Quantum Mechanics and the Spinorial Space-Time

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The mathematical properties of the spinoral space-time we introduced in previous papers can have strong implications for Quantum Mechanics and even be its real origin. We complete here our recent discussion of the subject showing that the function of space-time associated to the extended internal structure of a spin-1/2 particle at very small distances can be incompatible with a continuous motion due to the overlap in the time variable directly related to the fact that a spinor function takes nonzero values simultaneously in a whole time interval. Then, if discrete motion is required, the situation will be possibly close to that generating the Feynman path integral. Quantum Mechanics would in this way directly emerge from the spinorial space-time.

1. Introduction

What is the origin of Quantum Mechanics? Is it an ultimate fundamental property of matter, or a property of standard matter generated by a more basic scenario? In the present situation, the answer to this question is far from obvious.

We present here an attempt to explain Quantum Mechanics starting from a more fundamental scenario, using a spinorial space-time with a pre-existing vacuum dynamics that can be associated to a preonic picture.

It turns out, in such a picture, that Quantum Mechanics can be a direct consequence of the original spinorial time uncertainty.

The time spread of a spinorial extended function can generate an overlap between solutions "centered" at different times, leading to a structure incompatible with the same quantum dynamics that can produce a single solution to the vacuum equations for a given time.

2. The spinorial space-time (SST)

The spinorial space-time (SST) we introduced in 1996-97 [1, 2] can possibly be the natural frame to describe a world where fermions exist. Its implications turn out to be highly nontrivial for Particle Physics and Cosmology.

The SST is a SU(2) space-time with two complex coordinates replacing the four standard real ones. Its properties, with possible cosmological implications coming directly from its mathematical structure, have been dealt with in several subsequent papers including in particular [3, 4], [5, 6] and [7].

2.1. SST and cosmic coordinates

If ξ is a SU(2) spinor describing the cosmic SST coordinates (two complex variables replacing the standard four real ones) of a point of our space-time, it is possible to associate to ξ a positive SU(2) scalar $\mid \xi \mid$ such that $\mid \xi \mid^2 = \xi^\dagger \xi$ (the dagger stands for hermitic conjugate). A possible definition of cosmic time (in principle equivalent to the age of the Universe) can then be $t = \mid \xi \mid$ with an associated space given by the S^3 hypersphere $\mid \xi \mid = t$ with an additional spinorial structure that does not exist in the standard space. Other definitions of the cosmic time t in terms of $\mid \xi \mid$ (f.i. $t = \mid \xi \mid^2$) are possible, but they lead to similar cosmological results as long as a single-valued function of $\mid \xi \mid$ is used to define the cosmic time.

Taking $t = \mid \xi \mid$, and ξ_0 to be the observer

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position on the $\mid \xi \mid = t_0$ hypersphere, space translations inside this hypersphere (the space at $t = \mid \xi_0 \mid$) and simultaneously on all the hyperspheres of the SST are described by SU(2) transformations acting on the spinor space, i.e. $\xi = U \xi_0$ with:

$$U = exp \, (i/2 \;\; t_0^{-1} \, \vec{\sigma}.\vec{\mathbf{x}}) \equiv U(\vec{\mathbf{x}}) \qquad (1)$$

$\vec{\sigma}$ being the vector formed by the usual Pauli matrices and the vector $\vec{\mathbf{x}}$ the spatial position (in time units, at the present stage) of ξ with respect to ξ_0 at constant time t_0.

With these definitions, the origin of cosmic time naturally associated to the beginning of the Universe is given by the point $\xi = 0$ with the initial space contracted to a single point. One then gets an expanding universe where cosmological comoving frames are described by straight lines crossing the time origin $\xi = 0$ and are transformed into eachother by the cosmic SU(2). Thus, the SST geometry provides in a natural way a local privileged rest frame for each comoving observer, compatible with existing cosmological observations.

As already shown in [1, 2], an attempt to associate to the cosmic spinor ξ a space-like position vector with real cosmic space coordinates defined by $\vec{\mathbf{x}_c} = \xi^\dagger \vec{\sigma} \xi$ does not actually generate such spatial coordinates. One gets instead $\mid \xi \mid^2$ times a unit vector defining a local privileged space direction (PSD) "parallel" (in the SST) to the cosmic spinor ξ. In other words, the direction of $\xi^\dagger \vec{\sigma} \xi$ corresponds to the set of points whose SST space-time position is equal to ξ times a complex phase.

To define the standard real space coordinates in the SST, a space origin ξ_0 at the cosmic time $t_0 = \mid \xi_0 \mid$ is necessary, as in (1). Such coordinates correspond to a local description of the S^3 hypersphere.

This clearly suggests potential limitations of general relativity and standard cosmology. Rather than an intrinsic fundamental property of space and time, conventional relativity can be expected to be a low-energy symmetry of standard matter similar to the effective Lorentz-like symmetry of the kinematics of low-momentum phonons or solitons in a condensed medium [8, 9] where the speed of sound or the maximum speed of solitons plays the role of the critical speed. The speed of light would then be the critical speed of a family of vacuum excitations (the standard particles) not directly related to an intrinsic space-time geometry.

Space rotations with respect to a fixed point ξ_0 are given by SU(2) transformations acting on the spatial position vector $\vec{\mathbf{x}}$ defined by (1). A standard spatial rotation around ξ_0 is now given by a SU(2) element $U(\vec{\mathbf{y}})$ turning $U(\vec{\mathbf{x}})$ into $U(\vec{\mathbf{y}}) \; U(\vec{\mathbf{x}}) \; U(\vec{\mathbf{y}})^\dagger$. The vector $\vec{\mathbf{y}}$, related to $U(\vec{\mathbf{y}})$ in a similar way to (1), provides the rotation axis and angle. If a spin-1/2 particle is present at the position $\vec{\mathbf{x}}$ with an associated spinor ξ_p describing its internal structure, then ξ_p transforms into $\xi'_p = U(\vec{\mathbf{y}}) \; \xi_p$.

2.2. Some properties of a SST Universe

Three basic cosmological phenomena are automatically generated by the SST in a purely geometric way [3, 4] and without any explicit presence of standard matter:

i) The standard Lundmark-Lemaître-Hubble relation between relative velocities and distances at cosmic scale, with a ratio H (velocity/distance) equal to the inverse of the age of the Universe ($H = t^{-1}$).

ii) The privileged space direction (PSD) for each comoving observer.

iii) Furthermore, in the direct SST formulation, space translations form a (non-abelian) compact group, contrary to standard space-time geometry.

More details, including a study ot the cosmological implications of these properties, are given in [3, 4], [5, 6] and [7].

3. SST at small distances

Similarly to the cosmic SST with the associated SU(2), a local spinorial space-time with its own SU(2) group can be associated to each point ξ_0 in the SST, taking ξ_0 as the local origin.

The internal properties of the standard "elementary" particles are then described by structure functions taking values in the local SST.

A spin-1/2 particle wave or structure function defined at ξ_0 is then a spinorial wave function "centered" at ξ_0 and taking sigificant values around this space-time position.However, $\mid \xi_0 \mid$ is far from being the only value of time concerned, as will be seen in what follows.

4. SST and quantum mechanics

Assuming the (extended) internal structure of a standard "elementary" particle to be a space-time SU(2) eigenstate, the allowed spin (spinorial angular momentum) values would be multiples of 1/2, including 0, 1/2, 1, 3/2 and 2 but also possibly higher spins contrary to standard assumptions. Regge-like trajectories spaced by 1/2 in angular momengtum cannot be excluded.

All particles of standard physics can thus be generated starting from spinorial extended internal structures, and the existence of "elementary" spin-3/2 particles may even be natural in such a pattern. As the Poincaré group is no longer an exact symmetry, an alternative to the supersymmetry approach to space-time and internal symmetries can emerge as a new (approximate and broken) symmetry escaping standard theorems and no-go constraints [3, 4].

Do then the complex wave functions used in standard Quantum Mechanics (SQM) have a specific dynamical origin? The SST geometry can possibly provide a simple answer to this question, as vacuum excitations are expected to be described by (extended) functions of the internal spinorial complex coordinates and scalar products are naturally complex quantities.

In the SST geometry, the four standard real space-time coordinates are replaced by two complex ones as already stressed, and spinors replace the usual four-vectors. Then, the complex internal structure Ψ of a scalar particle can be, for instance, proportional to the hermitic scalar product of two SST spinors ξ_1 and ξ_2 : $\Psi \;=\; \xi_2^\dagger \, \xi_1$. The spinors ξ_1 and ξ_2 can in turn be associated to two wave or structure functions possibly corresponding to the constituents of the scalar particle.

4.1. Fron SST to quantum objects

Quantization can also emerge as a natural property in the SST approach, as the most basic "elementary" particles of the standard model (the fermions like quarks and leptons) are now actual representations of the group of space-time transformations and can be formed as vacuum excitations.

In the SST, a classical wave function for a spin-1/2 particle around a space-time origin ξ_0 can be, for instance:

$$\Psi_{sp}\ (\xi) = F(\mid \xi - \xi_0 \mid^2)\ (\xi - \xi_0) \tag{2}$$

together with:

$$\Psi^*_{sp}\ (\xi) = F(\mid \xi - \xi_0 \mid^2)\ (\xi - \xi_0)^* \tag{3}$$

where * stands for complex conjugate (opposite spin) and the real function F contains a suitable cutoff in $\mid \xi - \xi_0 \mid^2$.

The wave functions Ψ_{sp} and Ψ^*_{sp} clearly violate local standard causality. They take nonzero values for present and future values of cosmic time around $\mid \xi_0 \mid$, and replace distances on the S^3 space-like hypersphere associated to ξ_0 (all the SST points such that $\mid \xi \mid = \mid \xi_0 \mid$, see also [10]) by direct spinorial distances on the SST. Thus, F tacitly defines a space-time distance scale λ_{SST} below which causality does no longer hold in the conventional sense used for our standard space-time. The time-dependence of $F(\mid \xi - \xi_0 \mid^2)$ naturally defines an intrinsic time uncertainty for the particles so described.

λ_{SST} is then likely to correspond to the space-time scale below which standard physics does not apply. Its definition from (2) and (3) is previous to the introduction of a characteristic speed relating space and time units. At this stage of the description, only time units are actually present [2, 3]. We expect, however, a relevant velocity scale to arise from the basic dynamical process that generates such a spin-1/2 particle. Similarly, the propagation of the particle will be associated to a critical speed. Distance scales will thus emerge together with matter generation and propagation.

Vacuum excitations possibly described by complex wave functions spreading over larger (space-time) distance scales than the λ_{SST} scale can be associated to combinations of plane waves, leading to practical definitions of h, energy and momentum. At this stage, some uncertainty relations can be generated from the intrinsic SST spinor time uncertainty.

However, a crucial question remains to be dealt with: that of the quntization of vacuum excitations. In other words, why are there particles instead of just waves? The SST seems to be able to solve this enigma.

If the spinorial wave function of the spin-1/2 excitation describes a deformation of the vacuum structure, it seems reasonable that its normalization be determined by the requirement of preserving the validity of the same (preonic) fundamental equations that generate the physical vacuum. Just as the vacuum structure would be a unique solution of these equations, the same can happen for a local spinorial excitation of each relevant degree of freedom. The Pauli exclusion principle for spin-1/2 particles can also be generated in this way, if the vacuum structure does not allow for several identical spin-1/2 deformations at once in the same space-time region at very small scales.

4.2. How the SST geometry can rule out continuous motion and generate the Feynman path integral

A fundamental characteristics of any extended spinorial wave or structure function in the SST is that it takes nonzero values for a whole interval of time simultaneously. This is an essential difference with respect to standard extended objects in the usual (real) space-time. With four real space-time coordinates, the wave or structure function takes nonzero values simultaneously in several points of space for a given time, but there is a clear separation between different values of time.

Thus, a continous motion of a spin-1/2 particle described by a spinorial function of the type $\Psi_{sp}\ (\xi)$ would generate a significant time overlap in a region of the order of the size λ_{SST} covered by Ψ_{sp}. But the fact that a vacuum excitation defined by $\Psi_{sp}\ (\xi)$ be a solution of the equations of vacuum dynamics does not imply that this would be the case for the superimposed structure generated by continuous motion. $\Psi_{sp}\ (\xi)$ can be an acceptable excitation of vacuum dynamics, but not necessarily its continous motion in a time interval of the order of the particle spinor size. If the continous motion of the spin-1/2 structure is not acceptable by the vacuum dynamics, only a discrete motion will be possible with structures of the Ψ_{sp} type separated by large enough space-time intervals.

If the only solution for spin-1/2 excitations compatible with vacuum dynamics can be a discrete distribution with Ψ_{sp}'s separated by space-time distances larger than the particle size, several discrete trajectories can in principle be possible for a given particle. This seems to generate a situation potentially close to the grounds of the Feynman path integral. The Feynman approach can then that be close to the limit of the present dynamics when space-time distances are much larger than λ_{SST} . Fermi statistics would obviously hold for such quantum particles.

Similarly, the Bose statistics for integer spin particles will be naturally generated if they are made of two spin-1/2 structures and their internal size is at least larger than 2 λ_{SST} . More sophisticated compositions for particles of all spins can obviously be imagined provided the above description applies for the "most elementary" conventional particles.

5. Conclusion and comments

A possible fundamental origin of Quantum Mechanics has been naturally generated from the spinorial space-time with a dynamical preonic vacuum. The time dispersion of the spinorial extended objects plays a crucial role in the mechanism considered to prevent a continuous motion of vacuum spinorial excitations.

A natural complement to this SST approach can be [10] to incorporate superbradyons [8, 11] as the ultimate constituents of matter. Also, possible deformations of quantum mechanics at ultra-high energy [12, 13]) can potentially provide tests of the pattern suggested.

Ther space-time scale at which the preonic vacuum generates standard "elementary" particles can be a new fundamental scale larger than the Planck scale and leading to a new phase of the history of the Universe. Suerpbradyonic generation of matter may be able to replace the conventional Big Bang and inflation pattern [10, 11]. The superbradyonic vacuum can also modify standard quantum field theory, including the calculations leading to the standard cosmological constant [7, 10].

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