomy of nervous system, attached to a *soma*, and this is the concept that epitomizes, in the case of brain world, what we know as a light ray in the regular universe. The problem, therefore, comes down to a proper statistical description of a light ray, and we shall concentrate on it right away, in order to be able to write down the required mathematics. This will allow us to carry over the mathematical, as well as the physical, notions into the world of brain, a world 'synchronized', as it were, not by light rays as in the regular universe, but by their correspondents – the neurons. The concepts like *memory*, *connection* between neurons, and the *structure of the electro-magnetic fields* involved in the brain physics should then come out only naturally along this line, and we shall show here that they are coming indeed.

2. The Physical Description of a Universe

Rarely, if ever, is theoretical physics concerned with the definition of coordinates: the usual consensus is that the coordinates exist, they do have the meaning we happen to assign them, and the theoretical results can be expressed in such a way that, when it comes to verification, there is always a correspondence with the reality of things described by those coordinates. It is on this state of the case that the modern global positioning on Earth came to remind us that the special relativity, with all its particular requirements, actually represents a modality of defining the coordinates physically, by a condition of equivalence between them. This condition is always tacitly assumed in the classical cases, but never explicitly stated: the space coordinates are defined first and foremost by coordinate lines, along which we need to pinpoint some values uniquely corresponding to a position in space. However, for a holistic theory of the universe – of the kind we need to consider in order to describe the living brain – such a definition of the coordinates is not enough.

First, the brain is confined to skull, and if it is that some analogy with the light, which defines the relativistic coordinate systems involved in the description of regular universe, one needs a description of radiation from thermodynamical point of view, which involves an enclosure containing it. Then we need to choose that description of the thermal radiation which proved to be invariant to the changing in dimensions of the enclosure, and imposed the modern cosmology. Historically, such an addition to the reference frame was realized in the form of Wien-Lummer enclosure for radiation studies (Wien and Lummer, 1895). This device has had a crucial role in establishing the radiation laws, and their concordance with the observed properties of the radiation at large. That concordance, in the form of Wien's displacement law, contributed in establishing the quantum theory as a natural theory of light as we know it today.

It is along this line of historical development of physics, that the theories of the light ray have been improved, until they reached the discovery of a new natural phenomenon, namely the *holography*, to be added to classical list of phenomena related to light: *reflection*, *refraction* and *diffraction*. The holography allows then a just as natural description of the concept of memory, a thesis whose main promoter was the renowned psychiatrist and neurosurgeon Karl Pribram. And the holographic theory of the brain is entirely based on the quantum theory, once it is based on the idea of a hologram (Pribram, 2007). Therefore, if we need to involve the physics in the study of brain, we need first and foremost a coordinate system adapted to the skull, as representing the enclosure of the universe called 'brain'. This enclosure is our reference frame.

2.1. The Idea of Coordinate System in a Universe

Let us start with the idea of coordinate system. In order to describe the spatial position in a certain reference frame, one always needs such a concept, usually connected to a particular geometry that offers the meaning of coordinates. This is the typical case in physics, and it even became cursory, to the point where sometimes the coordinates are only mentioned with no precaution of defining them in a way or another. The modern idea of global positioning came to impose a closer consideration of the concept of *space position* itself, in the definition of which the idea of light ray needs to be taken as a fundamental concept. As it happens, the skull correlations revealed in EEG and MEG (Pribram, 1998), seem to uncover the fact that such a concept of ray, is to be somehow connected to the neuron. We take this idea for granted based on the considerations that follow.

The best idea of definition of a system of coordinates, in our opinion, is that of Bartolomé Coll who aims at defining physically the coordinate lines, and actually builds a general natural philosophy, as it were, to be followed in such a construction in any universe (Coll, 1985). We shall apply Coll's philosophy, but only for the three-dimensional case. It is in order to make this philosophy amenable for the physics of brain, that we reproduce here three essential endnotes from the Coll's work just cited above. First comes the idea of *lines of coordinates*:

> Typically, the definition domains of such systems correspond to *world tubes* obtained by evolution of *space-like tetrahedral figures*, over whose four faces, at every instant, *light beams fall on* (Coll, 1985, Endnote [6], our emphasis).

In the present work we use 'tetrahedral figures' in Euclidean reference frames where only one of the faces of tetrahedron is to be taken into consideration. This way eight tubes will be constructed for each and every reference frame. The structure of these light beam should be, and it is indeed, as 'physical' as possible. For us it is the classical light ray, to be described in detail in due time, and completed with a physical interpretation due to Louis de Broglie (de Broglie, 1926b, c). The word 'interpretation' is taken here in the precise meaning necessary for the construction of wave mechanics (Darwin, 1927). We shall return to this in due time. Only, the de Broglie's 'wave phenomenon called material point' gets here baptized by Bartolomé Coll as 'luxon', a generic name that we adopt without reserve. Quoting:

> Here we consider light in the *geometric optics* approximation, that is to say, *as a fluid* of point like "luxons" (Coll, 1985, Endnote [7], our emphasis).

Therefore, along the world tube representing a light beam, particularly a light ray, the luxons are traveling, and the light wave is laterally limited by the tube. Louis de Broglie then defines the world tube as a *capillary tube*, with the simultaneous luxons defining a surface evolving along the tube, just as Newton did for his definition of the light ray (Newton 1952, p. 1), thereby generating the whole physics of light. Among other things it becomes possible to define a physical coordinate line with respect to this capillary tube: *it is the coordinate along the normal to the surface determined by simultaneously travelling luxons*. Quoting, again:

> … the theoretical or experimental conclusion that a specific physical field, under particular conditions, depends only on the variable *r* is void or, at least, confuse, if the nature of the coordinate line "*r* variable" is not precised (radial, cylindrical, angular or other). And, from the experimental point of view, we need to describe *the physical procedure for its construction*. It is this sense that has, for us here, the word *operational* (Coll, 1985, Endnote [4], our emphasis).

It is this meaning of the word 'operational' that we also adopt all along the present work. The dendrites and axons of a neuron will be described as de Broglie capillary tubes along whose, some luxons are circulating. Only, for the neuron, the luxons must be particularly defined, and this is the point where cosmology enters the stage. For, we shall carry out this definition in relation with the physical structure of the universe represented by the living brain, after the physical example of the universe at large. But, let us first see what the de Broglie light ray involves from a physical point of view.

2.2. The Louis de Broglie's Light Ray

Therefore, our first task here is to describe a light ray – anaxon or a dendrite – which can be imagined as a tube of trajectories defined by the motion of some material points – which, following Bartolomé Coll, we label generically as *luxons* – along it. As we said, this task has already been accomplished in physics by Louis de Broglie who, aiming at proving a certain noncontradiction between the concepts of wave and particle, has actually brought a much greater service to knowledge in general (de Broglie, 1926a-e). Let us first see the facts.

At the time when he issued the two works just cited, Louis de Broglie was engaged in proving explicitly that there is no gap between geometrical optics and quantum theory. The specific problem at that time was, in de Broglie's idea, to prove that the light can be seen as a flux of photons, and he intended to show that this image contradicts neither the optical nor the mechanical rules of thinking. The optical rules were considered all concentrated in the description of propagation of light, as described for the case of vacuum by the D'Alembert equation:

$$\Delta u = \frac{1}{c^2}\frac{\partial^2 u}{\partial t^2} \tag{2.1}$$

In this context, Louis de Broglie took notice of the fact that an *optical solution* of the Eq. (2.1) should be written in the form:

$$u(\boldsymbol{x},t) = a(\boldsymbol{x})e^{i\omega[t-\phi(\boldsymbol{x})]} \tag{2.2}$$

which must then be submitted to some space constraints, evidently mandatory in optics by the presence of screens, diopters, or some other obstacles met by light in space. Then, de Broglie was forced to consider the light as a fluid of particles, for the incarnation of which the best candidate seemed, at that moment, the idea of photon, 'floating in the air' so to speak, for at that moment of time the photon was just getting baptized (Lewis, 1926). The light ray should therefore be taken as describing a flux of fluid particles.

Now, by taking the light quanta as those material particles able to explain, from a classical point of view, the particulate structure of light, de Broglie noticed that one needs to assume a solution of Eq. (2.1), having nonetheless not only the phase, but also the amplitude time dependent:

$$u(\boldsymbol{x},t) = f(\boldsymbol{x},t)e^{i\omega[t-\phi(\boldsymbol{x})]} \tag{2.3}$$

Here ϕ is the same function as in (2.2), embodying the earlier idea of Louis de Broglie himself, that the corpuscles and their representative waves have *the same phase* (de Broglie, 1923). Why should now the amplitude be variable with time?

De Broglie gives an explanation in the English version of the work cited (de Broglie, 1926c), and this can be summarized as follows: such an elementary particle must be described by a field satisfying the Klein-Gordon equation, not the D'Alembert's (Shpilker, 1984). This defines, choosing words of de Broglie himself, «the wave phenomenon called 'material point'», and can be written as:

$$\Delta u(\boldsymbol{x},t)-\frac{1}{c^2}\frac{\partial^2 u(\boldsymbol{x},t)}{\partial t^2}=\frac{\omega^2}{c^2}u(\boldsymbol{x},t); \quad \hbar\omega \equiv m_0 c^2 \tag{2.4}$$

The last identity in this equation represents de Broglie's initial idea from 1923, *apparently* prompted by the relativistic mechanics, according to which one can associate, via energy, a frequency to a classical material point: the *de Broglie's frequency*. Now, the fundamental solution of Eq. (2.4), based on which one can build the general solution as a linear combination according to mathematical rules, is taken by de Broglie in the general form:

$$u_v(\boldsymbol{x},t)=\frac{u_v}{\sqrt{x^2+y^2+\gamma^2(z-vt)^2}}\cdot\sin\left[\omega\left(t-\frac{\beta}{c}z\right)\right] \tag{2.5}$$

with a_v a constant, $\beta \equiv v/c$ and $\gamma^2(1-\beta^2) \equiv 1$, and the direction of motion chosen as the axis z of the reference frame. No doubt, the general solution of (2.4) can be taken as being a linear combination of waves of the form (2.5), having different velocities. However, any of these should have a space-time singularity: at the event that locates the 'material point' in motion with respect to a origin of space coordinates and time, its amplitude becomes infinite. Thus, when considering the classical material point a 'wave phenomenon', if this wave phenomenon is classically located as an event, *i.e. interpreted* as a particle, the representative wave of this particle has a specific singularity at its location: its amplitude becomes infinite. In other words, by *interpretation*, the very concept of wave acquires here a differentia, for the particle itself gets new properties above and beyond its usual classical depiction as a position endowed with mass or charge: it is a *singularity of the wave amplitude, whereby this one becomes infinite*.

However, from a 'phenomenological' point of view, we might say, the things are to be presented in quite a different manner. The wave is here a light wave, and it should be the locus, in a proper geometrical sense, of an ensemble of events representing the «wave phenomena called 'material points'». The linearity of the Klein-Gordon equation allows indeed a superposition of wave phenomena represented by (2.5) *with different velocities*, but there is a problem: as all of the material points move with the speed of light, one has $\beta \to 1$, and thus $\gamma \to \infty$, for all the waves of this type. So the resultant wave, if represented by a linear combination of such ‘wave phenomena’, must have a rather *vanishing amplitude* no matter where the material points representing the light are located in space and time. Thus, while the classical trajectory of a material point is the locus of successive positions of a material point in motion, in a wave representation of ‘the phenomenon called material point’ it is simply the locus of the events where the *amplitude of the wave vanishes*, *no matter of the time sequence and space locations of these events*. Therefore, along the space line representing (continuously or not) a trajectory of the ‘wave phenomena representing a classical material point’, the phase should also be arbitrary according to this optical representation, as the amplitude vanishes.

A little digression may be in order here: the phase and the amplitude of the optical elongation (2.5), which allowed the preceding speculations, are quite particular. However, only as such particulars allowed they the very construction of the special relativity, based on D’Alembert equation (Lorentz, 1904; Lorentz, 1916). Thus, against these speculations one might raise the objection that the representation (2.5) is just as… special as the relativity is, and a general definition of the optical signal in the form $A(\boldsymbol{x},t)\cdot e^{i\phi(\boldsymbol{x},t)}$ may render them obsolete. Two things have to be considered, however, when engaging along this line of thought. First, for a general signal like the above one, satisfying any desires of generality for both amplitude and phase, we *do not* have an equation of motion: in wave-mechanical terms, such a signal *is not interpretable yet* (Darwin, 1927). It is only when such a function becomes interpretable by ensembles of free particles that it becomes useful to physics. Uncovering a general equation to be satisfied by such a general function is vital for the natural philosophy in general, for then, based on it, one can argue just how ‘special’ is the special relativity, *viz*. one can give some reasons for a general… special relativity, so to speak, ideally even to find its general formulation. As it turns out, such a function satisfies the free particle Schrödinger equation (Schleich *et al*., 2013), given some natural conditions that define what came to be known in physics as a *Madelung fluid* (Madelung, 1927). Secondly, as Dirac once has noticed in his works which inspired a certain wave-mechanical approach to the idea of magnetic charge (Dirac, 1931, 1948), a general spatial geometric locus of zero amplitude of the signal might be instrumental for the condition of quantization based on the concept of wave function satisfying a Schrödinger equation for the *free particle*. Therefore, we should not avoid such a line of thought, by any means.

However, Louis de Broglie has elaborated on another observation, in concordance with his own idea of *phase waves*. Notice the fact that if the amplitude function f is to have any mobile singularities whatsoever, we need to decide the nature of them: are they space-time singularities where the amplitude goes to infinity, or just ‘phenomenological’ singularities where the amplitude vanishes. In order to decide their nature, notice that they have to move *across the surface of constant phase*, particularly normally to this surface. In this case the nature of singularity can be directly settled *by the amplitude only*, for the speed of a material point in a position M at the time t is, according to the mathematical laws, necessarily of the form:

$$U(\boldsymbol{x},t)=\left.\frac{\partial_t f(\boldsymbol{x},t)}{\partial_n f(\boldsymbol{x},t)}\right|_{M,t} \tag{2.6}$$

Here the variable n is taken *along the very trajectory of the material point* – the symbol n is here intended to suggest the idea of 'normal' to the wave surface – and the partial derivative upon time ($\partial_t f$) as well as that along the normal direction ($\partial_n f$), are taken in the position M at the moment t.

In order to use this definition, we need a few partial results of our optical and wave-mechanical representations. Thus, substituting (2.2) and (2.3) into Eq. (2.1), and making the imaginary parts of the relations thus obtained vanish (the physical results have to be real at any rate!), one can find the following equations connecting the *optical amplitude A* and *particle amplitude f* to *phase* ϕ:

$$\frac{2}{A}\frac{\partial A}{\partial n}\equiv\frac{1}{A^2}\frac{\partial(A^2)}{\partial n}=-\frac{\Delta\phi}{\partial_n\phi} \tag{2.7}$$

and

$$c^2\left(2\frac{\partial\phi}{\partial n}\frac{\partial f}{\partial n}+f\Delta\phi\right)=-2\frac{\partial f}{\partial t} \tag{2.8}$$

Then we simply have, as de Broglie noticed, that the Eq. (2.7) will describe the diffraction phenomena *according to physical optics*, while the Eq. (2.8) will describe the diffraction phenomena *according to quantum theory*, *i.e. by an ensemble of particles*, even though with this last concept taken as a classical material point. It should be indeed all about diffraction, forasmuch as we have to deal here with a space locus of events distributed in space, and not with a classical trajectory *per se*. Therefore, this is indeed an *interpretation of the wave* in the acceptance of the definition given by Charles Galton Darwin.

However, in the French version of his work (de Broglie, 1926c), Louis de Broglie assumes that if, as one *approaches at constant time* a light particle following its trajectory, the function f varies *as the reciprocal distance to that particle*, then in the position M of the particle the *ratio between f and* ($\partial_n f$) *vanishes*. This fact obviously generalizes the one represented by the Eq. (2.5), so that it can be taken as typical for the wave mechanics. Under this condition of space behavior of the amplitude, the Eq. (2.8) gives a special expression for the light particle velocity in a certain position, and this expression befits the classical character of phase. Indeed, using the Eq. (2.6) and the Louis de

Broglie's condition of 'approaching the point at constant time' in the form: $f/(\partial_n f) \rightarrow 0$, the formula for this velocity reveals the important fact that *the phase should be a potential of velocities*, *i.e*. it should assume the very *classical role of the variable of action*:

$$U(\boldsymbol{x},t) = c^2 \left.\frac{\partial \phi}{\partial n}\right|_{M,t} \tag{2.9}$$

Thus, the only thing left for explanation in this case, would be the construction of *a physical light ray*, and this can be classically understood as a thin pencil of trajectories of classical material points. So, de Broglie came to the idea that an *infinitely thin tube confining an ensemble of trajectories of light particles* would be able to do the job. Thus, the classical Newtonian image – or to be more precise, the Hookean image – of the physical light ray takes, within de Broglie's description, a geometrically precise modern shape: *a generalized cylinder, whose area of any transversal section is variable with the position along the ray*. An image perfectly fit for another kind of ray, *viz*. the neuron, in another kind of universe, *viz*. the brain. Given, of course, a few more essential details on which we have to work, in order to realize that fit.

And so it comes that de Broglie *assimilates a physical ray with a capillary tube of variable cross-section* σ, and he describes this tube by the known physical principles of the *theory of capillarity*. Assuming, for instance, that the flux of light particles is conserved along the ray – an assumption that can, in general, be taken as the fundamental attribute of the concept of ray within the theory of fluids – the equation representing this situation:

$$\rho U \sigma = const \tag{2.10}$$

should be satisfied, where ρ means the Newtonian volume density of the particles of light. Taking the logarithmic derivative in the direction of the ray, one can find

$$\frac{1}{\rho}\frac{\partial \rho}{\partial n} + \frac{1}{U}\frac{\partial U}{\partial n} + \frac{1}{\sigma}\frac{\partial \sigma}{\partial n} = 0 \tag{2.11}$$

By a "known theorem of geometry", as de Broglie declares, one can calculate the last term here.

Now, because the physical ray is a space construction – a solid shape, as it were – it would be hard to decide *the meaning of* $\partial/\partial n$ – is it effectively variation along the ray itself, or along the normal to the wave surface as de Broglie assumes!? – but to a good approximation we can take that it means variation along the normal, to start with. It is, indeed, only in this case that we can take advantage of that 'known theorem' to which de Broglie alluded, and according to which the last term in (2.11) is the double of the mean curvature of the surface $\phi = const$ in a given position (Mazilu *et al*., 2019, Chapter 3). That quantity has as expression the sum of the principal curvatures of the surface:

$$\frac{1}{R_1}+\frac{1}{R_2}=\frac{\Delta\phi-\partial_n^2\phi}{\partial_n\phi} \tag{2.12}$$

Here $R_{1,2}$ are the radii of curvature of the principal sections of the surface. With (2.9) and (2.12), the Eq. (2.11) now takes the form

$$\frac{1}{\rho}\frac{\partial\rho}{\partial n}=-\frac{\Delta\phi}{\partial_n\phi} \tag{2.13}$$

and comparing this with (2.7), one finds

$$\rho = const \cdot A^2 \tag{2.14}$$

Thus, Louis de Broglie (de Broglie, 1966) has the essential result of interpreting the physical optics based solely on diffraction phenomena *without making any reference to the idea of harmonic oscillator* and its classical dynamics in order to calculate the intensity of light. Indeed, the Eq. (2.14) shows that the density of the light particles conceived as classical material points, localized quanta as it were, or even luxons in the expression of Bartolomé Coll, *is proportional to the intensity of the classical theory of light*. The difraction phenomena are, therefore, explained by the corpuscular theory, just as well as the interference phenomena are, provided we add to the wave mathematical image a necessary property deriving from the wave representation of classical material point: the ratio between the amplitude of the wave and the normal derivative of this amplitude, taken at constant time, vanishes in the position of the ‘wave phenomenon called material point’.

An issue is still lurking in the background though, even a fundamental gnoseological issue for that matter: was this effort of mathematics, and stretch of imagination necessary at all for our knowledge? From the point of view of the continuity of the knowledge, the answer is definitely affirmative. Indeed, making reference to the harmonic oscillator in the case of light – in order to interpret the intensity of light, for instance, to say nothing of some other physically fundamental necessities – is, by a tad stretching the meaning of word, ‘illegal’. For, as a purely dynamical system, the harmonic oscillator is a dynamical system described by forces proportional with displacements (Hooke-type elastic forces), and in the case of physical optics the second principle of dynamics is only incidental, being introduced only by a property of transcendence of the second order ordinary differential equation: it describes any type of periodic processes. And the fact is, that in the foundations of modern physical optics, the periodic processes of diffraction have more to do with the theory of statistics than with the dynamics (Fresnel, 1827).

This is, however, not to say that the harmonic oscillator is to be abandoned altogether, as a model, because it is not the case, either from experimental point of view, or theoretically. All we want to say is that we need to find its right place, and the right form of expression in the theory, and this is indicated again through the order imposed by the measure of things, this time as their mass. Indeed, dynamically, the second order differential equation aferent to second principle of dynamics, involves a finite mass. On the other hand, for light, the mass – in any of its two capacities, gravitational or inertial – is conspicuously absent, and if the second order differential equation is imposed by adding the diffraction to the phenomenology of light, this means that this equation describes actually *a transcendence between finite and infinitesimal scales of mass*. As it turns out though, a universe with constitutive rest particles having negligible mass, is just as legal as a universe having negligible charge, like the universe we live in. The brain is just such a universe with rest particles having negligible mass!

2.3. The Madelung Fluid of Luxons

There is not too much to say over what was just said in the previous §2.2, in order to catch the general idea that the physical theory of a classical light ray, as completed by Louis de Broglie, can be taken as the theory of a physical ray in general. One just needs a few further 'tweaks', as it were, in order to bring it in the position of helping in operationally defining a coordinate system, according to the ideas of Bartolomé Coll and his collaborators (Coll, 1985; Coll and Morales, 1988; Coll and Morales, 1991; Coll, 2001). Of these necessary additions, we can recognize a few right away.

First of all comes the interpretation: Louis de Broglie just showed that adding particles to the optical idea of waves, produces the optical formula according to which the density should be proportional to the square of the signal amplitude of a wave representing the 'phenomenon called material point'. Then everything comes down to the *interpretation of the wave function*, which should be part and parcel of a *general interpretation process*, and this is the moment where the idea of ensemble makes its proper entrance into argument. Like in all classical cases, the ensemble enters first by its historical element – the classical material point – just as in the quintessential physical case of classical ideal gas. It is time now that we turn the floor over to Charles Galton Darwin for a brilliant choice of the proper words characterizing the physical situation:

> It is almost impossible *to describe the result of any experiment except in terms of particles* – a scintillation, a deposit on a plate, etc. – and this language is quite *incompatible with the language of waves*,

> which is used in the solution. A necessary part of the discussion of any problem is therefore *the translation of the formal mathematical solution, which is in wave form, into terms of particles*. We *shall call this process the interpretation*, and only use the word in this technical sense [(Darwin, 1927); our Italics].

Notice, in this context, the necessity of the presence of a surface in order to support, as it were, the records of a certain experiment: “scintillation, deposit on a plate, etc.”. This calls for a second addition we have in mind in order to properly complete the theory of physical rays according to de Broglie’s philosophy, namely the concept of a *physical surface*. To Louis de Broglie this was a portion of a vave surface limited by a capillary tube, and thus the definition imposes having a limited surface area, no matter of the direction of propagation in space.

However, the definition of a physical surface does not involve just its *geometrical properties*, but should also include some *physical ones*. For instance the surface of a fluid has superficial tension, and this varies with the electric and magnetic state of the fluid. Better yet, in order to describe a holographic universe like the brain, in the acceptance of Karl Pribram for instance, one needs to insure physical properties involving the idea of memory, and this needs a special description of the physics of a surface. We shall turn to these issues in due time.

Meanwhile we just need to find what is happening if in the de Broglie’s own theory we do not use the idea of frequency like de Broglie himself used it, *i.e. through a phase linear in time*. Fact is, that any signal represented in the complex form, with an amplitude and phase depending on time and position in space in a general manner:

$$\psi(\boldsymbol{x},t) = A(\boldsymbol{x},t)\cdot e^{i\phi(\boldsymbol{x},t)} \tag{2.15}$$

is the solution of an differential equation resembling the free particle Schrödinger equation, provided some specific conditions are satisfied (Schleich *et al*., 2013). Indeed, the complex form we are talking about here assumes a *general time and space dependence* for the phase, as well as for the amplitude of the signal. Such a functional form of the phase and amplitude of the wave function is the property used by Erwin Madelung for describing the first interpretation ever – in the sense of Darwin’s definition, of course – of the wave mechanics (Madelung, 1927). The essential *a priori* condition of Madelung’s interpretation is that the density of the fluid of particles must be proportional to the square of the magnitude of the wave function. This is, therefore, an unsecured assumption in his case. As it turns out, we can give it up, with significant consequences. Indeed, if the wave function is a complex function of the form (2.15), we have *the unconditional mathematical identity* (Schleich *et al*., 2013):

$$\frac{i\dfrac{\partial\psi(\boldsymbol{x},t)}{\partial t}+\beta\cdot\nabla^2\psi(\boldsymbol{x},t)}{\psi(\boldsymbol{x},t)}=-\left(\frac{\partial\phi}{\partial t}+\beta\cdot(\nabla\phi)^2-\beta\cdot\frac{\nabla^2 A}{A}\right)+\frac{i}{2A^2}\cdot\left(\frac{\partial A^2}{\partial t}+2\beta\nabla\cdot(A^2\nabla\phi)\right)\tag{2.16}$$

where β is a constant having the physical dimensions of a rate of area (m^2/s). Then in the 'specific conditions' necessary in order that $\psi(\boldsymbol{x},t)$ be a solution of the time dependent Schrödinger equation for the free particle, to wit:

$$i\frac{\partial\psi(\boldsymbol{x},t)}{\partial t}+\beta\cdot\nabla^2\psi(\boldsymbol{x},t)=0\tag{2.17}$$

are in fact the two known equations that guarantee the vanishing of the right hand side of Eq. (2.16), so that (2.17) can take place:

$$\begin{gathered}\frac{\partial\phi(\boldsymbol{x},t)}{\partial t}+\beta\cdot[\nabla\phi(\boldsymbol{x},t)]^2-\beta\cdot\frac{\nabla^2A(\boldsymbol{x},t)}{A(\boldsymbol{x},t)}=0\\ \frac{\partial A^2(\boldsymbol{x},t)}{\partial t}+2\beta\nabla\cdot[A^2\nabla\phi(\boldsymbol{x},t)]=0\end{gathered}\tag{2.18}$$

The first of these equations is the equivalent of classical Hamilton-Jacobi equation. The second one, is a continuity equation for the cases where the square of the amplitude of function $\psi(\boldsymbol{x},t)$ can be taken as a density. Obviously, according to Louis de Broglie's theory just presented above, the classical light rayis one of such cases, if it is conceived as a *flux of luxons* – to use our agreed terminology – in a thin capillary tube, and if the *moving phase surface* in this capillary tube is the *locus of vanishing of the ratio between the amplitude of the wave and its normal derivative*.

Now, an interesting turn of the tide in physics comes with these conclusions. Usually, de Broglie's doctrine is connected with the objective correlation between particle and wave. On the other hand, the Schrödinger doctrine is usually connected with the subjective correlation, according to which the wave describes the probability of presence of a particle in a place from the universe. And here we are now, with the conclusion of a necessary logical completion of the definition of classical light ray, enforced, as it were, by the phenomenology. This completion asks for a precise connection between the amplitude of the objective signal representing the light, and the density of the fluid of classical particles helping in the physical interpretation of light by a light ray. To wit, according to Louis de Broglie, the density of the fluid streaking along the light ray *must be* proportional with the square of the amplitude. Then notice that the de Broglie's original conclusion is pending on the admission of the fact that *the phase of signal is linear in time*. This is a consequence of adding the diffraction phenomenon to the classical Newtonian phenomenology of light, based on just reflection and refraction phenomena. Now, if we give up this condition, which comes down to *assuming free particles for interpretation* and, consequently, a functionally arbitrary phase as in Eq. (2.15), the signal representing the light ray *must satisfy the Schrödinger equation* (2.17).

Here, however, we have to pay a price: *the classical potential* suggested by the the first equation from (2.18) taken as a Hamilton-Jacobi equation for the phase of function $\psi(\mathbf{x},t)$, is only *defined* by the amplitude of this function, through equation

$$V(\boldsymbol{x},t) \equiv -\beta \cdot \frac{\nabla^2 A(\boldsymbol{x},t)}{A(\boldsymbol{x},t)} \tag{2.19}$$

This can be taken as a stationary Schrödinger equation, but *it is not a consequence of the nonstationary Schrödinger equation*, at least not exclusively, as in the original Schrödinger theory. In other words the nonstationary Eq. (2.17) is a mathematical tool of unquestionable existence and necessity – just like any other mathematical concept used by physics – *as long as the wave function is complex*. The problems arise with the Eq. (2.19), and they concern only the mathematical structure of the functions representing the amplitude and the phase of the wave function *already* satisfying the Schrödinger equation. These should tell us what is a free material particle from the point of view of wave mechanics. When it comes to considering the potential, the phase of wave function cannot be identified with the classical action quite unconditionally: this last one must satisfy the above constraints. Only in this instance can one have the freedom of using the potential in a two-way reasoning: either as a given function and then helping to find the amplitude – as it is currently used, almost exclusively, in physics – or, once the amplitude known, it helps to construct the potential.

In this last stance the theory of Louis de Broglie adds the *phenomenon of holography* to the phenomenology of light. It is just as it was, historically speaking, the case of Augustin Fresnel, who added the phenomenon of difraction of light to the classical phenomenology based only on reflection and refraction phenomena. Indeed, if the light transports information, the Eq. (2.19) shows that this is embodied in its amplitude, which then can be reproduced anywhere in the univers where the light ray goes. It is reproduced in the form of a potential to be calculated from the amplitude, which describes a physical system, like in the original case of Schrödinger (Schrödinger, 1933). Then all of a sudden, the words of Charles Galton Darwin acquire a deeper meaning than the existence of a surface on which the information is to be deposited: *this information should be deposited not as a photogram, but as a hologram*! In other words, the hologram is part and parcel of the light phenomenon, just like reflection, refraction and diffraction: we are not to forget it when describing the light; but mostly we are not to forget it when we use the light as a model, especially as a model of brain. To put it straight, Karl Pribram was right: the memory of brain is a hologram… if the neuron can be modeled as a light ray!

Thus, we can say that the Eq. (2.17) is indeed a universal instrument of our knowledge, once it ensues mathematically from a necessary complex form of the wave function. Therefore, the Schrödinger nonstationary equation for the free particles should be considered as essential, once it involves no. However, classically, these particles may not be free, as the first of the Eqs. (2.18) shows. In the very process of interpretation we need to provide the means of assembling them into physical structures. These are then described by the Eq. (2.19), giving the potential in terms of the amplitude of wave. Inasmuch as the potential shows classically where the forces responsible for these structures are to be found, the universe thus described is holographic. Consequently, if the function $\psi(\mathbf{x},t)$ represents itself an *ensemble of free particles* as required for a proper physical interpretation, these are free particles *not from classical point of view, but from the Schrödinger equation point of view*: classically they can be anything along the line of physical freedom. Like the luxons of Bartolomé Coll!

The main point of this image of interpretation is the shape of the capillary tube representing the light ray: it needs not be a straight cylinder, as de Broglie himself thought of it, but a *canal surface*, in general of variable cross section will suffice. A classical example may come in handy here, for it made history in building a conception: *the classical hydrogen atom*, to which, actually, the original Schrödinger theory is referring. Assuming space extension of the electron, this one describes a virtual de Broglie ray around the nucleus: a toroidal ray as it were. The electron can then be interpreted as an ensemble of luxons held together by 'forces' of the de Broglie type, describing the behavior of the classical amplitude. It is these forces, then, that are responsible for the cohesion of the electron. Some similar forces should then be responsible for the cohesion of the proton in the hydrogen atom.

The classical argument of interpretation of the wave function brought out by Erwin Madelung, assumes the classical objective existence of a potential (Madelung, 1927). As a result the potential appears as 'updated' by interpretation, with a term like (2.19), representing what Madelung calls the 'quantum contribution'. In this guise, the theory herebegs for a kind of generalization of the modern principle of asymptotic freedom: *in a region of pure quantum forces the wave function describes an ensemble of free particles*. For, indeed, the stationary Schrödinger Eq. (2.17) shows that the continuum described by the function (2.15), as interpreted by a swarm of free particles in the manner proposed by Madelung and enforced by de Broglie, appears as an ensemble of particles evolving under a purely quantal potential: *the whole potential*, not just part of it, is in fact a ‘quantum contribution’, as Madelung defines it. By its amplitude, the wave carries a memory that can be reproduced as a physical structure in any point of space. Thus, the description of the continuum by the function (2.15) is a purely undulatory description of a region of space-time. Its interior however, is a swarm of free classical particles – the Coll’s luxons – described by an equation of continuity for a density proportional to the square of the modulus of function (2.15). Each one of these classical particles has a momentum given by the gradient of phase of (2.15). However, a question still stands: *what this very region represents*? The answer to this question cannot be given classically, for the classical argument has already been exhausted. But Louis de Broglie taught us that it involves *the frequency, the surface concepts,* and with these the *concept of hologram,* on which we have to further elaborate in due time.

2.4. First Characterization of Direction Along the Ray

We are now in position to state that this interpretation is related to the SL(2,R)-type algebraical structures, which will be revealed in its details further in the present work. Both the classical mechanics and the general relativity contain a clear possibility of such an interpretation, for the case of the so called free fall in a gravitational field. It thus becomes obvious that we need to put this interpretation under the concepts related to the nonstationary Schrödinger equation for the free particle, insofar as this equation is a fundamental mathematical instrument.

Fact is that the nonstationary Schrödinger equation for the free particle admits, besides the clasical Galilei group proper, an extra set of symmetries (Niederer, 1972) that, in general conditions, can be taken in a form involving *just one space dimension and time,* described as a SL(2,R) type group action in two variables with three parameters (de Alfaro *et al*., 1976). Limiting the general conditions, the space variable can be chosen as *the radial coordinate in a free fall*, as in the case of Galilei kinematics, which can also be extended *as such* in general relativity, for instance in the case of free fall in a Schwarzschild field (Herrero and Morales, 1999; Herrero and Morales, 2010). The essentials of the argument of Alicia Herrero’s and Juan Antonio Morales’ work just cited, are delineated based on the fact that the radial motion in a Minkowski spacetime should be a conformal Killing field, which is a three-parameter realization of the SL(2,R) algebra in time and the radial coordinate. This is a Riemannian manifold of the Bianchi type VIII (or even type IX, forcing the concepts a little) when taking the stand of one of the epoch-making, and widespread, nomenclatures of the theory of general relativity (Bianchi, 2001). The bottom line here is that, as long as the general relativity is involved, the nonstationary Schrödinger equation must be taken to *describe the cosmological continuity of* *matter*. And since, as a universal instrument of knowledge, this Schrödinger equation is referring to free particles, we need to show what kind of freedom is this in classical terms. These classical terms are regulated by a Riemannian SL(2,R) type structure.

In order to show this, it is best to start with the finite equations of the specific action of SL(2,R) group, and build gradually upon these (Mazilu and Porumbreanu, 2018), in order to discover the connotations we are seeking for. Working in two variables (t, x) representing the time and the space variable respectively, the finite equations of this group are given by the transformations:

$$t \to \frac{\alpha t+\beta}{\gamma t+\delta}, \quad x \to \frac{x}{\gamma t+\delta} \tag{2.20}$$

This transformation is, indeed, a realization of the SL(2,R) action in two variables (t,x), with three essential parameters (one of the four constants α, β, γ and δ is superfluous here). Every vector in the tangent space SL(2,R) is a linear combination of the three fundamental vectors, the infinitesimal action generators:

$$\boldsymbol{X}_1 = \frac{\partial}{\partial t}, \quad \boldsymbol{X}_2 = t\frac{\partial}{\partial t} + \frac{x}{2}\frac{\partial}{\partial x}, \quad \boldsymbol{X}_3 = t^2\frac{\partial}{\partial t} + tx\frac{\partial}{\partial x} \tag{2.21}$$

These satisfy the *basic structure equations*:

$$[\boldsymbol{X}_1, \boldsymbol{X}_2] = \boldsymbol{X}_1, \quad [\boldsymbol{X}_2, \boldsymbol{X}_3] = \boldsymbol{X}_3, \quad [\boldsymbol{X}_3, \boldsymbol{X}_1] = -2\boldsymbol{X}_2 \tag{2.22}$$

which we take as standard commutation relations for this type of algebraic structure, all along the present work. The exponential group has an invariant function, which can be obtained as the solution of a partial differential equation:

$$(c\boldsymbol{X}_1 + 2b\boldsymbol{X}_2 + a\boldsymbol{X}_3) f(t,x) = 0$$

which, in view of (2.21), means

$$(at^2 + 2bt + c)\frac{\partial f(t,x)}{\partial t} + (at+b)x\frac{\partial f(t,x)}{\partial x} = 0 \tag{2.23}$$

The general solution of this equation is a function of the arbitrary values of the ratio:

$$\frac{x^2}{at^2 + 2bt + c} \tag{2.24}$$

which represents the different paths of transitivity of the action described by operators from Eq. (2.21).

In order to draw some proper conclusions from these mathematical facts, let us go back to the transformation (2.20) and consider it from the point of view of classical physics. The first principle of dynamics offers a special content to the classical time in its capacity of a sequence: it is causally and deterministically represented by the uniform motion of a free classical material particle. Such a particle is free as long as no forces act upon it. The Eq. (2.24) faithfully records this idea in an obvious form: the paths of transitivity of the group (2.20) are given by the 'radial motion', as it were, of a free classical material point, no question about that, for the quadratic polynomial in time represents a uniform motion in an arbitrary direction in space. Questions rise, however, and on multiple levels at that, when noticing that the general solution of Eq. (2.23) is an *arbitrary function* of the ratio (2.24). For once, we are compelled to notice that the *content of time* in (2.20) is not classical anymore, at least not in general, being a ratio of coordinates representing *two uniform motions*. Likewise, the second Eq. (2.20) can be taken as representing the *content of spatial coordinate* of the motion in terms of the classical coordinate of a uniform motion: as long as the some forces act, the space coordinate along the direction of action is not linear anymore, but its ratio to a linear motion can be taken as a coordinate. This much, at least, can be put in the common charge of the *wave mechanics* and *general relativity*, regarding an 'updating' of the idea of time and space contents for the necessities of constructing a proper light ray. But there is more to it, regarding the concept of freedom, because at this point we start to notice some apparently unrelated facts from the past, which seem to pick up concrete shapes, all converging to the ratio from Eq. (2.24).

First along this line, comes the second of Kepler laws, *viz*. that law serving to Newton as a means to introduce the idea of a center of force: if, with respect to such a material point, a motion proceeds according to the second Kepler law, then the field of force should be Newtonian. The wave mechanics shows that this law means more than it was intended for initially, namely that it should have a statistical meaning, according to the idea of Planck's quantization (Mazilu and Porumbreanu, 2018). Indeed, if x denotes the distance of the moving material point from the center of force, we have

$$x^2 d\theta = \dot{a} \cdot dt \quad \therefore \quad x^2 = \dot{a} \cdot \frac{dt}{d\theta} \tag{2.25}$$

where θ is the central angle of the position vector of the moving material point with respect to the center of force, and the letter a with an overdot means the 'rate of area'. In this form the law usually serves as a transformation in the mathematical treatment the central motion, defining a new time that can be identified physically as the eccentric anomaly θ. However, from the point of view of the physical content of time, the second equality in Eq. (2.25) tells us much more, if we take the argument out of the mathematical context of the classical Kepler problem.

To wit, consider again the mentioned classical hydrogen atom: an *extended body* revolving in a central field of Newtonian forces. It can be imagined as a swarm of classical material points, and such a swarm illustrates the classical laws, provided it is considered as a swarm of free material points in the classical sense of the word (Larmor, 1900). The model fits perfectly for the luxons of Bartolomé Coll, and is therefore prone to a generalisation for the physical unit of charge and mass. Then, in the first of Eqs. (2.20) this requirement would mean that the material points are considered *simultaneously*. Each material point can be located in the swarm by four homogeneous coordinates ($\alpha,\beta,\gamma,\delta$), or three nonhomogeneous coordinates, if the Eqs. (2.20) represent the content of time and radial coordinate for the space region covered by this body. The *simultaneity* condition of the free material points of swarm can be differentially characterized, giving a Riccati equation in pure differentials:

$$d\frac{\alpha t+\beta}{\gamma t+\delta}=0 \quad \therefore \quad dt=\omega^1 t^2+\omega^2 t+\omega^3 \tag{2.26}$$

Thus, for the description of the *extended body in motion as a succession of states of an ensemble of simultaneous material points*, or luxons, as it were, it suffices to have three differential forms, representing a coframe of the SL(2,R) algebra:

$$\omega^1=\frac{\alpha d\gamma-\gamma d\alpha}{\alpha\delta-\beta\gamma}, \qquad \omega^3=\frac{\beta d\delta-\delta d\beta}{\alpha\delta-\beta\gamma}$$
$$\omega^2=\frac{\alpha d\delta-\delta d\alpha+\beta d\gamma-\gamma d\beta}{\alpha\delta-\beta\gamma} \tag{2.27}$$

That this coframe refers to such an algebra, can be checked by direct calculation of the Maurer-Cartan equations which are characteristic:

$$d\wedge\omega^1-\omega^1\wedge\omega^2=0, \qquad d\wedge\omega^3-\omega^2\wedge\omega^3=0$$
$$d\wedge\omega^2+2(\omega^3\wedge\omega^1)=0 \tag{2.28}$$

Élie Cartan has shown that under these conditions one can prove that the right hand side of Eq. (2.26) is an exact differential (Cartan, 1951), therefore it should always have an integral. The Cartan-Killing metric of this coframe is given by the quadratic form $(\omega^2/2)^2 - \omega^1\omega^3$, so that a state of an extended orbiting body in the Kepler motion, can be organized as a metric phase space, a

Riemannian three-dimensional space at that. The geodesics of this Riemannian space, are given by some conservation laws of equations

$$\omega^1 = a^1 \cdot d\theta, \quad \omega^2 = 2a^2 \cdot d\theta, \quad \omega^3 = a^3 \cdot d\theta \tag{2.29}$$

where $a^{1,2,3}$ are constants and θ is the affine parameter of the geodesics, so that, along these geodesics the differential Eq. (2.26) is an ordinary differential equation of Riccati type:

$$\frac{dt}{d\theta} = a^1 t^2 + 2a^2 t + a^3 \tag{2.30}$$

This equation can be identified with (2.25), provided its right hand side is proportional to the square of a 'radial coordinate' of a free classical material point. Mathematically this requires an ensemble generated by a *harmonic mapping* between the positions in space and the material points, with the square of the 'radial' coordinate x measuring the variance of the distribution which describes the spreading of material points in space.

2.5. Necessities of Improvement for Adaptation

In order to be able to adapt a physical theory into describing the living brain, a few necessities of general improvement are in order, on which we need to work specifically. First, the basic idea is that we have to construct a coordinate system for the matter of brain, and this should be quite specific. However, it should be based on the general idea of light ray, as always was the case in physics. Only, the concept of light ray has to be improved itself, in order to account for the whole host of properties naturally invested in it, to which it answered only sporadically thus far. For, only having the whole set of properties at our disposal, shall we be able to chose those among them adequate in the description of the brain. As a matter of fact, this was the gist of history, and we have to follow it faithfully: the properties of the light ray have been discovered sporadically along the history, for timely necessities of explanation of the world around us. Rounding the concept with all its differentiae just gives us the chance to properly choose those appropriate from among them.

The pinnacle of the concept of light ray, seems to be the concept that we connected here with the name of Louis de Broglie. This concept of light ray harmoniously updates the classical concept due to Newton, up and above the classical update due to Fresnel. Happily enough, it turns out that the model responds to the classical concept of duality wave-particle, and also contains the Schrödinger theory under a remarkable condition: *the light ray thus described must possess the property of holography*. If it is to reveal here a historical continuity, one can say that while the classical concept of Newtonian light ray has been defined based on the classical phenomena of *reflection* and *refraction*, it needed to be completed, and Fresnel did it by introducing a new phenomenon: the *diffraction* of light. This, as it turns out, is not a systematic completion, inasmuch as the de Broglie's light ray reveals another phenomenon to be added to our experience: the *holography*.

Now, in order to use this concept of light ray for the world of brain, in which case the skull is the only global reference frame we can physically recognize right away, we need to develop, first and foremost, the statistical side of the theory of light ray. And this we shall start to do right away. As it turns out, the whole theory issues naturally from the requirement of de Broglie that the amplitude of the wave *at a certain time* goes inversely with the distance to the wave surface along its normal.

3. Phase Related to Signal Recording in a Universe

The physical description of a living brain involves almost exclusively recorded signal at locations on the skull. Now, a recorded signal can always be thought of as representing a wave function, independently of the idea of interpretation, as it were, *i.e*. independently of the fact that it is a solution of Schrödinger equation or not. However, in order to have a meaning for this signal we still need to treat the recording as a complex function of the form $Ae^{i\phi}$. Then, a meaning could be extracted from the data, if this complex function is taken to represent a harmonic oscillator in a given space point $\boldsymbol{x}$. In this case both the amplitude A and the phase ϕ are to be considered as arbitrary continuous functions of a *time sequence*, and this interpretation is expected to reduce such arbitrariness. The principle to be applied is just as simple as this: experimental practice always asks for a certain analysis of signal in the time domain, allowing us to assign physical properties to the magnitudes extracted from the recording. As it turns out, the statistical properties of these magnitudes have, indeed, remarkable statistical properties.

Start with the observation that a classically mandatory parameter in this analysis is *the frequency*, which can be extracted in a variety of ways from the data. The most common kind of frequency to be extracted from a recorded continuous signal is the *instantaneous frequency* (Mandel, 1974). This kind of frequency can be calculated as the first time derivative of the phase of signal function: it coincides with the regular frequency only in the classical cases where the phase is linear in time, like that considered by Louis de Broglie in his construction of the light ray, as shown before. Now, denote by $q(t) \equiv A(t)e^{i\phi(t)}$ the signal function in this instance, *i.e*. as a local – at an arbitrary location in space –'elongation' representing the recorded signal. We want to associate this signal with a mechanical oscillator in order to have an acceptable physical interpretation of the parameters extracted from the data, especially of the phase as a function of time. This association comes down to the following equivalences, representing connections between amplitude and phase as functions of time at a certain position:

$$\ddot{q}(t)+2\lambda\dot{q}(t)+\omega_0^2 q(t)=0 \quad \therefore \quad \begin{array}{c} \dfrac{\ddot{A}}{A}+2\lambda\dfrac{\dot{A}}{A}+\omega_0^2=\dot{\phi}^2 \\ \dfrac{\dot{A}}{A}+\dfrac{\ddot{\phi}}{\dot{\phi}}+\lambda=0 \end{array} \tag{3.1}$$

from which, denoting by {*,*} the *Schwarzian derivative* of the first symbol in curly brackets with respect to the second one (Needham, 2001), we have:

$$\omega_0^2-\lambda^2=\dot{\phi}^2+\frac{1}{2}\{\phi,t\} \tag{3.2}$$

According to the procedures of time-frequency analysis of the signals (Cohen, 1995), the Schwarzian derivative of the phase, appearing in the right hand side of this equation, is bound to represent some statistical properties of the frequency thus defined. Specifically, as we shall document later on here, we are naturally led to think of the *variance* of signal frequency thus defined. This means that, the signal having a well defined instantaneous frequency *as an exact mechanical frequency* of a damped harmonic oscillator, should have $\{\phi, t\} = 0$. This would mean

$$\phi(t)=\frac{\alpha t+\beta}{\gamma t+\delta} \quad \therefore \quad \dot{\phi}(t)=\frac{\alpha\delta-\beta\gamma}{(\gamma t+\delta)^2} \tag{3.3}$$

Therefore the most general signal having *mechanically well defined parameters* should be of the form

$$q(t)=(at+b)e^{-\lambda t}\exp\left(i\frac{\alpha t+\beta}{\gamma t+\delta}\right) \tag{3.4}$$

Now, for a proper choice of the arbitrary constants of integration *a* and *b*, the Eq. (3.4) is, in fact, a special connection between the group variables exhibited earlier in this work. But let us recount the results here, in order to better realize what we have acquired thus far.

3.1. Statistics in Defining a Harmonic Oscillator

Notice an apparent 'contradiction' above: according to Eq. (3.2) the instantaneous frequency of a mechanically well defined signal must be a constant in time, which is not the case with the phase and frequency from Eq. (3.3). In fact, the vanishing of the Schwarzian of phase means a mechanically defined instantaneous frequency, indeed, but *at any time* along the signal. The Eq. (3.2) should be read as it was conceived to start with, and then there is not any real contradiction: it defines *the mechanical parameters* ω_0 and λ from *the recorded data*. Taken as such it only shows that it is impossible to solve this task in a one-to-one way. The best we can do is to find the quadratic expression from the right hand side of the Eq. (3.2) as a function of time, using the instantaneous frequency defined in Eq. (3.3). The two mechanical parameters are thus defined up to an arbitrary hyperbolic rotation. However, we drew attention to this possible issue, inasmuch as the usual physical point of view is that *there is always a local harmonic oscillator* as part of the structure we are studying, whose parameters ω_0 and λ are known. This *a priori* philosophy is always a source of possible contradictions. It is our opinion that the data must be treated more realistically, and hence needs a necessary settling of the physical concepts themselves, before even starting to use one theory or another.

A first incentive along this path, is the fact that the phase itself is defined up to a homographic transformation, in view of the invariance of Schwarzian to this specific transformation (Needham, 2001). That is to say, the condition $\{\phi, t\} = 0$ describes a class of functions ϕ, which can be obtained from one another through linear fractional transformations. The 'contradiction' above can then be clarified by the curvature properties of the Schwarzian [see (Flanders, 1970); see also (Duval and Ovsienko, 2000), for a modern treatment of the problem]. Maintaining the mathematical guise here, we can simply declare the obvious: the recorded signal is revealed with the aid of a local clock, which should be a periodic motion, or a known periodic process in general, and the definition (3.3) should be read in reverse actually. To wit, it provides the times recorded by the clock of known frequency, rather than the frequency when the time is known, according to equation:

$$\xi(t) \equiv \frac{\sqrt{\alpha\delta - \beta\gamma}}{\sqrt{\dot{\phi}(t)}} \tag{3.5}$$

This gives a specific Schwarzian curvature in the form:

$$\frac{\ddot{\xi}(t)}{\xi(t)} = -\frac{1}{2}\sqrt{\alpha\delta - \beta\gamma}\,\{\phi, t\} \tag{3.6}$$

which vanishes only when the time is so chosen that the phase is homographic in time. However, the property represented by Eq. (3.6) is a general property independent of the functional form of the function $\phi(t)$ and its role in the physical theory. More to the point, given *any* such function, not just a homographic one, the function defined by $\xi(t) = C\cdot[(d/dt)\phi(t)]^{-1/2}$, satisfies the second order differential equation

$$\frac{\ddot{\xi}(t)}{\xi(t)} = -\frac{1}{2}C\{\phi,t\}$$

involving the Schwarzian derivative. In other words, for continuous well-behaving functions, this second order differential equation actually represents a connection between the two kinds of derivatives used in any calculational process in which they happen to be involved. If, then, the frequency of the local oscillator is known, the phase must depend on time in a specific way. We shall return to this issue later on.

Taken face value, however, the physical theory of harmonic oscillator reveals one of the most interesting properties of the energy. It is related to the conservation law that describes this physical quantity, from which an observation noticed and exploited especially by Louis de Broglie ensues. Namely, the equation of motion of the damped harmonic oscillator, used in (3.1) for extracting the physical properties of the oscillator from our signal, is able to tell us exactly which one of the two parameters concerns a statistics related to the time sequence only. This characterization can be easily obtained for the harmonic oscillator, due to the fact that the two kinds of mechanical energy involved in the physical description of this simple system – kinetical and potential – are well defined. As strange as it might seem at a first sight, this is quite a rare situation in physics in general, and it can be positively used in the manner that follows.

The physics knows here about the well-established result that the equation of motion of the *undamped* harmonic oscillator is a direct consequence of the property of stationarity of the *time average of the difference between the kinetic and potential energies* – the Lagrangian – over the whole period of the motion. Indeed, the action between two moments of time, from which we extract the equation of motion of the oscillator, is the time integral of the Lagrangian between the two time moments. Assuming, then, that the *physical time is a uniformly distributed statistical variable*, the physical action can be, indeed, construed as the time average of the difference between kinetic and potential energies, as de Broglie once noticed (de Broglie, 1961; de Broglie 1962). Therefore, one can say that the undamped harmonic oscillator *is a system which distributes the two kinds of interaction mechanical energies* – kinetic and potential – in such a way that the average of their difference over any time sequence included in the period of motion, is stationary.

Before going any further, let us stop for a moment, in order to pinpoint an important idea already mentioned quite a few times in different junctures of our discussion in this work. Namely, the concept of time here deviates significantly from the regular time concept of classical dynamics, by assuming a differentia which brings it closer to the *time of special relativity*. Let us emphasize once again that, if we need to describe a general concept of time, then we have to assume that this concept must have *two* differentiae: that revealed first in the classical case, related to the property of continuity of motion, and the one associated mainly with the special relativity in describing an electrodynamical universe, whereby the time is a parameter of *global ordering of events*. It is in this last instance that the time is defined by the idea of sequence, which is a special case of an ensemble of time moments. As the Feynman's development of quantum electrodynamics shows, such an ensemble may not even be necessarily a *causal sequence* in the classical sense. All it needs is only to remain *deterministic* from the physical point of view (Feynman, 1949).

Now, continuing on with our discussion of the time statistics related to the Lagrangian of harmonic oscillator, not quite the same mathematical argument can be applied in obtaining the classical equation of motion of a *damped* harmonic oscillator [the left hand side of the Eq. (3.1), for instance]. This one does not involve in its physical structure *a direct, uncontrolled transition*, as it were, between the kinetic and potential energies, as reflected in the time average of the Lagrangian. However, the physics underlying the case can still be saved by the *very same statistical argument*, for the statistics involved in defining the action that provides the equation of motion is essentially the same from a general theoretical point of view. Only its type changes, however in a precise manner: *by the character of its basic distribution density*. Indeed, the common observation of a physical nature here, is that the equation of motion of the damped harmonic oscillator can be obtained by making stationary the action related to the Lagrangian:

$$L(q,\dot{q},t)=\frac{1}{2}(M\dot{q}^2-Kq^2)e^{2\lambda t};\quad \omega_0^2\equiv\frac{K}{M},\quad \lambda\equiv\frac{R}{M} \tag{3.7}$$

The first term in paranthesis here is the *kinetic energy* of the particle of mass *M*, while the second one is the *potential energy* of the elastic force acting on it. *R* is the damping coefficient, assuming that the damping is proportional to velocity. Then, according to its definition, the action corresponding to this Lagrangian, is given by an integral like

$$S_R(t_0,t_1)=\frac{1}{2}\int_{t_0}^{t_1}(M\dot{q}^2-Kq^2)e^{2\lambda t}\,dt \tag{3.8}$$

The variational problem associated with this action leads to a *Caldirola-Kanai Hamiltonian*, if it is to judge from a purely physical point of view (Caldirola, 1941; Caldirola, 1983; Kanai, 1948). This Hamiltonian turns out to be no more the sum between kinetic and potential energies as they appear in the Lagrangian from Eq. (3.7). The participation of physical parameters to time variation is the main thing to be noticed here: depending on the sign of damping coefficient, the inertial mass increases while the elastic stiffness decreases, or the other way around. Therefore, there is still an interdependence between the terms of the Lagrangian, but with *the notable participation of the physical parameters of the oscillator*. The Hamiltonian may not even be a conserved energy, as in the case of undamped harmonic oscillator. However, the physics embodied in Eq. (3.8) can be, as we said, saved by statistics, for the action integral can still be construed as a time average of the difference between the two well-defined mechanical energies, but on this occasion for different probabilistic measure of the time domain.

Indeed the exponential factor from the integrand of (3.8) can be interpreted as an *exponential distribution density describing the ensemble of time sequences* inside the time interval between the moments t_0 and t_1. In the case of undamped harmonic oscillator, the action is $A_0(t_0,t_1)$ – the index 0 of the action is referring to the value of the damping coefficient – and the exponential factor is 1. This particular action can be, indeed, interpreted as a mean over a *uniform distribution* of times in a sequence, as stated before. The difference between the two cases – zero and nonzero damping coefficient – rests only upon the exponential factor in expression of the action integral, which, from a statistical point of view, *is thus not an attribute of the oscillator per se, but of the time domain*, in its stance as a measured sequence. One can say that an evolution for the damped harmonic oscillator means an ensemble of events characterized by sequences of *equally probable times* in a certain time interval, just like in the undamped case. However, the 'equally probable' attribute in a time sequence is now defined not by a uniform probability distribution, as in the case of undamped oscillator, but by *an exponential distribution proper*.

In this context, the Eq. (3.2) has a precise statistical meaning, as we anounced before. Indeed, if we write it in the form

$$\omega_0^2 = \lambda^2 + \dot{\phi}^2 + \frac{1}{2}\{\phi, t\} \tag{3.9}$$

then the statistical character of the frequency of undamped harmonic oscillator becomes apparent. At least in the case of the phase like that from Eq. (3.3), the undamped frequency can be regarded as a standard deviation of a *quadratic variance distribution function* of the type involved in the statistics that led to the initial Planck quantization [see (Morris, 1982) for the statistical theoretical concept]. One can therefore say that the instantaneous frequency of a recorded signal is indeed connected to a statistic of the time sequences revealed with a local harmonic oscillator with time-variable physical parameters in the sense of Caldirola-Kanai Hamiltonian theory.

3.2. The Necessity of Space and Time Scale

Thus, at least for the case of damped harmonic oscillator, the physical character of time is, first and foremost, plainly a statistical property. This property is the one that allowed Richard Feynman the construction of his sum over paths, to begin with. It explains why Feynman has placed so much physical emphasis upon harmonic oscillator. In hindsight, this emphasis cannot be explained but only by taking into consideration the results of Berry and Klein regarding the forces of Newtonian type (Berry and Klein, 1984). According to these results, the presence of oscillators at a certain space scale is indicative of the existence of Newtonian forces – the only scale invariant forces in a physical system existing on different space scales. In order to better illustrate the issue at hand, we extract a couple of phrases from the Abstract – giving the customary short presentation of this kind of works – of the Feynman's 1942 famous dissertation. This excerpt contains an observation explaining the importance that the approach of the wave mechanics initiated in that work, bestows upon harmonic oscillator:

> As a special problem, because of its application to electrodynamics, and because the results serve as a confirmation of the proposed generalization, *the interaction of two systems through the agency of an intermediate harmonic oscillator is discussed in detail*. It is shown that in quantum mechanics, just as in classical mechanics, *under certain circumstances the oscillator can be completely eliminated*, its place being taken by a *direct, but, in general, not instantaneous, interaction* between the two systems [(Brown, 2005); *our Italics*].

There is not too much to say over these words, in order to see in them the future results of Berry and Klein, indeed: the oscillator is present in any conservative Hamiltonian approach whereby the time is specially defined under condition of invariance of Newtonian forces. Involving in its physical structure parameters from 'two worlds', as it were – the far away part of the universe and the closest of its part – the oscillator is the best suited physical structure for describing the interaction between two systems. More importantly though, as we shall see here, this is the property that allows us to turn the special relativity into a universal theory, which thus can stay at the foundations of that special mathematics associated with the scale relativity physics.

It is in order to make this statistical property of time into a physical property, that we need to exhibit the physical reasons for changing the time sequence statistics. This too, will help in a proper understanding of the explanation of the physical parameters of harmonic oscillator, inasmuch as the change of the time statistics seems to be, at least to a certain extent, intrinsic to the *physical properties* of the harmonic oscillator. Indeed, considering the oscillator only, the Caldirola-Kanai Hamiltonian corresponding to the Lagrangian from Eq. (3.7) indicates, as we mentioned above, the variability with time of the physical parameters reflecting interactions with the *remote* and, respectively, *close* environment of the particle representing the oscillator as a physical structure: the *inertial mass* and the *elastic stiffness*. The case from Eq. (3.8) is only a particular one among those which led to the *classical idea of gauging*. Before anything should be said here, let us present a first instance of that classical idea of gauging, and its relation which the ideas of *interpretation* and *memory*.

3.3. A First Gauging and a Definition of the Memory

The equation of motion from the left hand side of (3.1) cannot be obtained quite directly from the variational principle applied to action (3.8), even after adjusting the statistics of time sequences to a genuinely exponential one: one still needs some definite conditions at the ends of the time interval. The first of these conditions, and the most important among them, is that the trajectories of motion must all end in the same position at the time ends, *i.e*. all pass through the same end points, spatially speaking:

$$\delta q\big|_{t_0} = \delta q\big|_{t_1} = 0 \tag{3.10}$$

Further on, the idea of *cycle* connected to the concept of harmonic oscillator, triggers the condition that the evolution starts and ends at the same point:

$$q(t_0) = q(t_1) \tag{3.11}$$

Moreover, if the situation is described in the phase plane of the harmonic oscillator, we need a condition like this for the velocities too. It is therefore a matter of problem setting, to decide which specific conditions we need to take at the ends of time interval, in order to apply them over the variational principle, in order to define it properly. However, conditions like (3.10) and (3.11), involving the ends of the time interval, or some variations thereof, are essential in any formulation of that principle. When we consider them, the Lagrangian proves not to be unique from the point of view of the variational principle: it is defined up to an additive function which represents an exact time derivative, and takes the same values at the ends of time interval. In order to show this, it is better to reason on a general Lagrangian, explicitly dependent on time, like in Eq. (3.7), but in a more general manner, and then, based on this treatment, to evaluate our case specific case given by Eq. (3.7).

Let us therefore apply the variational principle in order to obtain the equation of motion for a Lagrangian of the functional form $L(q,dq/dt,t)$. The physical action is given as the definite integral:

$$S_R(t_0,t_1)=\frac{1}{2}\int_{t_0}^{t_1}L(q,\dot{q},t)\,dt$$

The principle of stationary action – the Hamilton principle – shows that for the real motion, the variation of this action, taken into consideration the conditions (3.10) must vanish. Thereby equations of motion are obtained, as Euler-Lagrange equations corresponding to the given Lagrangian.

Notice, however, that in order to get the Euler-Lagrange equation we need the assumption that the Lagrangian has equal values at the end times of the motion, otherwise a redundant term would remain in the variation, which would allow in no condition to extract those equations. As a consequence, in the very same working conditions we can add to the Lagrangian any function of time just as well, provided it has equal values at the ends of time interval: our equations of motion do not change. In other words, within our working conditions, the Lagrangian is defined up to an additive function of time, which is the time derivative of a function having equal values at the ends of the time interval, but otherwise arbitrary.

This is the basis of a well-known, and very instructive, classical *gauging procedure*. However we read it here a little bit differently, having in mind the idea of time sequence as discussed above: *we can reduce the Lagrangian to a perfect square, by gauging it in the manner just described*, and this reduction has a significant meaning. The procedure is well known and largely exploited in the control theory (Zelikin, 2000), so that we can shorten the story. The cycling condition (3.11) now enters the play. All one needs is to add to the Lagrangian from Eq. (3.7) the term representing an exact derivative:

$$\frac{1}{2}\frac{d}{dt}(w(t)\cdot e^{2\lambda t}\cdot q^2)$$

where $w(t)$ is a continuous function of time, and then ask that the final Lagrangian should be *a perfect square*. In view of condition (3.11), the final equations of motion do not change. Now, the new Lagrangian of the gauged harmonic oscillator, proves to be a *perfect square*, just like the classical kinetic energy that generated idea in the first place:

$$L(q,\dot{q},t)=\frac{1}{2}M\cdot e^{2\lambda t}\cdot(\dot{q}+\frac{w}{M}q)^2 \tag{3.12}$$

provided $w(t)$ satisfies the following Riccati equation:

$$\dot{w}=\frac{1}{M}w^2-2\frac{R}{M}w+K \tag{3.13}$$

Obviously, under this condition, the Lagrangian (3.12) leads to the same equation of motion as Lagrangian from Eq. (3.7), if we use the condition (3.13) in the results of the corresponding variational problem. However, as we just said, the Lagrangian (3.12) has the property of the classical prototype of the Lagrangians – *the kinetic energy of a free particle* – of being a perfect square. It describes a 'free particle' with its *mass exponentially variable* in time and the *velocity redefined appropriately*.

What is the reason of this reading? Again, the point here is to *physically interpret* – with the interpretation defined in the sense of Charles Galton Darwin – a simple system like the harmonic oscillator. This task usually entails some allegedly fundamental interactions in its physical structure, in order to carry the interpretation over to an ensemble. Naturally, first we need *the constitutive element of this interpretative ensemble*, which is the harmonic oscillator. However, this comes with strings attached, in the form the interactions involved in the explanation of its parameters. The *mass is here inertial* and physics assigns to it an interaction involving the *remote part of the universe*. The elastic stiffness is of a *deformational nature*, and the physics associates with it the *close part of the universe* representing a static environment, like any deformation ever, since Robert Hooke. The damping term would then represent a *transition* between the physical properties of the oscillator induced by the two parts of the universe. According to our previous analysis, this property is delegated to the *statistical properties of the time sequences*, which is quite natural, inasmuch as the oscillator properties are induced by the universe, and the time sequences in a universe are cosmologically decided.

It is according to this view, that the problem of interpretation needs to be solved, and the Lagrangian from Eq. (3.12) provides such a solution: it allows us to identify the harmonic oscillator with a free particle. The velocity of this particle is $dq/dt+(w/M)q$, depending linearly on the solutions of Riccati Eq. (3.13). Then, it is this last equation that needs a sound interpretation, which turns out to be statistical: $\dot{w}$ is the variance function of an exponential family of distributions having quadratic *variance function*, for which w is the *mean* (Morris, 1982). The probability distributions of this ensemble vary in time, but now the time itself represents a parameter indexing the family of probability densities, in much the same manner the temperature marks an ensemble of molecules in thermal equilibrium. Mention should be made that even an undamped oscillator can be nontrivially made this way into a free particle. But there is more to it, mostly along the idea of holography.

3.4. The Holographic Time

As we have shown in Chapter 2 here, the holography must be a natural property of the world we live in, just like the reflection, refraction and diffraction of light. Actually this is the spirit of the initial work of Dennis Gabor that started the idea of holography (Gabor, 1948). It was precisely directed to the poor description of the phenomenon of difraction, more to the point, to its inappropriate connection with the other two phenomena relating to the general classical wave theory: reflection and refraction. To wit, the operation of electronic devices is obviously based on diffraction. These devices admit, through their objectives, a certain amount of improvement for the image that goes through them. Optimizing the images means reducing in aberation, and in most of the cases this becomes an impossible task: there is an inherent limit of technological possibilities. Dennis Gabor noticed, however, that this approach is unnecessary. Quoting:

> The new microscopic principle described below offers a way around this difficulty, as it allows one to dispense altogether with electron objectives. Micrographs are obtained in a two-step process, by electronic analysis, followed by optical synthesis, as in Sir Lawrence Bragg's 'X-ray microscope'. But while the 'X-ray microscope' is applicable only in very special cases, where the phases are known beforehand, the new principle provides a complete record of amplitudes *and* phases in one diagram, and is applicable to a general class of objects (Gabor, 1948).

A few more words are necessary in order to properly understand this excerpt. Notice first that in the association wave-particle here, the electrons of the electronic microscope device are supposed to correspond to electromagnetic waves of X-ray type, for which the difraction pattern is connected with the *presence* of matter – atoms, specifically – in periodic crystals (Gabor, 1949). Remember that in the case of light, such diffraction patterns are obtained when passing the light through pinholes – *i.e*. to the *absence* of matter – and the question is raised: *what is the connection between the two physical situations*? For, in view of the wave-corpuscle duality, the two situations must be the same from a conceptual point of view.

Now, Gabor took notice of the fact that the X-ray diffraction pattern for crystals can be explained by the change in phase in the reflected radiation waves, due to the interaction with the electromagnetic structure of the lattice atoms. Therefore, such a pattern can be explained by the presence of matter, which is certainly not the case for a pinhole. Here the case is, obviously, quite contrary: the matter should count as absent. Naturally, if the de Broglie duality is universal, then there should be a universal property of the wave, to reproduce the properties of matter even when this one is absent. Dennis Gabor assumed, and even proved experimentally, that the general case occurs, indeed, when we have a "complete record of amplitudes *and* phases in one diagram", a condition missing for the particular arrays of atom in a crystal. In this last case it is only the amplitude of the signal that counts experimentally and, as Gabor himself observes, the emphasis is "somewhat unlucky". Quoting:

> It is customary to explain this by saying that the diffraction diagrams *contain information on the intensities only, but not on the phases*. The formulation is somewhat unlucky, as it suggests at once that *since the phases are unobservables*, this state of affairs must be accepted. In fact, not only that part of the phase which is unobservable drops out of *conventional diffraction patterns*, but also *the part which corresponds to geometrical and optical properties of the object*, and which in principle could be *determined by comparison with a standard reference wave*. It was this consideration which led me finally to the new method [(Gabor, 1949), our emphasis].

The fact that phases contain no information in issues related to interpretation, was the hallmark of theoretical physics until the work of Yakir Aharonov and David Bohm, which stirred up the idea of connection between *potential* and *phase* in wave-mechanical problems (Aharonov and Bohm, 1959). In view of our presentation here, one should be entitled to say that the Gabor's principle is actually a proof, *avant la lettre* as it were, of the Aharonov-Bohm effect. As a matter of fact, a kind of general type of Aharonov-Bohm effect, according to which, given a right theoretical approach…

> One might therefore expect wave-optical phenomena to arise which are due to the *presence of a magnetic field* but not due to the *magnetic field itself*, *i.e.* which arise whilst the rays are in field-free regions only [(Ehrenberg and Siday, 1949); our Italics]

has been voiced, partly based to Gabor's own previous work, just about the time when he introduced the idea of holography. We shall pursue here, in a genuine manner, is true, that difference mentioned by Ehrenberg and Siday, between the *presence* of charge and the *action* of the field it creates, which was the mark of Maxwellian electrodynamics from its very beginning.

For the rest, we need to notice that the Gabor's target is 'the conventional diffraction pattern', which is incomplete from the point of view of duality wave-corpuscle. The apparent proposal is that the phase should be observable in a hologram, which is just as natural as the diffraction phenomenon itself. The degree of generality of the holographic principle has been noticed by its author from the very beginning:

> *The new principle can be applied in all cases where the coherent monochromatic radiation of sufficient intensity is available to produce a divergent diffraction pattern, with a relatively strong coherent background*. While the application to electron microscopy promises the direct resolution of structures which are outside the range of ordinary electron microscopes, probably the most interesting feature of the new method for light-optical applications is the possibility of recording in one

> photograph the data of three-dimensional objects. In the reconstruction, one plane after the other can be focused as if the object were in position, though the disturbing effect of the parts of the object outside the sharply focused plane is stronger in coherent light than in incoherent illumination. *But it is very likely that in light optics, where beam splitters are available, methods can be found for providing the coherent background which will allow better separation of object planes, and more effective elimination of the effects of the 'twin wave' than simple arrangements which have been investigated* [(Gabor, 1949), our emphasis].

The last italicized part was the main object of technological development in the last times. However, the universality of this principle begs the question: what is the relevant property of waves that makes it work in the world at large? The answer was provided a long time ago by Hugh Christopher Longuet-Higgins, as a property of ensembles of damped harmonic oscillators, involving the Eq. (3.12) in a particular take (Longuet-Higgins, 1968). However, in order to properly understand such an answer we need, in fact, a proper view on the idea of scale invariance in the universe (Mazilu *et al*., 2019).

We stop here for the moment being. The previous elaboration reproduces the gist of a statistics involving the transition between kinetic and potential energies as illustrated by the case of harmonic oscillator. As it turns out, this is an old problem involved in the very dynamics of the harmonic oscillator, which was the first physical system to raise doubts on the issue of sufficiency related to the definition of the absolute temperature. Thus, it further turns out that the Planck's quantization is by and large not the only lesson we need to learn from this moment of our knowledge. Most importantly, we should say, is the fact that *we need to account for the very structure of the constitutive element of the ensemble serving for interpretation*, as defined for the necessities of the wave mechanics. However, before going any further along this line, it should be worth settling an important idea for the future development.

4. Conclusions

In this first part of the work we propose here, a few tasks of selection and adjusting the physical models necessary in explaining the physics of brain are accomplished. The general reason and, as such, the principle of selection is that of interpretation, that led to modern quantum physics. The neurons are thus to be modeled as light rays, but the physical light rays need to be understood and explained themselves in a proper way. As it turns out, this way includes the holography as a natural phenomenon connected to light. We describe it theoretically by Schrödinger equation, and thereby we get the suggestion of how the brain can be explained as a hologram, an old idea in the brain phenomenology.

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PRINCIPII FIZICE ÎN EVIDENȚIEREA MECANISMELOR DE FUNCȚIONARE A CREIERULUI. PARTEA I

(Rezumat)

Lucrarea se adresează unei comunități largi de cercetători ce abordează creierul uman din diverse puncte de vedere. Ideea noastră esențială este că indiferent de punctul de vedere al abordării în cercetarea creierului, un cercetător trebuie să înțeleagă posibilitatea fizică de operare a acestuia. În lucrarea de față descriem această posibilitate, modelând creierul ca pe lumină. Proprietatea fizică esențială este fractalitatea. Ea va fi explicată, mai întâi pentru lumina însăși, apoi aplicată ca atare la cazul creierului. Funcțiile esențiale ale creierului: memoria, achiziția de informație și manipularea acestei informații, vor fi explicate ca fenomene fractale în tranziții de scală. Modelul fizic astfel construit este, într-adevăr, util în ghidarea oricărei cercetări asupra creierului, indiferent de natura sa.