Linking quantum mechanics and general relativity together ?

Reflections and Propositions

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Abstract

We examine the possible relations between general relativity and quantum mechanics, from the point of view of their representations of space and time, which are different. We refer to our own understanding of space and time, built in opposition to each other from the physical phenomena, and not constituting an *a priori* external frame. Within a relation-based thinking, we can only compare the phenomena to the other phenomena, and, from this confrontation, space-time frames arise, as drawn by the trajectories of certain phenomena arbitrarily considered in a privileged way. It is within this framework that one must think the possible association of general relativity (which has not the monopoly of space and time) and quantum mechanics (which has not the monopoly of quantization, to be understood from the comparison of two classes of phenomena within a probabilistic approach). The general question to ask is that of possible exchanges between the different points of views, supported by the various possible phenomena, that is to say those on which space and time are defined, and the others. Space and time do not disappear, the points of views are exchanged. These exchanges are made possible by representing space and time, like the other phenomena, by a pair of fields (r, t); r and t are vectors in a three-dimensional space (time is marked by the position of a moving point in the same space as that defining the positions of the ordinary points), as opposed to field pairs (f, g) associated with the other phenomena (such as the pair of the electric and magnetic fields). One may ultimately envisage quantization of space and time; one may also envisage the definition of time and space solely by quantum mechanics. A preliminary and qualitative framework is presented as a basis for future quantitative research.

Keywords : quantum mechanics ; general relativity ; Lorentz transformations ; special relativity ; quantization ; space ; time ; movement ; free fall ; gravity ; zeroth degree physical laws ; duality ; fields ; 3 + 3 dimensions ; disappearance of time and space ; electromagnetism

Introduction

It is recognized by experts that one of the most important issues in physics today is to understand how to link up the two major theories of the discipline that are quantum mechanics and general relativity (e. g. Smolin, 2000, 2006 ; Rovelli, 2004). At first sight, both theories do not have the opportunity to meet: quantum mechanics is concerned primarily with microscopic phenomena, while general relativity is used to study the structures of the universe at cosmological scales.

However, the question arises of linking them:

- First, we may want to discuss phenomena that are defined on time and space scales where the two theories converge, such as at moments close to the Big Bang or in black holes: matter is highly concentrated (small space scales) and very massive (action of gravity); the question also arises in situations where quantum effects occur at the macroscopic scale.
- Second, one may wish to examine the correlation between the two theories from a conceptual point of view: an incompatibility is indeed manifested in the image they convey of space and time. In the case of quantum mechanics, space and time are parts of an outer frame ("background") where the phenomena unfold themselves, while in general relativity, time and space become "dynamic" variables, depending on the changing distribution of masses. One also speaks of an antagonism between the two theories from the point of view of the punctual or stretched-out definition of the parameters they deal with, and related aspects of probability, quantization[1] and "uncertainty."

Thus, many physicists propose avenues for research that can be summarized as follows: we must quantize gravity, we must quantize space and time, we must more deeply connect quantum mechanics with space and time, that must be given a status of dynamic variables inside this theory; we need a probabilistic view of relativity, and its dealing with indeterminacy or uncertainty relations, etc.

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[1] The rest of the text will show with what nuances (and with what extension) to understand the terms of *quantization* and *quantizing*.

In the following, it is on the second place of discussion mentioned above that we will restrict ourselves, and it is the *match between the two theories as to their understanding of space and time that we will examine*, staying on a very general standpoint. We will only allude to the many technical difficulties discussed in the literature. This review will be supported by the author's reflections on space and time concepts (see references and Appendix 1). Say briefly, we are promoting a vision where time and space are not thought independently of each other, but in close association (relativity theory only connects the numbers that one may read on rulers and clocks, but keeps two separate concepts, and, in its mathematical representations, plans in advance to handle separate variables within a four-dimensional space). Space and time are built from the physical phenomena in general (and the "movements" that they allow to define), gravity having no special role. We can define a multiplicity of local times associated with the deployment of the phenomena, among which a marker is selected (this is not always possible) to define a unique time; it is associated with the position of a point moving in space with three coordinates[2] (think of the position of the sun in the sky, or that of a photon in an atomic clock). This approach provides new rules for thinking, and ways to rewrite the equations for the description of the physical phenomena. It does not avoid conceptual difficulties and the need for a renunciation to a complete understanding of the world (situation of "incompleteness").

In this text, we will first examine how space and time are constructed from the phenomena in general, and how the phenomena relate to the other phenomena as regards space and time. If specific lessons seem to be learned from quantum mechanics and general relativity, the question of their connection must be discussed in the general terms of the joint representation of space and time by several phenomena. We will then show how we can consider linking quantum mechanics and general relativity, provided we re-examine the two theories as to their handling of space and time, along some research directions that will be indicated.

The author has a limited knowledge of the physical theories discussed here; he does not know all the attempts made to connect them (the literature quoted in this article is very limited: we relied on basic physics textbooks such as those of Landau and Lifshitz (1970), Basdevant and Dalibard (2002), Rougé (2002), or less technical books such as that of Klein and d'Espagnat

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[2] Attention, we do not say that time has three coordinates, but that scalar t is constructed from the three coordinates of a moving point.

(1993)). Thus this text first wants to present a conceptual framework and some hints to discuss these issues, in view of more quantitative works in the future [3].

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[3] At the time we gave a provisional end to this work, we discovered the work of Patrick Iglesias- Zemmour (2013) on the " geometry of movements." We are pleased to see that the research we have been conducting for fifteen years to reconsider physics based on the unique category of movement (in place of the time / space duality) is consistent with other researches conducted by mathematicians.

Part I: General approach

1. Space and time are defined by the phenomena

One of the first outcomes of our work is to understand that time and space are not provided to the physicist as an external scene independent from what we call the phenomena, but that they are built on the phenomena; there is virtually no spatial nor temporal framework (no scene, no "background") without the phenomena (this result is consistent with the spirit of general relativity). The phenomena themselves are defined in opposition to each other as we discuss in the next section (we are inside the world and we can only compare the phenomena to the other phenomena). We believe that, in its basic expression, a phenomenon φ must be characterized by two three-dimensional fields f and g in duality (refer to the pair (E, B) in electromagnetism)[4]; a phenomenon is responsible for the mobility and immobility relations of the material points of the world, as a support for our associated constructions of time and space. In special relativity, space and time are associated with an elementary phenomenon φ_0: the propagation of light in vacuum; to it we associate two fields in duality, a space field r, and a time field t, both represented by three-dimensional vectors[5]. Time is defined by the movement of a material point in the three-dimensional space (a material point in the large, including photons and other particles). *This is basically this condition that will allow the openings discussed here.* It seems important for us to use, for r and t, the name *fields*, putting them on the same footing as other physical fields, defined by pairs of vectors (f, g) functions of r and t; the interest of this "symmetric" view between pairs (f, g) and (r, t) will appear in the following.

A basic correlation between the space and time concepts appears within the same frame, and it is not necessary, in order to define a "space-time", to consider frames in relative motion as stated in relativity theory. As we said, there is no neutral background without the phenomena, and, to-day, the phenomenon defining the rest frame is the propagation of light; *the spatial coordinate axis is basically a light path, and it already contains both space and time.* The link between two frames is constrained by adopting the same ratio between time and space units

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[4] We will start with *one* phenomenon as defined by its pair (f, g); but, as we just said, one phenomenon cannot be defined alone and will be defined by comparison with at least one other phenomenon defined by its pair (h, i); the latter may or may not identify with space-time (r, t) as the following will precise it.

[5] We will not use specific symbols for the vectors, and we will suppose that the context will allow to understand.

within each frame, based on the same phenomenon; so there is a correspondence between the election of an elementary phenomenon used to define time and space inside a single frame (here the propagation of light) into the equation $r = ct$ (to take vectorially), and the Lorentz transformations connecting two frames R and R' (written with six relations for the equations relating the six components of vectors r' and t' to r and t); we write it simply as:

$$\begin{aligned} r' &= ar + bt \\ t' &= br + at \end{aligned} \tag{1}$$

The symmetry of the spatial and temporal points of view is expressed by the symmetry of the matrix connecting $(r, t)^T$ to $(r', t')^T$ (only two coefficients a and b, for $c = 1$). At this stage, we do not care (we do as if it were possible) about other physical phenomena than the elemental propagation phenomenon, which remains implicit or mostly hidden. Lorentz transformations for another phenomenon φ_1, marked by the duality (f, g), will have the same expression as (1) (or expressions being derived therefrom by linear transformations; see Guy, 2012) and therefore could equally provide the definition of a space-time, as through φ_O (see below)[6].

2. Compositions / oppositions between the phenomena

If one wants to look more closely, and by extension of what we have just seen, we will agree that, in order to speak of a phenomenon (etymologically, that what "appears"), something must occur, that breaks from the "background", or, according to what we have said, a second phenomenon φ_1 must be opposed to the first implicit phenomenon φ_0 that builds the starting space-time frame. We can say that, in order to speak of a phenomenon, one implicitly opposes a situation where it happens or it is manifested, to a situation where it does not act, nor shows up. This opposition between phenomena (a phenomenon φ_1 that is specially noticed –as marked by the fields (f, g) on the one hand; and an implicit phenomenon φ_0 defining the fields (r, t) on the other hand) reads on the zeroth degree laws (Guy, 2012) which compose or combine the two field pairs (r, t) and (f, g):

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[6] f and g behave like space and time.

$$\frac{\partial f_i}{\partial t_j} = \frac{\partial g_j}{\partial x_i} \qquad (2)$$

In these relations, each field is defined by three components: (f_1, f_2, f_3) for f, (g_1, g_2, g_3) for g, (x_1, x_2, x_3) for r, and (t_1, t_2, t_3) for t; one sees that the roles of f and g on one side, x and t on the other, could be exchanged. We speak of zeroth degree laws, expressing the least we can say about the physical quantities: we do not know them alone, substantially; we only know their variations in space and time, related to variations of other quantities in duality. From these relations, one derives many others, particularly those showing scalar time t, being the magnitude of vector t. We see in these zeroth degree laws (*that are Lorentz invariant*) some forms of Maxwell's equations, of the laws of mechanics and of many other laws. In special relativity, where a single phenomenon (the propagation of light) is designated, we apparently do not see the other opposable phenomena, contrary to what has just been postulated. The answer is that phenomenon φ_0 may be opposed against all potential phenomena φ_i. So at first, it is announced that the propagation of light does in vacuum, as opposed to the propagation in matter (then going to electromagnetism or general relativity theories). We can also say that the first phenomenon φ_0 on which we build the space-time frame (i.e. the movement of light, complying with the assumption $c = const$), faces all unknown and unknowable φ_i phenomena that comprise the veiled reality with its "incompleteness " character; it is among them that we make the decision to elect the light as the phenomenon on which to stop in the course of a regression that would take us to infinity, taking for granted the epistemological assumption $c = const$ (this is to be understood within a relation-based thinking, see Guy, 2011a). The starting propagation phenomenon φ_0 in one frame is also composed with the understanding of its propagation φ_1 in other moving frames (and the regression to infinity also regards the constancy and the "value" of its velocity in the different frames).

In general relativity, one apparently deals with one metrics associated with a single space - time (we say it is distorted by matter). In reality, there are indeed two coupled views, marked by the distinction between the length dl associated with the overall metrics, and the small changes dx_i of the coordinates. Thus $dl^2 = \Sigma g^{ij} dx_i dx_j$ implicitly opposes a situation without matter with $g^{ij} = 1$ (dl and dx have the same values) to a situation where matter is present, with $g^{ij} \neq 1$ (dl and dx are different). That is to say, in its spirit, general relativity falls within the situation of opposition between various phenomena that we highlight. We do not discuss here the dimensionality of the mathematical space associated with the metrics, to be rewritten in 3 + 3 dimensions[7], nor the need, for the proper functioning of our approach, to show two fields in duality for gravity; in the sequel, we will consider this possibility is implicit, together with that to modify general relativity within this perspective (see section 8). In general relativity, the possibility of opposing two classes of phenomena is also present in a hidden way when we speak of the "curvature of space" by the masses: for example we compare the path of a light ray coming from a star in the case when the sun is absent (one says the trajectory is not curved, it is called a straight line; this refers to the elementary phenomenon without gravity) and in the presence of the mass of the sun (propagation in the presence of gravity, second phenomenon). We do it for the sun (eclipse experience) but we implicitly consider that this can always be done, every time we write a non-Euclidean metrics.

3. "Flat" space-time / "curved" space-time

The words space and time are bound to the first phenomenon, often implicit, that is of interest; to this phenomenon is credited a regularity with respect to which a second phenomenon (it is called as such: a *phenomenon*) unfolds as being "curved". The composition or opposition between both phenomena is manifested by a composition or opposition between the two space-times attached to them[8]: the first as "flat", is defined by the regular and rectilinear coordinate grid, setting a frame; the second as "curved", is associated to the second phenomenon which manifests itself (as a phenomenon) in opposition to the first.

We can illustrate this opposition by taking again the example of the deflection of the light coming from a star by the sun. To the extent that, in our understanding, the rulers and the clocks are defined by the same propagation phenomenon, the light in this case, the very path of the photon that bypasses the sun is the exact image of the space-time associated to light (Figure 1; the following drawings are a support of our qualitative discussion). One thus

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[7] It seems useful to distinguish between the size (in the sense of dimensionality) of the physical or geometric space where the movements of objects are defined (this includes both space and time; for us it is 3, -cf. the analysis of Poincaré in *La valeur de la science*, 1905-) and the size of the model or the mathematical space constructed out of the physical space. The same word dimension is used but covers two different concepts. It seems to us appropriate to rest on a model space with 6 dimensions (isolating 3 dimensions for space, in its restricted sense without time, and 3 dimensions for time; we can even go to 9), before eventually building a mathematical 4-dimensional space (3 for space and one for time).

[8] See footnote 10 below for the use of the term "space-time" in our approach.

opposes the path of a photon from a star when the sun is absent (we call it the straight or flat path) to the path of the photon when sun is present during an eclipse (we call it the curved path). The opposition between the words "straight" (or flat) and "curved" is made possible by the opposition between the two experiments, to the extent that, when the sun was absent, we began by declaring as straight the first path of the photon: what is curved is qualified as such by a comparison. If the sun were always present when we look at this star, we would declare as straight the path of the photon that reaches us. On the whole, the choice of the words used depends on the phenomenon that we choose as a basis, as a reference; it is indeed a matter of point of view, but one has to start with a first choice.

In the spirit of our approach where space and time measurements are associated to a movement (via a "phenomenon"), we can truly say that space-times are *trajectories*, and preferably use this word more in line with our view; the comparisons / contrasts between phenomena and space-times that we have presented are to some extent simply comparisons / contrasts between trajectories[9].

4. Exchanges between the firstly defined space and time and the physical fields

What can then be done, as we began to suggest, is to swap the two previous points of view, and see the second path as straight, and the first as curved (Fig. 2). This is exchanging the elementary space-time field[10] associated to the first implicit phenomenon of light propagation in vacuum on the first hand, and the derived physical field, associated with gravity in our example, which is manifested in the “second” phenomenon of propagation of light as distorted by the attracting masses, on the other hand.

There may be a number of reasons to switch our views, and to consider in the first place the second phenomenon (and make it implicit), and in the second place the first one (and make it explicit). In the case of the influence of a distribution of masses along the light path, one can

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[9] The standards for space and time provided by the rulers and the clocks actually disappear behind the only “standard of movement” provided by light (Guy, 2013d), giving still more relevance to our use of the trajectory concept for assessing the space-time.

[10] To be more coherent with our relational approach, we should speak of space-time, not for a single duality of the type (r, t) or (f, g), but for the minimal association of two phenomena in composition one with the other, in the pair {(r, t), (f, g)}. The reader can rectify in the rest of the text. The matter is then to change the order of the pairs in the association {(r, t), (f, g)}; we give the space and time wordings to the first pair (see also footnote 15).

be in a situation where the amount of matter is such that the straight path in vacuum appears as idealistic. One thus leans on the effective light path to which space and time measurements are associated. This is what happens in general relativity when going from time and space intervals dx_i and dt to the overall metrics dl, via the metric tensor g^{ij} which is a function of the mass distribution. We exchange time and space in their first sense (associated with dx_i and dt) against a new time and a new space, associated with a new "straight line" marked by dl (the research of geodesics does identify this dl as a straight line).

One can imagine various situations where the movements that truly matter to the observer, and for which he wants to save the energy cost for example, are associated with a phenomenon distinct from the elementary propagation of light; then it is appropriate to measure time and space themselves with this cost that has a more direct meaning. In many every-day life situations, we do not directly use standard length units (meters, kilometers) to designate a distance, but units that are closer to what actually matters for us as human users, e.g. hours of walking when we are hiking in the mountains. If one has a helicopter and does not care about the energy cost, the equivalence remains between the budget for the engine and the distance expressed in standard units. If one travels with a car on straight roads on flat terrains, one can talk equally of distance traveled or of fuel used; but if one travels in the mountains with winding roads, the distance measured by a straight line connecting the two extreme points has less sense, and one may want to express the distances with the gasoline consumption. This opposition between the local and the global is a matter of scale: still using the example of light, one can consider that, at the scale of our planet, its path is straight (associated with a φ_0 for r and t), whereas at the scale of its travel between galaxies, the curvature of its path must be taken into account (associated with φ_1 for f and g; or again: associated with a non-Euclidean metrics as in general relativity).

In these situations, the displacements to be computed are related to local fields that may be variable (taking again the previous example, one can imagine that the road itself be distorted even during the progress of the traveler). We can then no longer have an overall quantitative point of view, that is to say, announce in advance a distance and a time having their value for the overall path. This does not mean that space nor time (nor the background) are gone, but we cannot associate to them, in their first sense, wide-ranging measurements, they have only a local meaning; we lose the ability to define a synchronized space-time; there remains a multiple time (like in general relativity). What has disappeared is time, or space, based on their first definitions (as if we wanted to give them a basic meaning), but once the exchange between viewpoints is done, we can again talk of time and space, then under the second point of view. In these new conditions, one no longer sees the old time and old space and their associated old straight lines; one sees the news straight lines to which can be well attributed the words time and space[11]. The regular frame has become even more invisible or implicit, but it is always necessary to think about it, in order to make a comparison with the irregular path that is put forward in the new situation. It is in fact hidden; this comes into play as soon as one considers the dimensionality of a mathematical variety, as soon one defines coordinates and axes to measure physical quantities, as soon as a phenomenon appears as constructed by the comparison with another implicit phenomenon, that we call an absence of phenomenon (one can even say that time is hidden as a parameter to define the mathematical line of real numbers R, Teissier, 2009). The exchange between the fields (r, t) and (f, g) is first local, but then one may wish to connect the local "maps" inside an "atlas" (as is done in general relativity).

The exchange between two phenomena is a way of saying that there is no fundamental difference between the stage (the "background") and the actors; this is a matter of choice and perspective. One can also say that both are defined by each other. To recognize it is useful to discuss some common expressions in general relativity: there is no deformation of space-time by matter, there is no more a distortion of a trajectory by matter: a trajectory has no quality by itself, it is not "modified"; it is seen / declared curved or straight as compared to another trajectory which is seen / declared straight or curved. There are only comparisons between trajectories associated with particular phenomena, together with the choice of a basic trajectory to define what is regular. One could oppose spatio-temporal axes defined by the movement of neutrinos nearly un-sensitive to masses, to the axes defined by the photons, which are "bent" with respect to the first ones (when we think of the travel between Paris and New York we do not think at first of the almost straight line across the earth that the neutrinos discussed at the moment could follow).

In order to get a time in general relativity, we talk about the “proper time” to be integrated along the entire path of a mobile, but this proper time is implicitly compared with a time

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[11] In the foregoing example, the distances and times are measured by liters of gasoline, thanks to a change of perspective (gasoline is "first", and firstly defined time and space are derived); the vocabulary was changed, the choice of units was changed. But, if one desires, one has the freedom to restore the old vocabulary with a new meaning.

along a "straight" line associated with an undisturbed phenomenon. The proper time is then not proper to the mobile, which has no meaning; it is proper to the relations to the places visited, it reflects a local link between time and space, that is "disturbed" (to compare with a link between space and time without disturbance, within the starting “free” phenomenon).

Returning to our general discussion with its use of the symbols (f, g) to designate the fields in duality (the starting space-time field is designated by (r, t) or by {(r, t), (f, g)}), we can therefore in some situations have interest to say: *the fields f and g are our reference, and the measurements of space and time r and t (as we understood them first) are functions of f and g*[12]. We then make an exchange between the pairs (f, g) and (r, t); *it is made possible by the symmetry of the zeroth degree laws, also translated into the identity of the Lorentz transformations for the pairs (r, t) and (f, g), making use of the vector character of the variable associated with time.* Look at the example of the electric and magnetic fields associated with a moving charge, with E = E (r, t) and B = B (r, t); one can reverse these laws as r = r (E, B) and t = t (E, B) where the vectors E, B, r, t have all three coordinates (we then assume implicitly that, by doing so, we are not outlawed by general relativity that would have a monopoly on the definition of r and t; see below).

Finally, note that, as we said, if we want the good functioning of the exchange (r, t) / (f, g) i.e. between space and time fields and other physical fields (for example for gravity), the latter shall be described by such a pair; we will discuss it in Section 8.

5. Numerical values attached to space and time variables or their substitutes

We could try to compute quantitatively the various foregoing trajectories, in terms of φ_1 field equations dealing with (f, g) pairs, as a function of the starting fields φ_0 (r, t). We will not do it here and postulate that these trajectories are defined by constant values of certain variables associated with φ_1 fields (potentials, field components or quantities obtained by various changes of variables; in the previous examples dealing with travels in the mountains, we can say that the movements that "count" correspond to differences in the gravity field g, and not to equipotentials). All this can be understood as part of variational principles incorporating the

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[12] We are free to call f and g time and space (or space and time).

laws being used, and/or least distance principles defining metrics (e. g. Basdevant, 2002). Thus we assume that, thanks to these methods, we can ultimately replace the (x, t) grid by the (f, g) grid, where x and t will then appear as functions of f and g. One can also, if one desires, use the same units for the various fields (f, g) and (x, t) and/or change the words in the vocabulary (cf. our discussion in footnote 11).

6. Note on quantization and probabilistic approach (the inspiration of quantum mechanics)

Quantization

Aspects of quantization are to be understood, as above, by oppositions or compositions between different points of views. Quantization is not the property of any phenomenon; it appears, it is manifested, only by comparing two scales, two phenomena. Otherwise how would we be able to see it, to put it into light, to talk about it? We need to think of the intermediate values of a physical quantity (first point of view, let us associate it to phenomenon φ_0) that will be skipped in the quantization (second point of view, let us associate it to phenomenon φ_1). This can be stated in terms of probability: the missing values have a low probability, or a probability equal to zero, to appear. Depending on the scale and the phenomenon that is chosen as a starting point, the quantization is assigned to one or the other of both phenomena; that is to say, if φ_0 is selected as the basis, φ_1 appears or is said quantized; but we can exchange our views. This understanding answers the objections of Simone Weil (1942) who did not accept that we can define energy quanta without considering intermediate values; according to her, all physical quantities (especially energy) may be understood by weight movements in space and time, and to skip portions of space or time has no meaning.

As such, aspects of quantization are also not specific to quantum mechanics, but appear as the properties of some solutions of partial differential equations with boundary conditions (Basdevant and Dalibard, 2002). In this case, the basic space where the whole continuous set of values (which will be "quantized") is envisaged may be the "usual" space-time[13]. The space

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[13] It is often, rectify, a space of energies, that one can put in fact in relation with the usual space-time, as we comment it further.

and time variables are involved in the partial differential equations modeling the problem being studied. If we take the example of the position of an electron in an atom, modeled by a Schrödinger equation (depending on space and time variables), we oppose a situation where all positions are possible (call these positions as ruled by φ_0 (r, t)), to an inhomogeneous or quantized distribution, where the positions of the electron are restricted to special radiuses (as governed by the equation, let us refer it to φ_1). At these particular positions of the electron, discrete values of energy are associated. We can then write laws E = E(r) (where the energy E is a function of distance r) which show quantization. If rather than be guided by the distance r, we prefer to be guided by a continuous energy range, we can reverse the laws E(r) in r = r (E) and then define a quantized geometric space for r. That is to say *the space intervals corresponding to the different energy values do not all have the same probability* (see also Fig. 4). This may be expressed in terms of the wavelengths of the radiation emitted during the transitions between different positions of the electron: one can oppose an implicit situation where all wavelengths λ are equally represented in space, to this other situation where light interacts with matter (the electrons in the atom), and wherein all λ are not shown, but appear quantized.

Nature gives us, in the macroscopic domain, such examples of quantization of time and / or space, not to be understood "alone", but by the composition / opposition between two views. This is highlighted by the exchange between the starting spatial and temporal scales on the first hand, and that of the physical quantity the range of which we study in space and time on the second hand. We examined ourselves such phenomena that develop in space and time and show abrupt changes (shock waves type) and are modeled by systems of partial differential equations (Guy, 1993, 2005). Quantization then relates to mineral compositions in rocks, or, by exchanging composition field and space-time fields (r, t), relates to space and time themselves. In other words, if one compute space and time by the concentrations of some chemical constituents, then standard space and time are derived fields and appear as quantized. Time, or space, associated to an intermediate composition between the quantized compositions is of low probability relative to the time or space associated to the compositions forming the boundaries of the quantization domain (Fig. 4). We coined this: quantization by fluid-rock interaction. In the case of physics, the opposition between the two points of view showing a quantization, call them φ_0 and φ_1, can be understood by saying that quantization does not come out from light properties alone (φ_0), nor from matter properties alone (φ_1), but from the composition, or the interaction, between light (φ_0) and matter (φ_1). In the Schrödinger equation, the light-matter interaction is written within the Hamiltonian where the potential to which matter (the electron) is subjected, is usually the electromagnetic potential. A symmetry thus appears between light and matter. These qualitative considerations would require further theoretical studies (all partial differential equations are not put on the same footing as regards quantization; one must especially distinguish linear and nonlinear case).

Let us stop again on what is designated by "quantization of space and time", to insist on the fact that, in the relational approach which is ours, we then keep two space and time scales (and, as we have said, it is the comparison between them that allows us to speak of quantization, attributed to one or the other). In doing so, we can keep the vocabulary of space and time for each of the two scales, or only for one of them. For the other, space and time are marked by a physical quantity that keeps its name, even if it is a tracking of space and time that is done. Let us illustrate each of these two situations with two new examples. First example: on earth, time (with space) is measured historically by the position of the sun: it varies continuously around the globe with longitude. But this continuous scale is not practical for human communities that have cut it into various time zones, expressing as many jumps or quantizations. The two scales coexist: the ideal scale supported by the physical earth and which makes it possible to think of all the intermediate times; and the new scale of human meaning that cuts this first scale into "discrete" pieces. The non-uniformity of the human scale is reinforced by the fact that time zones are narrowed in areas occupied by oceans where few men reside, whereas there is a tendency to expand them in inhabited continental areas. At a given moment, all the possible times (1st scale) do not have the same probability (2nd scale). In the second example, corresponding to that discussed above, it is decided to rely on a continuous scale of concentrations of a chemical compound to identify the entire set of values of space and time (we could identify these by the values of the electric and magnetic fields in another situation). This ideal scale is opposed to another scale where the (old) vocabulary of space and time is still used and allows to speak of quantization of these quantities.

If, more generally, we consider the space (the set) of events (i.e. the tests of the probability theory) on which we define probabilities, two views still show up: on one side, the space of events allows to consider all intermediates of the studied variables; and on the other side, by contrast, the values of the probabilities associated to them provide possible quantization. One should strictly distinguish between the level of events and that of the mathematical set (tribe) that we can build on them, the probabilities being defined on the elements of this tribe; if we consider the so-called Borel tribe associated to the mathematical real line (R set) on one side, and segment [0, 1] used for the definition of probabilities on the other side, one is led to possible exchanges between portions of R, as described qualitatively in Fig. 4. We assume that, in one way or another, the usual space-time dimensions are always hidden in the space of events (Guy 2017b).

General probabilistic approaches

The use of probabilistic concepts in quantum theory goes beyond what concerns quantization in the restricted sense, or other said discretization, that is to say the possible jump of certain values for different physical quantities. Probabilities are not immediately needed, as was discussed at the beginning of this section about the solutions of partial differential equations with boundary conditions. However, this use is crucial for accounting for concepts and quantum properties in the broad sense, such as the superposition principle, the non-locality properties, and so on.

If quantization does offer probabilistic aspects, we can also say this relates to the general use of probabilistic concepts in quantum theory. In quantum physics, one does not represent the objects studied as material points with a precise location, but as associated with a function that spreads in space, the amplitude of which will give a probability of presence: the wave function ψ. We can justify this use by saying that a Gaussian distribution (function having a certain spreading, as the wave function) is the approximation of a Dirac distribution (associated with the presence or absence of a material point in a clearly defined locality). This choice is fundamental for the further development of the mathematical theory; from it a whole series of results are derived, such as the Schrödinger equation and the quantization rules, the so-called uncertainty relations (derived from the properties of the Fourier transform applied to the wave function), the definition of operators, the correspondence between operators and parameters of classical mechanics etc. This probabilistic approach can in principle be applied to various aspects of physical reality. In the spirit of our discussion, it should be noted that one will need two vectors ψ and φ in duality, each with three coordinates (see section 8.2), in order to express the zeroth degree laws, which also allow for exchanges, in the sense that we have defined, between fields (r, t) and fields (ψ, φ).

7. Multiplicities of space-times composed with one another[14]

The exchange between two phenomena in their role to serve as standards, and the elimination of time and space is not a goal by itself. As we said, it may be required by the better fitting of one representation relative to another. It also draws one's attention to the options lying beneath the various representations used, and to the ways to attain further progress. In the previous section, two phenomena φ_1 and φ_0 are defined in composition with each other, and exchanging them does not seem to pose any difficulty in principle, if not technical. We must then amend what we wrote in the abstract or in the introduction to our work: strictly speaking, the compatibility problem between different phenomena, in relation to their representations of space and time, does not arise when they are two. This makes sense provided we have, from the start, at least two phenomena, counting for one the phenomenon which allows to gauge the coordinate axes. The elucidation of this is useful when one wants to discuss the problem of the coexistence of quantum mechanics and general relativity; when reviewing their relations, we should examine "how many" phenomena are concerned.

When we are dealing with more than two phenomena, in the sense given above, for example first phenomenon φ_0 associated to the fields (r, t), second one φ_1 associated to the fields (f, g), and third one φ_2 associated to the fields (h, i), there may be a problem; various cases arise.

1. If the three phenomena are independent, that is to say if the fields (f, g) and (h, i) have no common physical factors, we can make different choices:

1A. - Replace (r, t) by (f, g) or by (h, i). There are altogether three possible choices for the standard fields defining space and time: (r, t), (f, g) or (h, i). Final election depends on what is most convenient. For example, one can write the laws ruling (h, i) as a function of the standard fields (f, g), while time and space are also "derived" with respect to f and g.

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[14]. We do not speak in this section about quantization in the restricted sense (see section 6) although it is already possible, reserving for the second part of our text the discussion on quantum mechanics in the broad sense.

1B. - Eliminate (r, t) and consider only the pairs {(f, g) (h, i)} or {(h, i) (f, g)} according to the fields on which we rely to define our space and time vocabulary[15].

1C. – Make do with two strictly independent associations: {(r, t), (f, g)} on one side and {(r, t), (h, i)} of the other; each association can be revised at will, while conducting exchanges between (r, t) and (f, g), or between (r, t) and (h, i). In this case, each of the two independent associations conveys its own space-time, that is to say, two different ways to define r and t from the different phenomena may be separately considered. This is the case where the particles being studied may be divided between those sensitive only to fields (f, g), and those sensitive only to fields (h, i).

2. There may be conflicting situations when associations such as {(r, t), (f, g)} on one hand, and {(r, t), (h, i)} on the other hand were at first defined and studied as unconnected, and understanding that they are not independent, therefore are not compatible. That is to say, they involve common physical factors, intervening in both (f, g) and (h, i). One cannot then, exchanging with φ_0, define space-time as based either on φ_1 or on φ_2 (Figure 3). We must then resume the writing of the equations. Different cases are possible.

2A. Perhaps one of the two theories, which led to the writing of fields (f, g) or (h, i), must be given up because it is very inconvenient compared to the other. It is like trying to define time and space as based on both sound propagation and light propagation. The use of sound will be abandoned, not that the approach based on sound is wrong in absolute terms, which does not make sense, but that its implementation is more difficult and of less general applicability than the one supported by light[16].

2B. It is also possible that, due to interactions between them, the two phenomena should be taken again and rewritten within a single formulation that combines them better.

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[15] In the pair of type {(f, g) (h, i)} describing a minimal space-time that makes use of two phenomena in composition (f, g) and (h, i), we will agree to put in first that which defines the uniform grid of space and time, that is, here, (f, g). See footnote 10.

[16] The example chosen does not fully agree with our general standpoint. Let us retain that there are cases when, for various reasons, one is led to eliminate one of the two phenomena, φ_1 or φ_2.

In these situations, we understand that the fundamental problem is not the founding of space and time: they have no existence "by themselves", they are "second" and determined by the phenomena. There is no obstruction to our approach, there is "only" the need to work again and ask: *what conventions are most useful to adopt?*

How then one manages to establish a common formalism? We do not discuss the general method; we may for example write variational formulations (based on an energy unifying concept allowing "transfers" from one phenomenon to another, with the use of Lagrangians or Hamiltonians) or write the zeroth degree laws displaying the moments associated with energy. In these situations, it may be not practicable to define time and space parameters as global for the whole system, we can do it only locally, based on the dynamics of the system. The various choices made must be accepted in their consequences within the recursiveness circles affecting the concepts and the equations.

Such conflicts may be for example that of a situation where both gravitational and electromagnetic phenomena intervene (as opposed to the mere propagation of light in vacuum, without massive nor charged particles) or that, for some cases that interest us especially here, where both gravity and the phenomena described by quantum mechanics do play. The latter contain electromagnetism, to which can be added the strong and weak interactions. If we add the gravitational potential to the quantum formalism (that we know is possible), we can no longer oppose gravity to quantum mechanics nor discuss the "privileged" role of the former to define space and time (which indeed for us is not a disadvantage, as we will repeat below).

Second part: application to quantum mechanics and general relativity

8. In what directions to re-examine general relativity and quantum mechanics?

We can draw from the above the first few lessons: - general relativity has not the monopoly of space and time; - quantum mechanics has not the monopoly of quantization. So we see that, in some way – it is not just gravity nor space-time that can or must be quantized; - it is not just quantum mechanics that can or must be more closely blended with space-time. How then restate our original question, bearing on the coexistence between quantum mechanics and general relativity? In our understanding, we cannot try to adjust both theories as if they were finished and intangible, in particular in their representation of space and time. Each of them needs to be reviewed as to its relations to time and space (this observation meets with one made by Lee Smolin, 2006, who declares that the problem of the misfit between the two theories is based on the fundamental misunderstanding of what is time; more precisely, for us, this is the misunderstanding of the relationship between time and space, while space is another face of time). Only after such a re-appraisal of the two theories can we seriously consider linking or associating them together[17].

8.1. Reconsider general relativity

Some previous results are consistent with the spirit of general relativity. So are - the status of space and time as dynamic variables or fields (Rovelli, 2004, also talks about space and time as *fields* in general relativity), - the absence of a unique and synchronized time for universe models (or the multiplicity of times), - the "disappearance" of space and time (Saint-Ours, 2011; Rovelli, 2006) etc. We retrieved these properties from a general point of view, by examining the "sharing" of time and space between several phenomena; general relativity therefore does not have their exclusivity. General relativity is not *the* theory of space and time. Space-time is not distorted by matter: there is no primordial space-time waiting to be distorted. Neither space, nor time disappears when considering local situations "influenced" by masses; the point is a possible exchange of the views and the ways of calling things. Space and time are present in any phenomenon, in any relation (Guy, 2011a). General relativity is also not consistent with its own words, announcing that space and time are on the same level and, ultimately, not distinguished: it considers indeed four dimensions from the start and

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[17] Basically, one must adopt the framework of a relation-based and not substance-based thinking and, technically, 3 + 3 dimensions.

carefully distinguishes the temporal and spatial factors within the metrics (the use of "pseudo" to qualify a pseudo-Euclidean or pseudo-Riemannian metrics in relativity recalls that time and space are a priori distinguished from each other in this theory). Our approach where space and time are strictly of the same nature (everything can be designated with the vocabulary of one or the other) is instead a way to complete the goal of general relativity under this prospect.

How did we get to this monopoly of general relativity on space and time? The equivalence principle enunciated by Einstein had a major role: the free fall seems to annihilate gravity, and a choice of a space-time frame is equivalent to a gravity field. This finding was based on Newton's second law that binds force, acceleration and mass. Whenever we talk about acceleration, we associate it with a mass, and gravity comes in (the equivalence principle also connects inertial mass and gravitational mass). We must take a step back from this approach, noting that Newton's second law is not specific to masses, but must be understood more broadly as expressing a duality between an energy and an associated momentum (Guy, 2012). This duality is expressed within a zeroth degree law written for all types of phenomena. One could consider a "free fall" erasing an electromagnetic field acting on particles insensitive to gravity; contemporary news about Higgs boson reminds us that we can consider massless particles (insensitive to gravity). For the phenomena where one can or wants to ignore the mass, there is an equivalence between Newton's law involving acceleration and free fall without gravity! Several authors have commented in this direction (Basdevant, 2002, gives the momentum in the presence of a magnetic field, different from mv; in his treatise on physics, Feynman, 1979, also addresses the issue of the duality energy / momentum for electromagnetic phenomena outside the masses). In the case where electromagnetic phenomena are added to gravitational effects, the energy-momentum tensor contains terms of electromagnetic origin, in addition to gravitational terms, and a movement of "free fall" therefore does not selectively cancels the gravity field but a combination of both fields (electromagnetic and gravitational).

Finally, we observe that the equations of gravity (that can be derived from those of general relativity with appropriate simplifications) do not meet the conditions of symmetry that we have put forward when writing the zeroth degree relations. These conditions are essential to enable the general exchange between the (r, t) and (f, g) fields as we discussed it. On this basis, we must reconsider the equations of gravity (see an attempt in Guy, 2010b) seeking a general form comprising an additional field h (with speed-dependent forces due to the moving masses). This approach is not without consequence on the way to formalize general relativity. In the development of our approach, it remains necessary to restate the whole formalism in 3D or 3 + 3 dimensions, by specifying time from a (mobile) point in the three-dimensional spatial frame. Some authors find some mathematical discrepancies in general relativity[18]: can the remarks we made above about the non-deformation of space-time by matter, and the non-substantial but relational character of energy (Guy, 2012), help avoid the problems?

8.2. Metric approach and duality of fields in gravity (general relativity): avenues for research

Several times in the above, we postulated that, by adding a second field h to the Newtonian static attraction field g, we could treat gravity and general relativity by a pair of two fields (g, h). Compared with electromagnetism, we can give the second field h the property of depending on the velocities of moving masses, as is the case for the magnetic field B as opposed to the electric field E in the pair (E, B). But this does not correspond to the approach taken in general relativity, where one relies instead on a metric.

The question then arises to relate this possible use of a pair (g, h) to the metric formulation of general relativity. This question brings us closer to that of the link between Einsteinian formulation and Newtonian formulation of gravity. We know classically that, in the case of a metric with spherical symmetry, the search for geodesics (paths of lesser distance) leads to a formulation that can be identified with the Newtonian formulation; we then establish a formal link between the Newtonian attraction potential and the connections $\Gamma_{jk,i}$ of the metric.

It turns out that, in the case of more general metrics, not with spherical symmetry, various authors have shown, interestingly for our purpose, that new equations are derived from the expression of the least distance: to the equation that we can understand as the Newtonian law, come indeed additional terms of the centrifugal and Coriolis type, called by some authors gravito-magnetic terms, and which make explicitly the link that we seek. We can cite, without concern for completeness: El Majid and Mizony (2006), Thiring (1918a and b), Buchert (2006), Damour (2006), Mashhoon et al. (1984), Pfister (2014) etc.[19]

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[18] E.g. G.E. Romero (2012) : Adversus singularities : the ontology of space-time singularities, arXiv.

[19] Michel Mizony (pers. comm., 2012) points out that we can associate three "proper times" (τ_r, τ_θ, τ_φ) to the three equations derived from the general metric, supporting our approach to construct the scalar time on three parameters.

We will remember from all this, that, at least at the level of the principle, there is an equivalence, for very general metrics, between the usual metric formulations of general relativity and the field pair formulation (g, h) that we offer. This is also connected with the modified law of gravity proposed in Guy (2010b) (there are many other laws of this type in the literature). It remains to look in detail, both in terms of mathematical formulations and values given to physical quantities and parameters, how this can work or not[20]. The correspondence between the metrics allowing such reconciliations and the type of systems accommodating them (via the definition of the inertial frames responding to them) will also have to be specified.

8.3. Reconsider quantum mechanics

In quantum mechanics, the wave function is the basic mathematical tool: it is a scalar, while, as we said, we need to handle three-dimensional vectors, and in pairs, so that the symmetries between the physical fields and the space and time fields may fully operate. In the case we represent the physical variables by probabilistic functions, we are led to define pairs (ψ, φ) of two three-dimensional vectors representing some probabilities associated with the physical quantities along the three coordinates, and write for these couples zeroth degree laws such as:

$$(3) \qquad \frac{\partial \psi_i}{\partial t_j} = \frac{\partial \phi_j}{\partial x_i}$$

From which we can derive other laws such:

$$(4) \qquad \sum_i \frac{\partial \psi_i}{\partial t_i} - \sum_i \frac{\partial \varphi_i}{\partial x_i} = 0$$

$$(5) \qquad \frac{\partial \psi}{\partial t} - \sum_i \frac{\partial \varphi_i}{\partial x_i} = 0$$

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[20] Can we say that the two fields extracted from a general metric fulfil Maxwell type equations? What are the orders of the relative magnitudes of the constants appearing in the two laws then in play?

by summations, and by using the scalar t as obtained from its components t_i (see Guy, 2012); one can obtain even other expressions by exchanging spatial and temporal variables. Various interpretations can be given to these laws, such as balance equations with source terms (temporal derivatives) and flux terms (spatial derivatives)[21], or as transport derivative; we can also think of the ergodic principle by coupling two probabilistic points of view (in space / in time). Such laws are Lorenz invariant (Guy, op. cit.), as opposed to the Schrödinger equation, which does not possess this property. The proposed law (3) brings us closer to Dirac's work (whose equation formally resembles that given above), to Pauli's, and to spinors, about which there is an abundant literature. In order to obtain a ψ vector, we can proceed in the same way as we did for energy, starting from the classical scalar ψ, and using the cosines of the direction that is most relevant for our problem (Guy, 2012). We can also define a vector from the beginning, noticing that the usual scalar ψ alone is not blameless: a mobile might be nowhere on an axis, or even two axes, while the integral of ψ over the entire space could still be equal to one, thanks to the contribution of the other axe(s). Couldn't we define a probability for the coordinate along each axis, together with normalization requirements for each axis, and then define a scalar ψ in different ways? We do not go further into the mathematical details for the moment and suppose that it is possible.

9. Technical problems and associated comments on some works in the literature

Numerous technical issues deserve to be discussed in relation with the approach presented. It is interesting to see that many of them have already been addressed in the literature, and meet the points discussed here. We have cited some in our works, and the reader can refer to them, knowing that our knowledge of the relevant literature is limited. The attempts of the authors are dispersed and their scope remains modest because they do not fit into a general understanding of the space and time concepts. They are nonetheless precious because they most often show rigorous mathematical derivations[22].

We can mention the numerous works that operate the equations of the physical models with

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[21] In quantum mechanics, one also speaks of probability densities and probability fluxes (Rougé, 2000).

[22] On this point, it does not seem appropriate to dismiss too quickly the works by the physicists that are critics to relativity theory; the reader will have understood that we do not follow them into their final conclusions to reject the theory.

dimensionalities different than the usual value of four (three dimensions for space and one for time) and that seemingly solve such or such problem met in the standard 4D frame. Thus, according to some authors (these include for example Demers (1975), Franco (2006), Pappas (1978, 1979), Souriau (1970), Tsabary and Censor (2005) and Ziino (1979a and b)), one can find dimensionalities equal to six, with three dimensions for time, or equal to three when time is not distinguished, or just as one of the system parameters; there are also models with 1 + 1 or 2 + 1 dimensions (one or two dimension (s) for space and one for time; in the case of 1 + 1 dimensions the entire symmetry between space and time allows promising results, which cannot however be generalized to the ordinary case of 3 + 1 dimensions because of the loss of the symmetry then between space and time). These attempts, which on some aspects are similar to what we have done, refer to different topics such as Maxwell's equations, Lorentz transformations, and the connection between quantum mechanics and general relativity. The meaning of time is usually not addressed, the authors merely observe a better mathematical functioning than for the problem posed for a dimensionality of four (for example, according to Chen, 2005, the best dimensionality that would allow some linking between quantum mechanics and general relativity is three).

There is also everything related to the discussion of the basic equations of quantum mechanics; the Schrödinger equation is not Lorentz-invariant, and so not totally satisfactory. Then we find the issue of defining a three-dimensional ψ, where various works of the literature must be examined. Remaining in the field of quantum physics, we speak today of the non-temporality and non-locality phenomena. Can we claim that these phenomena, difficult to interpret, can be understood from our perspective? Non-temporality: in fact time does not "pass" anywhere, it does not apply to all reality, it is a construct supported by a part of what we see. Non-locality: yes, space (within the "spatial relations") is a construct that does not tell us the whole of reality, the “deep” part of which escapes us[23].

There is still what regards the equations of gravity and their links with those of general relativity. The literature is vast and many attempts have been made to derive them under the fashion of Maxwell's equations (see recent work by Buchert, 2006).

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[23] To speak of non-locality and non-temporality places us immediately in opposition to a temporality and a locality considered as first. Should we not rather say that we are facing a very rich reality (which is beyond us and is partially veiled) within which we cut, in a more or less provisional or imperfect way, a duality (space, time)? Other finer cuts would be possible...

We have not talked about string theory and the many developments in this area that we ignore almost completely; a number of theoretical results, which meet the issues discussed here, have been established. The working of the equations, regardless the meaning we give them, has by itself a meaning and deserves to be examined in connection with our ideas. Nevertheless we notice that we do not find in this theory any conceptual reflections on space and time; yet this seems a prerequisite for any progress. In a number of variants of string theory one finds the dimensionality of nine (9). By adding to the six dimensions that we postulate (3 for space and 3 for time), three degrees of freedom corresponding to the fundamental uncertainty on the scales adopted for each coordinate axis (in relation to the uncertain status, or "ill-certain " or “a-certain” of the constancy of the speed of light; it defines the scales along the three coordinate axes which both have a temporal and a spatial meaning), we also get a dimensionality of nine (this is discussed with Ph. Coueignoux, pers. comm.). Is it a coincidence, this point would need a closer investigation…

10. On the coexistence between quantum mechanics and general relativity as regard their representations of space and time

To summarize, what can be said about the coexistence between quantum mechanics and general relativity, from the perspective of their relations to space and time? If we go back to the first ideas we inherit from our scientific education, we will say, with some distance: - general relativity is interested to embody time and space within the gravitational phenomenon; - quantum mechanics describes the phenomena inside a space-time frame independent from them, and studies the behavior of material particles at the microscopic level in a probabilistic approach; it accounts for what is called quantization, corresponding to non-homogeneous behaviors. If we now assume that we have implemented the changes suggested in the previous sections, we will postulate that each of the two theories is defined by two fields in duality: (g, h) for gravity (that we will consider as equivalent to general relativity in this form), and (ψ, φ) for the microscopic phenomena described by quantum mechanics; each pair is itself defined in composition / opposition with a basic field (r, t) associated with the elementary phenomenon that supports our definitions of space and time. The starting problem can then be reformulated as follows: are the three field pairs (r, t), (g, h) and (ψ, φ) compatible? How can they coexist? Can we eliminate one of them, (r, t) for example, out of the three? Eliminating (r, t) is not "mandatory", it meets the desire to consider situations where the elementary phenomenon of light propagation in vacuum (constructing the starting field (r, t)) is not completely appropriate to the treated problem. If one wants to operate this removal, the question is whether one has the logical or mathematical possibility, when taking into account the links between the different phenomena. Above, we have discussed this problem from a general standpoint, and we can respond by adjusting our answers to the specific case of the two theories of interest. Several cases are possible (we keep the same items as those distinguished in Section 7):

1. Fields (g, h) and (ψ, φ) are independent because the phenomena considered within each pair are different: (ψ, φ) only takes into account electromagnetic, strong and weak interactions, to the exclusion of gravity (one considers equivalently that this can be neglected), while (g, h) on its side only accounts for gravity to the exclusion of other interactions. Several choices can then be made (some of them ultimately reach the same structure as above, but we present them separately because they correspond to different lines of attack):

1A. Choose one of three pairs as defining the basic space and time fields (3 options).

1B. Completely eliminate the pair (r, t) and consider the {(g, h) (ψ, φ)} space-time. Depending on what we take as a "basis" to define space and time we can say: - (ψ, φ) is quantized, or - (g, h) is quantized; - (g, h) serves as background for (ψ, φ), or - (ψ, φ) serves as background for (g, h). It is then conceivable (again through such exchanges) to define space and time only by quantum mechanics.

1C. Consider that there are two space-times co-existing in the same place (within the same physical space but with different spatial and temporal relations)[24]: {(r, t), (g, h)} on the first side, and {(r, t) (ψ, φ)} on the second side, within each of which one can conduct exchanges and make time and space “disappear” (in their original meaning). For the second pair, by

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[24] This situation can be illustrated by the coexistence of astronomical time and atomic time (to which are associated spaces that can be said astronomical / atomic); if we compare the two scales they construct, differences are observed of the order of the atomic second in one astronomical year. But it is the latter that we privilege, ultimately, by the insertion of a few atomic seconds. By doing so one does not make a distortion compared to a true time given by the atom, one leans on a convention of human nature (made possible by the fundamental nonexistence of time in itself), and keeping the (astronomic) seasons with their full social meaning!

exchanging the roles between the fields (x, t) and (ψ, φ), we may then speak of a "quantization" of space and time[25]. The combination of the two theories, general relativity and quantum mechanics, permits us to think in such a way, the first inspiring us as to the definition of time and space by the phenomena, and the second as to their "quantization ".

2. If the two groups of phenomena described by the fields (g, h) and (ψ, φ) are not independent, either because we have put gravity within (ψ, φ), or that we have put other interactions than gravity in the energy-momentum tensor used to define the metrics involved in the pair (g, h) (we momentarily suppose we managed to do it from a technical point of view), a conflict may arise.

2A. We can then eliminate one of the two; for example consider there is no separate gravity but simply the pair {(r, t), (ψ, φ)}; it looks like some of the previous cases, but now quantum mechanics is richer. We can also prefer not to consider "quantum mechanics" as separate and stay with the pair {(r, t), (g, h)} for gravity.

2B. One can reconsider the equations and find a unique theoretical frame.

Case 3 (new[26], compared to the list of section 7). One can also consider the case where the two groups of phenomena are not independent, but we still want to consider gravity separately, for instance discussing the movement of charged particles sensitive to mass in (ψ, φ). Whether we add gravity (**case 3a**) or not (**case 3b**) in the potentials of (ψ, φ), this corresponds to the current situation of an *approximation*: we consider that we examine the phenomena at two distinct, non-overlapping, space and time scales (a microscopic scale on one side, a cosmological scale on the other). Case 3a corresponds to a somewhat contradictory attitude where quantum mechanics is refined with gravity to the microscopic scale (with gravity laws that are also used for other scales) without compromising a separate analysis of gravity on large scales; for case 3b, one reciprocally considers that the phenomena usually put in quantum mechanics (electromagnetic, strong and weak interactions) are negligible at large

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[25] It is then quantization in the broad sense (see section 6), the first pair {(r, t), (g, h)} can already produce by itself simple effects of discretization.

[26] Cases 3 and 4 are new insofar as we are now dealing with quantum mechanics and general relativity as practiced today, and not with phenomena defined by indeterminate pairs (f, g).

space and time scales. One could imagine to perform some computations in order to see at which space and time scale such particular effect is negligible, according to the options taken. In these cases, there may be some asymmetry depending if one keeps or not at one side or the other (i.e. the side called "gravity" and that called "quantum mechanics") all fundamental phenomena (those of gravity stricto sensu, the electromagnetic, strong and weak interactions).

Case 4 (is also new). Finally it may happen that one understands that the laws of gravity used for large scales on one side (as separated from other interactions) and those employed at the microscopic level on the other side, are different. It may correspond to well-defined situations, such as that of the MOND model for large scales. We are then taken to one of the previous cases, but with a different functioning. It may be that we did not understand the phenomenon of gravity, that is to say we did not understand its hidden connections with the other interactions. It is then necessary to clarify this point before continuing...

Quantum mechanics differ from general relativity by two types of choices (in addition to that pertaining to space and time): - the considering of the phenomena probabilistically, and – the taking into account, in the list of physical phenomena (involved in the Hamiltonian of the Schrödinger equation for example), those related to electromagnetism or weak or strong interactions, but not to gravity. The prohibition to include gravitational interactions within the quantum mechanics computations is an outcome of the "classical" analysis according to which gravity is closely linked to general relativity and space and time (and also negligible at short distance). This veto may be overcome. As we said, we can put gravitational interactions of Newtonian type in a Hamiltonian, and operate quantum formalism identically to the standard case involving the other interactions. This leads to a quantization of gravity. If the question of the space and time definitions does not seem more a bone of contention between quantum mechanics and general relativity, we can wonder in the end whether the problem doesn't rather lie in the understanding of the relationship between gravity and the other interactions (electromagnetic, weak and strong interactions) and in the choice to add the gravitational potential to quantum mechanics.

11. Quantum mechanics and general relativity and situations of "uncertainty"

We did not talk about the so-called indeterminacy, or uncertainty, relations, and about the possible conflict between quantum mechanics and general relativity from that point of view. This does not seem to be a problem. Uncertainties are present, in classical mechanics as well as in general relativity, in the definition of the positions of the material points, the exact characteristics of mobility and immobility of which are unknown; at some point, an arbitrary choice is needed, which is the same for the construction of time and space in opposition to each other (Guy, 2004, 2011a). These uncertainties can be modeled by contrasting two reference frames, and compute the differences between the values of the variables in one frame, and the values in another frame "slightly" modified from the first. The modification of the frames is governed by the small speed v of their (unknown) relative movement. When going from the starting frame to the modified one, we must continue to impose conservation constraints of various kinds; such as those ruling the Lorentz transformations (preserving the "speed" of light, for example); the action of the Lorentz group shows up, as governed by the small velocity v. The transformations, considered as infinitesimal, relate to the previous uncertainties[27] (that is another way to understand so called physical relations of zeroth grade, Guy, 2012).

If now we recognize that the studied variables show up in pairs, the previous group can operate on these dualities and show relations between the uncertainties associated to the quantities in duality. That is to say that *the uncertainties that we discussed in the previous paragraph will occur within pairs and be linked*; we arrive at what we may well call the uncertainty relations within the meaning of quantum mechanics. We followed this approach in Guy (2004) (expressing dualities between space and time variables using a tensor formalism) and obtained general relations, that we can write as : $\delta x.\delta t = A(v)$ (dealing with space and time variables, where A is a function of the unknown speed between the two reference frames[28]). We find in the literature a variety of pragmatic uncertainty relations of the same type (see Burderi and Di Salvo, 2012, for a recent example similar to our result) but which are not incorporated into a conceptual framework as proposed here. More generally, for variables in duality within the zeroth degree relations, and given the equivalence between pairs of physical fields such as (r, t) and (g, h) (leading to the possible "disappearance" of time and

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[27] Or « ill-uncertainty », or « a-certainty » Guy, 2014b

[28] More precisely $(\delta x/x).(\delta t/t) = A(v)$, Guy 2014b.

space), one derives new uncertainty relations as compared with those initially written for space and time, and that one can write δg.δh = A(v) (Bohr and Rosenfeld, 1933, 1950, wrote such relations for the electric and magnetic fields, to be compared with those that we could derive from our approach).

This approach, that can be developed from a general standpoint, and that appears in deep connection with the principle of relativity (in the action of the Lorentz group) joins with what is practiced in quantum mechanics. In this case the duality appears between a function and its Fourier transform, and the uncertainty relations link the spreading, in the statistical sense, of the quantities. Basdevant and Dalibard (2002) show that a still more general duality may be envisaged between quantities that do not commute in the sense of the quantum formalism. Balibar et al. (2007) indicate meanwhile that the uncertainty relations can be considered, in quantum mechanics itself, as resulting from the action of the Lorentz- Poincaré group on the variables in duality that are the wave function and its Fourier transform. This result is to be seen in the wider context of the action of a group on a duality, as we said.

So we have a convergence (at least on the resulting type of formulae, if not fully by the same conceptual approach) between the uncertainty relations in quantum mechanics and similar relations in relativity. The relations mentioned just now are equalities. Inequalities are obtained in particular conditions that we will not discuss here.

Note that we used the same word "uncertainty" for situations having different meanings (and corresponding to quantities that can be added together, without making an a priori distinction between them): - indeterminacy, referring to the spreading of a physical quantity which, by nature, cannot be accurately measured (Lévy Leblond, 1996); - uncertainty, referring to the measurement operation itself (to be ascribed either to the measuring device or to the operator); and - non-certainty (or ill-certainty, or a-certainty, to distinguish it better from the two others, Guy, 2013b and 2014b) referring to our basic ignorance on the constancy of the standards and of the reference frames.

12. Conclusion

In this text, we merely provided a very general framework within which to state, in our own way, the question of the connection between quantum mechanics and general relativity. As we said, general relativity has not the monopoly of space and time, nor quantum mechanics that of quantization; neither gravity nor space-time alone can or must be quantized, but, through an exchange of views, every phenomenon in inhomogeneous composition with another; quantum mechanics cannot nor must not be alone more closely interconnected with space and time, but, similarly, every phenomenon that can be "exchanged" with space and time. One may ultimately consider a quantization of space and time, or envisage the definition of space and time within quantum mechanics alone.

There are many ways to marry the two theories. The strongest link concerns the case where we eliminate the standard field of space and time (r, t) between the pairs {(r, t), (g, h)} and {(r, t), (ψ,φ)}, respectively associated with general relativity and quantum mechanics. We set free from this field because the propagation of light in vacuum that corresponds to it (and which served as a common basis of reckoning for gravity and quantum mechanics) is ideal and no longer corresponds to the situations we want describe: these are concentrated and "cluttered" with both massive and charged matter, they are those where a "quantum gravity" is necessary.

We arrive at the model designated by the pair {(g, h), (ψ, φ)} or {(ψ, φ), (g, h)}. According to the situations (according to the choices made), we could say: (g, h) (that is to say the field described by (g, h) and put in relation with general relativity) serves as a background for (ψ, φ); or (ψ, φ) (that is, the field described by (ψ, φ) and related to quantum mechanics) serves as a background for (g, h). We may have said that (ψ, φ) is quantized or that (g, h) is quantized. That is, the uniform mesh of space and time (in the background) can be based on one or the other of the two pairs of fields (g, h) or (ψ, φ), and the quantization can be said to relate to one or the other of the two pairs associated with gravity or quantum mechanics. In the above, the word quantization is taken in a broad sense. Because, as noted above, it is not so much the use of probabilistic representations in (ψ, φ) that drives the quantization properties in the restricted sense, or discretization, than the inhomogeneous composition between two phenomena ; (ψ, φ) plays in the formalism the mathematical role of any pair (h, i). On another hand, there is an original correspondence between the mathematical formalism and the pragmatics of the physical experiments that refer to the use of the wave function. In particular, with the role of probabilities: $\psi(r, t)$ thus makes it possible to quantify the probability that such event will occur in r and t; conversely, we have to wait for several experiments to make some statistics and say: we are positioned in r and t. More than quantization-discretization, it is the principle of superposition, and all that derives from it, which is peculiar to quantum mechanics.

To build a physical representation, we need a regular reckoning grid. But we must also, to speak of a phenomenon, assess unhomogeneities with regard to this grid. It turns out that in the foregoing, each of the two theories brings us a philosophy, a way of thinking rather one of the two terms of this conceptive tool. Linking general relativity and quantum mechanics combines two basic ingredients of a quantitative description of the world: the first leads us to understand physical quantities, including space and time, in composition with each other. The second emphasizes the non-uniformity aspects of the dispersion of a physical quantity and the associated probabilistic (and quantization) aspects.

The identity of the spatial and temporal relations helped to formulate these questions in a new manner.

It is also the relational approach that underlies it. The two theories are thus connected, but we continue to talk about both. Quantum mechanics and general relativity do not fully identify. Even if one knew how to connect in the same formalism gravity and electromagnetism (to which we can add the other interactions), we would need the two visions conveyed initially by the two theories. Each of them provides one of the two indispensable conceptual components for constructing a coherent whole (in a sense we are at a deeper level than the alliance of gravity and electromagnetism alone, admittedly rather commanded by general relativity and quantum mechanics respectively). We can still say that we have arrived at a single phenomenon in the usual sense (let us call it quantum gravity) in the pairs $\{(g, h), (\psi, \varphi)\}$ or $\{(\psi, \varphi), (g , h)\}$: it combines the two theories that we wanted to unite. This way of doing things reconciles two contradictory points of view, the one of speaking of a single phenomenon, and the other of still considering the one and the other theory for itself in an alliance where each appears as complementary to the other (understood as relational to the other and in need of the other to function[29]).

As we have seen, we must reconsider a number of technical points before confronting and coordinating the two theories. In particular, we must restate quantum mechanics by defining ψ and φ vectors in duality; and restate general relativity so as to encompass two gravitational fields in duality, similarly to electromagnetism; the whole must be rewritten in 3 + 3 dimensions. This is a big project for which various partial attempts can be found in the literature; we will need to link more closely our approach to them; the rephrasing of the mathematical formulations will show whether the tracks mentioned here are passable or not.

If we manage to progress in this direction, all the interest (hidden for the moment in the notation (ψ, φ)) will be to grasp how the particular relations between quantum mechanics and experiment may be combined with the manipulation of the other phenomenon at play (inherited from gravity). If it is this last phenomenon in the pair (g, h) which serves as a basis for the spatio-temporal grid, one is brought back to the usual situation (which includes what is called quantization). If, on the other hand, we rely on (ψ, φ) to build the space-time field, the assignment of some place and time to the field values (g, h) (and their possible quantization s.l.) will be "contaminated" by the proper way quantum mechanics has to conceive experiments, especially in their probabilistic aspects.

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[29] Very pragmatically one needs, in order to make a minimal representation of the world operate, two phenomena to put into relation with each other, as being brought by the observation of the empirical reality (here gravity and electromagnetism, in the broad sense that is to say including other interactions), whether these two phenomena may or may not join together in an ultimate way. This "relational" need to put two "phenomena" in composition with one another, goes as far as the apprehension of situations of non-locality and non-temporality (specific to quantum mechanics) to be combined with those of locality and temporality (found rather on the side of gravitation).

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I thank all the people with whom I could discuss the matter exposed here. I also thank, in advance, the readers for their reactions. The two French versions of this paper (2013, 2016) were downloaded between 5000 and 6000 times (September 2018). Since then, my understanding of things has evolved, new papers have appeared and I would not write in exactly the same way. In order to reach more readers by an English translation, I decide to deliver the text in the state without addition nor modification, corresponding to the second French version. In this text there are parasitic lines with small black squares that I have not managed to delete.

Appendix 1

Elements for a physical theory based on the identity of the spatial and temporal relations

The author has published in a dispersed manner elements for a physical theory based on the identity of the spatial and temporal relations, or, in other words, on the single category of "movement." These are, for a majority, preliminary texts deposited on open archives (HAL), with all the limitations that this implies. Here is a review of the titles up to year 2016 (the French titles of the works have been translated into English). For those papers posterior to 2016, refer to: Guy (book to appear): *Space = time, dialog on the system of the world* (Presses des Mines, Paris).

General conceptual framework:

- Think space and time together, Philosophia Scientiae, 15, 3, 91-113 (Guy 2011a).
- English version: Time and space are of the same stuff, HAL: http://hal.archives-ouvertes.fr/hal-00651429/ (Guy, 2011d)
- Contradictions in the thinking of space, time and movement, in Guy ed., 2010, Proceedings of the Workshop on contradiction, Presses des Mines, pp. 85-92 (Guy, 2010c).
- Towards a relation-based thinking, dialogue between a scientist in politics and a physicist, Proceedings of the Second workshop on contradiction, coordination B. Guy, Presses des Mines, Paris, 77-87 (Dujardin and Guy, 2012).
- Call movement or piece of movement any amplitude of sensible reality, HAL: http://hal.archives-ouvertes.fr/hal-00562672/ (Guy, 2011c)
- Measure the space of a moment, Grand Angle, Journal of the Conférence des Grandes Ecoles, No. 37, February 2013, pages 2, http://www.cge-news.com/main.php?p=696 (Guy, 2013b).
- For a new paradigm: the conceptual dichotomy between time and space has become an obstacle to the progress of thought: let us start by the movement, 2014 <hal-01061765> (Guy, 2014a).
- Time: its inexistence, its other properties, 2016 <hal-01286466> (Guy, 2016a).
- The relations between the concepts of space, time and movement must be discussed again, Connaissances et savoirs, Paris, 2016, 44 p. (Guy, 2016b).

General considerations can also be found in:
- On lightning and thunder, a stroll between space and time (about the theory of relativity), EPU Editions, Paris, 224 p. (Guy, 2004).

Physical development

First step: write the Lorentz transformations with a time parameter figuring a position (3 + 3 dimensions):
- Lorentz tranformations and time: proposal to use a three-dimensional parameter defined by a movement. The issue of time in physics, Internet Archive: http://archive.org/details/LesRelationsDeLorentzEtLeTempspropositionDutilisationDun (Guy 2010a)

Consequences of the effects of contraction-dilation of the space and time variables, and other technical aspects (twin paradox)
- See: On lightning and thunder, a stroll between space and time, op. cit. (Guy, 2004).
- About age and ageing of two twins (theory of relativity), 2015 <hal-01196320> (Guy, 2015a).

Zeroth degree of physical laws:
- Zeroth degree of physical laws, heuristic considerations, HAL: http://hal.archives-ouvertes.fr/hal-00723183 (Guy, 2012)

Modified gravitational laws:
- A modified law of gravitation Taking account of the relative speeds of the moving masses. A preliminary study, http://hal.archives-ouvertes.fr/hal-00472210/fr (Guy, 2010b)

Uncertainty or ill-certainty relations:
- On lightning and thunder, walks between space and time, op.cit. (Guy, 2004)
- For a principle of ill-certainty in physics, 2014 <hal-01062731> (Guy, 2014b).

Understanding of space and time standards
- On the "speed" of light and its measurement: disappearance of space and time standard; the standard movement; http://hal.archives-ouvertes.fr/hal-00814874/; and communication to 22 °

General Congress of the French Physical Society, Marseille, in July 2013, P082 (Guy, 2013d).

The irreversibility of time:

- On lightning and thunder, walks between space and time, op.cit. (Guy, 2004).
- Particles, scale, time structure and the second law of thermodynamics, entropy Meeting the challenge, thermodynamics An international conference in honor and memory of Professor Joseph Henry Keenan, MIT, Cambridge, MA, USA, October 4-5, 2007. The American Institute of Physics, p. 174-179 (Guy, 2008).
- The architecture of thermodynamics and its future developments, HAL: http://hal.archives-ouvertes.fr/hal-00611861/en/ (Guy, 2011b).
- English version: The architecture of thermodynamics and Its future develoments, HAL: http://hal.archives-ouvertes.fr/hal-00863970 (Guy, 2013a).
- Time and space arrows: understanding the second law of thermodynamics, 2015, <hal-01223419> (Guy, 2015b).
- Space, time and entropy, 2016, 110 p., Editions universitaires européennes, 110 p. (Guy, 2016c).

Aspects of quantization and probabilistic aspects for a macroscopic phenomenon:

- Mathematical revision of Korzhinskii's theory of infiltration metasomatic zoning, Eur. J. Mineral., 5, 317-339 (Guy, 1993).
- The behavior of solid solutions in transportation geological processes: the quantization of rock compositions by fluid-rock interaction, in: Complex inorganic solids, structural, stability and magnetic properties of alloys, edited by P. Turchi, A. Gonis, K. Rajan Meike and A. Springer, 265-273 (Guy, 2005).
- Chance, space, time: introduction to a relational approach to probability. Hasard, espace, temps : introduction à une approche relationnelle de la probabilité, <hal-01468456>, (Guy B., 2017b).

- Geological time, 2011 <hal-00530143> (Guy, 2011e).

Aspects of human and social sciences:

- Social groups, space, time, dialogue between a physicist and anthropologist, p 26, http://hal.archives-ouvertes.fr/hal-00468407/en/, Guy, 2010d.
- Think time and space together, op. cit. (Guy 2011a)

- From nature's space and time to man's space and time, about the relations between prehistory and geography, 2016 <hal-01334999> (Guy, 2016d).
- Urban disruptions, a spatio-temporal pragmatics, Parcours Anthropologiques, 10, 2015, 46-64. On line : https://pa.revues.org/422 (Guy, 2015c).
- Looking for cybertime, reflections on cyberspace, 2015 <hal-01175466> (Guy, 2015d).

- Immediacy, instantaneity, velocity, acceleration… : what does the current functionning of these words tell us about our understanding of space, time an movement ? Workshop : « Looking for time (@la recherche du temps)… hyperconnected individual, accelerated society : tensions and transformations », Ecole supérieure de commerce de Paris Europe (ESCP Europe), à paraître, 2016 (Guy, 2016e).
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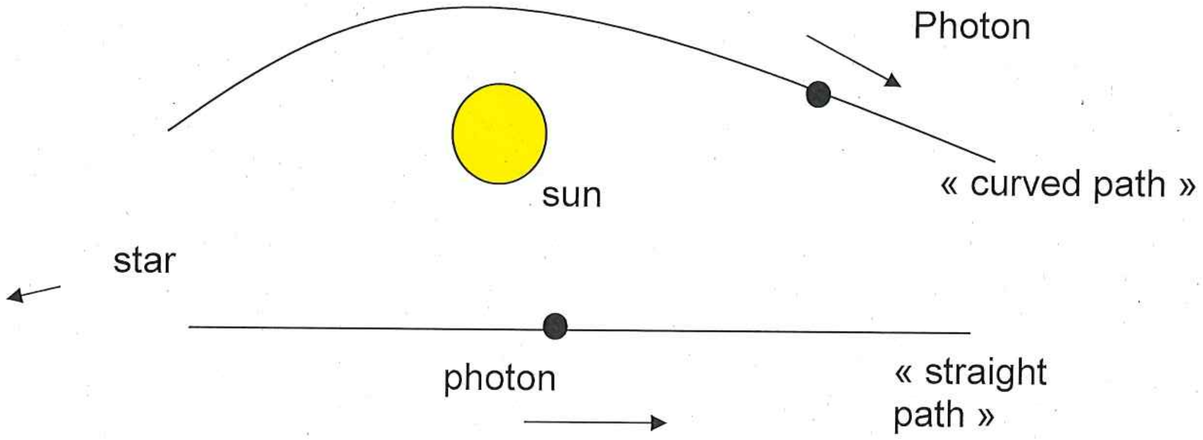

Figure 1

Two space-times are opposed to each other, or, which is equivalent in our understanding, two trajectories: the first associated with the propagation of light (from a distant star) without being influenced by the masses (straight line, bottom), and the second associated with the path of light bent by the presence of the sun, as on the occasion of an eclipse (curved line, top).

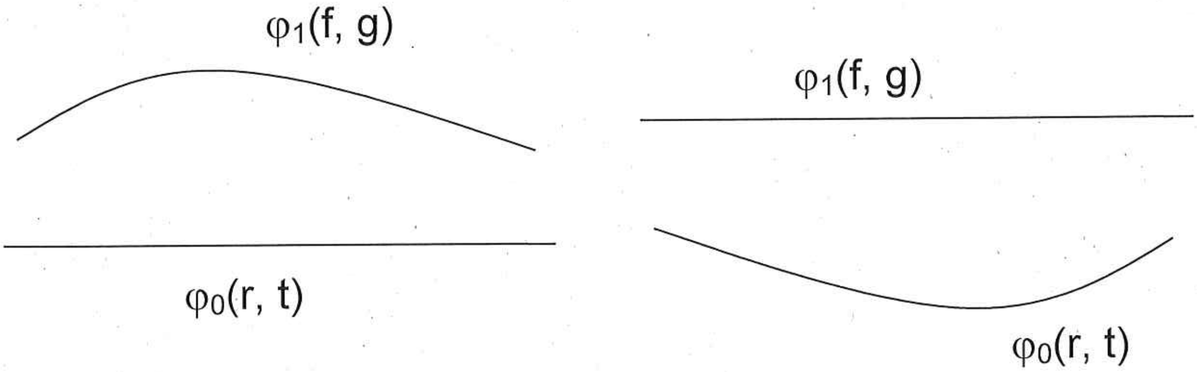

Figure 2

Left: two space-times are displayed, each by a curve or trajectory governed by a phenomenon, either φ_0 or φ_1: φ_0 is associated with r and t fields (space and time) and φ_1 is associated with f and g fields.
Right: we exchanged the two views; φ_1 is considered first, φ_0 is derived.

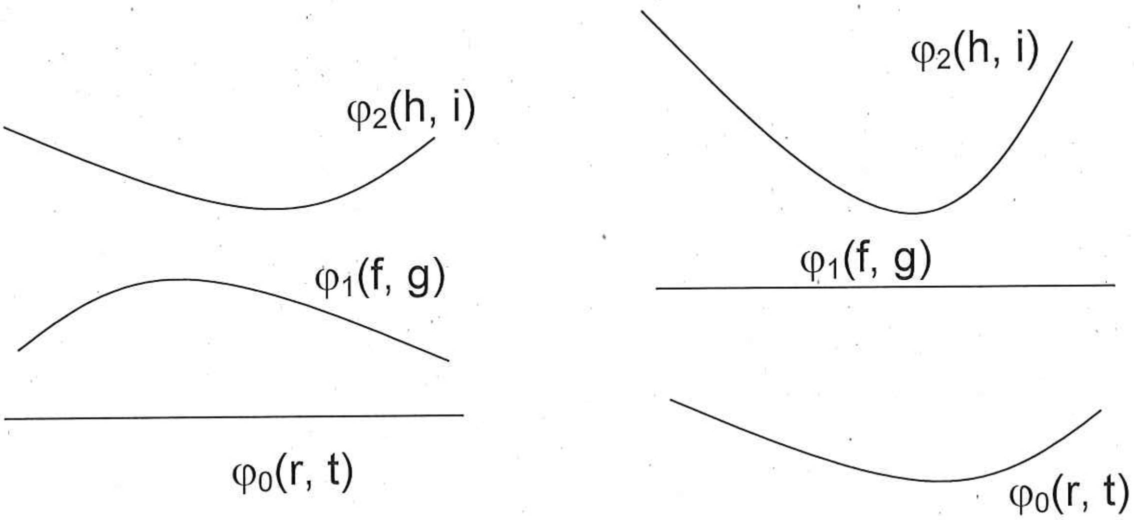

Figure 3

Case where three phenomena are considered. If they are compatible, we can rely on any we wish in order to define space and time. There are three possible choices. Here we have shown two of these choices: on the left φ_0 defines the regular grid for space and time; on the right φ_1 defines the regular grid. In each case, the two other fields (φ_1 and φ_2 on the left, φ_0 and φ_2 on the right) are considered as derived. If the three phenomena are not compatible, one needs to resume the writing of the equations (various cases are possible, see text).

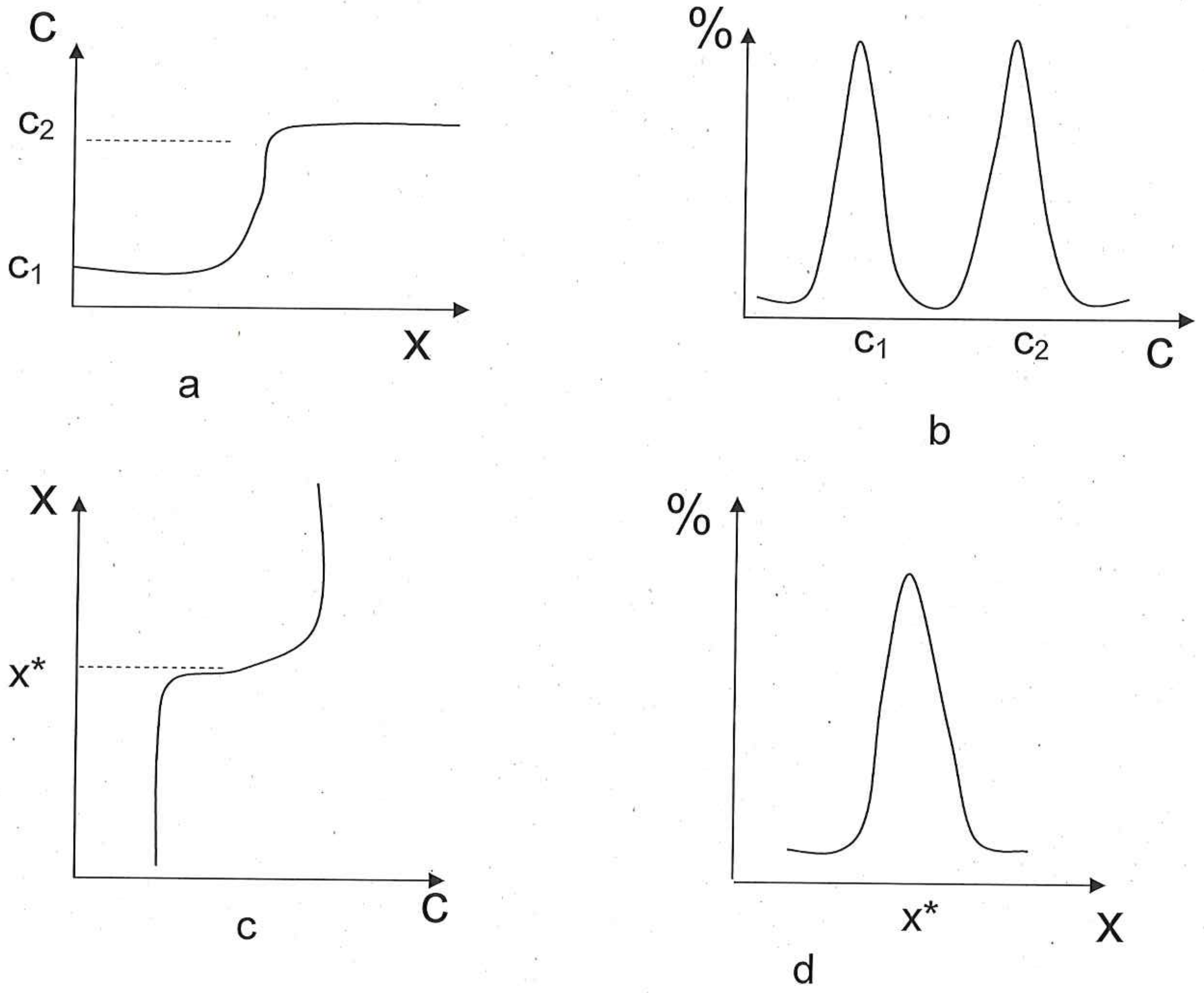

Figure 4

4a Field of a physical quantity, c, unfolding in space x, and showing preferentially two levels of values c_1 and c_2 (quantization/discretization); the switch between the two values occurs around x = x* (x* is shown in Fig. 4c).
4b The quantization shown in Fig. 4a is illustrated by the histogram, or spectrum, of values of the variable c: two peaks around the two values c_1 and c_2 respectively.
4c Field of the quantity x depending on the quantity c (point of view dual to that shown in Fig. 4a, with an exchange of the coordinate axes): one states that space x is a function of the quantity c. If c is now used to measure space, the initial space x is also quantized and preferentially shows a value x*.
4d The quantization shown in Fig. 4c is shown on the histogram: compared to the continuous evolution of c, space is more likely to be around the value x *.
In the abstract spaces on which we define the probabilities (%), the physical space x of uniform distribution is hidden (for c, Fig. 4b); or the space c of uniform distribution is hidden (for x, Fig. 4d). This illustrates the relational aspect of the quantization, thinkable only within the comparison of two points of view (it is not a substantial property). In the general case, a physical quantity is defined a priori in relation to a uniform substrate which, a priori, is implicitly space-time. It is seen from the preceding examples that any curvature of a function c(x) defines a non-uniform probability for c (uniformity of c would correspond to the linear relation c = ax + b).