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Article

The Origin of Quantum Mechanics

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Abstract

In this paper, we derive the full quantum mechanics theory and its postulates from a totally classical field theory. We just extend the Lorentz symmetry group of space-time by adding a new simple abelian symmetry, gauge them both, and find the resultant equations of motion. Then, all the postulates of quantum mechanics, including spin and the Planck constant, are derived easily and naturally. The interpretation of quantum mechanics gets new insights. Furthermore, the speed of light constant, the number of space-time dimensions, and the Minkowskian metric are derived as collateral results. all in one piece, however ambitious it may seem, it just works. In short, Quantum mechanics is a classical field theory after all, mathematically proven.

Keywords: quantum mechanics interpretation; spin; wave-function collapse; quantum mechanics postulate; particle-wave duality; Lorentz symmetry; Planck constant

1. introduction

Quantum mechanics is a well-established theory, but the origin of its postulates or axioms [6] is not proved yet. Every physicist takes them for granted in his research with no further questions. Many quantum phenomena are still not well-understood. For example, the *Measurement problem* and the *wave function collapse* have many interpretations, and there is no consensus on any specific solution [5]; The *particle-wave duality*, the matter is both a wave and a particle at the same time, how is that possible?; What is the meaning of $\hbar$ constant; Why is the energy-momentum quantized? The superposition principle, which states that a particle is a combination of many different states at the same time, what is the physical mechanism?

Furthermore, every particle has a spin. This is also taken for granted. What is its physical origin? The spin isn't found in classical physics. How can a plain wave have a spin or angular momentum? And many other open questions and deviations from classical mechanics.

Quantum mechanics came in the first, mostly by hand, to fit the observations and famous experiments like the double slit experiment and wave-particle duality nature. However, it still lacks a rigorous mathematical framework, which is provided here. All the quantum mechanics postulates and principles will be derived from a classical field theory and all the above phenomena will be easily explained and understood in the text. This paper is structured as follows: In the Section 2, we extend the Lorentz symmetry group by adding a new abelian symmetry group. In the Section 3, we find the equation of motion solution under this symmetry and derive the quantum states, the Planck constant $\hbar$, the speed of light, and the number of space-time dimensions. In the Section 4, we derive the quantum operators, uncertainty relation, and the quantization conditions. In the Section 5, we find the representation of the particle under the Poincaré group and extract the complex wave function. In the Section 6, we show how all the quantum mechanics postulates are derived from the current model and thus prove the whole theory of quantum mechanics. In the Section 7, We deduce the entanglement of particles. In the Section 8, we finally show that the angles of the extended Lorentz symmetry are just the quantum action, and Feynman's path integral formulation is deduced.

2. Extending the Lorentz Symmetry Group

We start by extending the Lorentz group as follows:

First the $SU(2) \times SU(2)$ group is the double cover of the Lorentz Group $SO(1,3)$ [1] :

$$SO(1,3) \hookrightarrow SU(2) \times SU(2) \cong SL(2, C), \quad (1)$$

rename it into,

$$SU^L(2) \times SU^R(2), \quad (2)$$

$(\vec{j}^L, \vec{j}^R)$ Are the generators of $SU^{L/R}(2)$. The Lie algebra of the new generators satisfies [3,4] :

$$\begin{aligned} [j_i^R, j_j^L] &= i\epsilon_{ijk}j_k^L, \\ [j_i^R, j_j^R] &= i\epsilon_{ijk}j_k^R, \\ [j_i^L, j_j^R] &= 0, \end{aligned} \quad (3)$$

where $i = 1, 2, 3$. We expand this symmetry to :

$$[SU^L(2) \times SU^R(2)] \times [U^L(1) \times U^R(1)] \cong U^L(2) \times U^R(2), \quad (4)$$

This is done by adding $j_0^{R/L}$ the generators of $U^{R/L}(1)$.

This expansion of the Lorentz symmetry of space-time doesn't contradict the Coleman-Mandula Theorem [10–13], which argues that any symmetry group of the S-matrix must be a direct product as follows: Symmetry Group = Poincaré Group $\times$ Internal Symmetry Group. This means that any additional symmetries must be *internal*, i.e., they must commute with the space-time (Poincaré) symmetries. No non-trivial mixing of space-time and internal symmetries is not allowed in this framework. In our case, it is not violated as the extension $U^L(1) \times U^R(1)$ commutes with the proper Lorentz symmetry group $SU^L(2) \times SU^R(2)$, so it can be considered as an internal symmetry from another point of view.

3. The Equation of Motion and Emergence of Quantum States

The covariant derivative under the extended lorentz symmetry is:

$$D_\mu \phi^{R/L}(r_\mu) = [\partial_\mu - igq^{R/L}\omega_\mu^{R/Li}j_i^{R/L} - ig_0q_0^{R/L}\omega_\mu^{R/L0}j_0^{R/L}]\phi^{R/L}(r_\mu), \quad (5)$$

where $i = 1, 2, 3$. ϕ^R Lies in $(0, n)_{0, q_0^R}$ representation and ϕ^L lies in $(n, 0)_{q_0^L, 0}$. So they have spin, by definition. $(\omega_\mu^{R/L0}, \vec{\omega}_\mu^{R/L})$ are the gauge fields of $U^{R/L}(1), SU^{R/L}(2)$ respectively. Using the symmetry between left and right-handed groups, we assign: $(\omega_\mu^{R/L0}, \vec{\omega}_\mu^{R/L}) \equiv (\omega_\mu^0, \vec{\omega}_\mu)$. $q_0^{R/L}, q^{R/L}$ are the conserved charges of $U^{R/L}(1), SU^{R/L}(2)$ respectively. defining the following ratios :

$$\begin{aligned} \frac{|g_0q_0^L|}{|gq^L|} &= -a \\ \frac{|g_0q_0^R|}{|gq^R|} &= +a, \end{aligned} \quad (6)$$

using the symmetry between the left-hand and the right-hand, defining: $|q^R| = |q^L| = q, |q_0^R| = |q_0^L| = q_0, \vec{j}^L = \vec{j}^R = \vec{j}, j_0^L = j_0^R = j_0$. Then Equation (5) becomes:

$$D_\mu \phi^{R/L}(r_\mu) = [\partial_\mu - igq(\omega_\mu^i j_i \pm a\omega_\mu^0 j_0)]\phi^{R/L}(r_\mu), \quad (7)$$

The constant a is nothing more than the speed of light constant: $a = c$. Then defining:

$$\begin{aligned} j^L &= (cj_0, \vec{j}) \\ j^R &= (cj_0, -\vec{j}) \end{aligned} \quad (8)$$

The covariant derivative Equation (7) becomes:

$$D_\mu \phi^{R/L}(r_\mu) = [\partial_\mu \pm igq\omega_\mu^v j_\nu^{R/L}] \phi^{R/L}(r_\mu), \quad (9)$$

where $\omega_\mu^v = (\omega_\mu^0, \vec{\omega}_\mu) \cdot j_\nu^{R/L}$, $\phi^{R/L}$ lie in any representation. For example, in the spinor representation, the generators are,

$$\begin{aligned} j_\mu^L &= (cI, \vec{\sigma}) \\ j_\mu^R &= (cI, -\vec{\sigma}) \end{aligned} \quad (10)$$

which are just the well-known Pauli four vectors, i.e.,

$$\begin{aligned} j_\mu^L &= \bar{\sigma}_\mu/2, \\ j_\mu^R &= \sigma_\mu/2 \end{aligned} \quad (11)$$

The $1/2$ is a normalizing factor. $\phi^{R/L}$ lies in the spinor representation and has spin $1/2$ (charge), which are just the left and right-handed Weyl fermions $\phi^{R/L} \equiv \psi^{R/L}$; $j_\mu^{L/R}$ is an orthonormal basis of the space-time under the trace norm, i.e. $\text{tr}(j^{L/R\mu} j_\nu^{L/R}) = \delta_\nu^\mu$. Hence, the number of generators of the extended Lorentz symmetry is the number of space-time dimensions, and the special division into subgroups $U(2) = SU(2) \times U(1)$ makes it a Minkowskian space-time instead of Euclidean space-time. The position vector $r_\mu^{R/L}$ lie in the adjoint representation (real) and have spin 1 (charge) with left/right-handed chirality. For simplicity, we set $r_\mu^L = r_\mu^R = r_\mu$.

Next, substituting $q = \hbar, g = 1$, $\hbar$ is the Planck constant, and $\partial_\mu \equiv I\partial_\mu$, we obtain,

$$D_\mu \phi^{R/L}(r_\mu) = [\partial_\mu \pm i\hbar\omega_\mu^v j_\nu^{R/L}] \phi^{R/L}(r_\mu), \quad (12)$$

Defining $\hbar\omega_\mu^v j_\nu^{R/L} := \hbar\omega_\mu^{R/L}$. $\omega_\mu^{R/L}$ is a four vector with the orthonormal basis $\{j_\nu^{R/L}\}$. setting $\omega_\mu^{R/L} \equiv \omega_\mu$ due to the similarity between right and left-handed. The covariant derivative becomes:

$$D_\mu \phi^{R/L}(r_\mu) = [\partial_\mu \pm i\hbar\omega_\mu] \phi^{R/L}(r_\mu), \quad (13)$$

The Lagrangian for a massless particle charged under the extended Lorentz symmetry is:

$$\mathcal{L} = (D_\mu \phi^{R/L}(r_\mu))^\dagger D_\mu \phi^{R/L}(r_\mu), \quad (14)$$

Notice that when $\hbar = 0$ it gives back the classical dynamics by the classical Lagrangian :

$$\mathcal{L} = \partial_\mu \phi^{R/L}(r_\mu) \partial^\mu \phi^{R/L}(r_\mu) \quad (15)$$

And the equation of motion is

$$\square \phi^{R/L}(r_\mu) = 0, \quad (16)$$

The equations of motion of Equation (14) are :

$$D_\mu D^\mu \phi^{R/L} = 0, \quad (17)$$

explicitly,

$$\left(\square - 2i\hbar \omega^\mu \partial_\mu - \hbar^2 \omega_\mu \omega^\mu \right) \phi^{R/L}(r_\mu) = 0, \quad (18)$$

For simplicity, assuming ω_μ is constant, i.e., $\partial_\mu \omega^\mu = 0$, the solution is as follows, We try a plane-wave solution:

$$\phi_c^{R/L}(r_\mu) = e^{ik_\mu r^\mu} \phi_c^{R/L}(r_\mu = 0) \quad (19)$$

which also satisfy $\square \phi_c^{R/L} = 0$, i.e., the classical solution in Equation (16). Next, calculating:

$$\square \phi^{R/L} = -k^\mu k_\mu \phi^{R/L} = -p^2 \phi^{R/L}, \quad (20)$$

$$\omega^\mu \partial_\mu \phi^{R/L} = i(\omega^\mu k_\mu) \phi^{R/L}, \quad (21)$$

Then plugging into Equation (18), we obtain:

$$\left(p^2 + 2\hbar(\omega^\mu k_\mu) + \hbar^2 \omega^2 \right) \phi^{R/L} = 0. \quad (22)$$

Dividing out $\phi^{R/L} \neq 0$, we get the extended dispersion relation:

$$p^2 - 2\hbar(\omega^\mu k_\mu) + \hbar^2 \omega^2 = 0. \quad (23)$$

We complete the square:

$$(k^\mu + \hbar \omega^\mu)^2 = 0, \quad (24)$$

which implies that the shifted momentum $p^\mu := k^\mu + \hbar \omega^\mu$ is null:

$$p^\mu p_\mu = 0. \quad (25)$$

So the general solution of Equation (17) is a superposition of plane waves satisfying this dispersion relation:

$$\phi^{R/L}(r_\mu) = \int d^4k g(k) e^{ik_\mu r^\mu}, \quad \text{with } (k^\mu + \hbar \omega^\mu)^2 = 0. \quad (26)$$

assigning $p^\mu = k^\mu + \hbar \omega^\mu$, then

$$\phi^{R/L}(r_\mu) = e^{-i\hbar \omega_\mu r^\mu} \int d^4p f(p) e^{ip_\mu r^\mu}, \quad (27)$$

defining,

$$\phi_c^{R/L}(r_\mu) = \int d^4p f(p) e^{ip_\mu r^\mu}, \quad (28)$$

which is a superposition of classical plane waves satisfying Equation (19). then Equation (27) becomes:

$$\phi^{R/L}(r_\mu) = e^{-i\hbar \omega_\mu r^\mu} \phi_c^{R/L}(r_\mu), \quad \text{where } \square \phi_c^{R/L}(r_\mu) = 0 \quad (29)$$

- $\phi_c^{R/L}(r_\mu)$ is a solution to the free massless classical particle ($\hbar = 0$ or $\omega_\mu = 0$).
- The exponential factor $e^{-i\hbar \omega_\mu r^\mu}$ accounts for the phase shift introduced by the constant field ω_μ .

Next, choosing the classical solution to be a constant instead of a wave:

$$\phi_c^{R/L}(r_\mu) = e^{-ik_\mu r^\mu} \phi_c^{R/L}(r_\mu = 0) \equiv \phi_c^{R/L}(r_\mu = 0) = \text{constant} \quad (30)$$

which is obtained by choosing $k_\mu \equiv 0$, meaning it is a static solution and has no classical energy-momentum (k_μ). Equation (29) becomes:

$$\phi^{R/L}(r_\mu) = ce^{-i\hbar\omega_\mu r^\mu} \quad (31)$$

assigning initial conditions $c = \phi^{R/L}(r_\mu = 0)$,

$$\begin{aligned} \phi^{R/L}(r_\mu) &= e^{-i\hbar\omega_\mu r^\mu} \phi^{R/L}(r_\mu = 0) \\ &= e^{-i\hbar\omega_\mu^v j_v^{R/L} r^\mu} \phi^{R/L}(r_\mu = 0) \end{aligned} \quad (32)$$

Then p_μ from Equation (24), becomes,

$$p^\mu = \hbar\omega^\mu \quad (33)$$

which is just *the quantization of energy-momentum!* Hence, we obtain the *particle-wave duality* as the solution in Equation (32) is a wave in space-time together with this result. The choice $k_\mu \equiv 0$ means there is no more classical energy-momentum in the universe, only the quantized energy-momentum p_μ .

next, plugging $p^\mu = \hbar\omega^\mu$ into Equation (32), and changing coordinates $r_\mu \rightarrow r_\mu/\hbar$ gives,

$$\begin{aligned} \phi^{R/L}(r_\mu) &= e^{-ip_\mu^v j_v^{R/L} r^\mu/\hbar} \phi^{R/L}(r_\mu = 0) \\ &= e^{-ip_\mu r^\mu/\hbar} \phi^{R/L}(r_\mu = 0), \end{aligned} \quad (34)$$

where $p_\mu^v = \hbar\omega_\mu^v$. This is the familiar evolution in space-time of a *quantum state / wave function!*

4. Derivation of the Quantum Operators

4.1. the Energy-Momentum Operator and the Uncertainty Relation

Using the bra-ket notation $|\phi\rangle$ of linear algebra, the solution in Equation (34) can be rewritten:

$$\langle r_\mu | \phi^{R/L} \rangle = \langle r_\mu = 0 | e^{-ip_\mu r^\mu/\hbar} | \phi^{R/L} \rangle \quad (35)$$

where we use the Riesz representation theorem [7] of the inner product $\langle r_\mu | \phi^{R/L} \rangle = \phi^{R/L}(r_\mu)$. $\phi^{R/L}$ is a state with energy-momentum p_μ , so it can be defined by its eigenvalue as $|\phi^{R/L}\rangle = |p_\mu^{R/L}\rangle \equiv |p_\mu\rangle$, and the solution is rewritten as:

$$\langle r_\mu | p_\mu \rangle = p_\mu(r_\mu) = \exp(-ip_\mu r_\mu/\hbar) p_\mu(r_\mu = 0) \quad (36)$$

which is an eigenvector of the energy-momentum operator extracted as follows: We start by projecting Equation (33) on the state $|\hbar\omega^\mu\rangle$ with the eigenvalue $p^\mu = \hbar\omega^\mu$ gives

$$p^\mu |\hbar\omega^\mu\rangle = \hbar\omega^\mu |\hbar\omega^\mu\rangle \quad (37)$$

then projecting on $\langle\phi|$

$$\begin{aligned} \langle\phi| p^\mu |\hbar\omega^\mu\rangle &= \langle\phi| \hbar\omega^\mu |\hbar\omega^\mu\rangle \\ p^\mu \phi(\omega^\mu) &= \hbar\omega^\mu \phi(\omega^\mu) \end{aligned} \quad (38)$$

Applying inverse Fourier transformations $\{\omega_\mu \leftrightarrow r_\mu\}$ on both sides, by using the Fourier transformation of a derivative, we obtain,

$$p^\mu \mathcal{F}^{-1}\{\phi(\omega^\mu)\} = -i\hbar \frac{\partial}{\partial r_\mu} \mathcal{F}^{-1}\{\phi(\omega^\mu)\} \quad (39)$$

defining $\mathcal{F}^{-1}\{\phi(\omega^\mu)\} := \tilde{\phi}(r^\mu)$, then,

$$p^\mu \tilde{\phi}(r^\mu) = -i\hbar \frac{\partial}{\partial r_\mu} \tilde{\phi}(r^\mu) \quad (40)$$

This is also equal by definition,

$$\hat{p}^\mu \tilde{\phi}(r^\mu) := p^\mu \tilde{\phi}(r^\mu) = -i\hbar \frac{\partial}{\partial r_\mu} \tilde{\phi}(r^\mu) \quad (41)$$

therefore,

$$\hat{p}_\mu = -i\hbar \frac{\partial}{\partial r_\mu} \quad (42)$$

which is the *energy-momentum operator* in r^μ space. defining the *four-position operator* $\hat{r}_\mu$ acting on $\langle r_\mu |$ state from Equation (36):

$$\langle r_\mu | \hat{r}_\mu = \langle r_\mu | r_\mu \quad (43)$$

satisfying the *uncertainty relation* $[\hat{r}_\mu, \hat{p}_\mu] = i\hbar$. Next, multiplying Equation (42) by a constant r_μ^0 and rearranging, we obtain:

$$ir_\mu^0 \frac{\hat{p}_\mu}{\hbar} = r_\mu^0 \frac{\partial}{\partial r_\mu} \quad (44)$$

Taking the exponent of both sides gives,

$$e^{\frac{i}{\hbar} r_\mu^0 \hat{p}_\mu} (\cdot) = e^{r_\mu^0 \frac{\partial}{\partial r_\mu}} (\cdot) \quad (45)$$

The exponent is a mapping from a Lie algebra vector space $\mathfrak{g}$ to the equivalent group G (unitary), $\exp : \mathfrak{g} \rightarrow G$. then acting on $\phi^{R/L}(r_\mu)$,

$$e^{-ir_\mu^0 \frac{\hat{p}_\mu}{\hbar}} \phi^{R/L}(r_\mu) = e^{r_\mu^0 \frac{\partial}{\partial r_\mu}} \phi^{R/L}(r_\mu) \quad (46)$$

this equals,

$$e^{-ir_\mu^0 \frac{\hat{p}_\mu}{\hbar}} \phi^{R/L}(r_\mu) = \phi^{R/L}(r_\mu - r_\mu^0) \quad (47)$$

defining,

$$e^{-ir_\mu^0 \frac{\hat{p}_\mu}{\hbar}} := T_{r_\mu^0} \quad (48)$$

$T_{r_\mu^0}$ is a unitary operator ($\hat{p}_\mu$ in the exponent is hermitian) performing a translation $(r_\mu - r_\mu^0)$. Then the solution can be written as:

$$\phi^{R/L}(r_\mu) = e^{-i\hat{p}_\mu r^\mu / \hbar} \phi^{R/L}(r_\mu = 0), \quad (49)$$

4.2. The Angular Momentum Operator and Quantization Conditions

The solution of the Lagrangian in Equation (14) after a coordinate change from linear coordinates r_μ to cyclic coordinates γ_μ , by the same steps in the linear case, we obtain,

$$\phi^{R/L}(\gamma_\mu) = e^{-i\hbar j_\nu^{R/L} \gamma^\nu} \phi^{R/L}(\gamma_\mu = 0), \quad (50)$$

There $\phi^{R/L}(\gamma_\mu)$ is a rotation of the initial state $\phi^{R/L}(\gamma_\mu = 0)$ under the extended Lorentz symmetry $U^{L/R}(2)$. Equating to the solution in Equation (32) in the linear coordinates, we obtain the relation,

$$\omega_\mu^\nu r^\mu := \gamma^\nu \quad (51)$$

which is a generalization of rotation in 2d dimensions $\omega t = \gamma$. This explains why the gauge fields ω_μ^ν have angular velocity units. The *angular momentum operator* is easily derived from the exponent of the solution in Equation (50), which is the part coupled to angles γ^ν :

$$\hat{L}_\nu = -i\hbar j_\nu^{R/L} \quad (52)$$

For example, for a spinor representation, $j_\nu^{R/L} = (I/2, \pm \vec{\sigma}/2)$ the operator becomes:

$$(L_0, \vec{L}) = (-i\hbar \frac{I}{2}, \pm i\hbar \frac{\vec{\sigma}}{2}) \quad (53)$$

$\vec{L}$ is the familiar operator for the angular momentum of spin 1/2 particles in quantum mechanics. L_0 is the energy of rotation (similar to the energy component of the energy-momentum vector $(E, \vec{p})$ in a linear movement). Next, Substituting $\hat{L}_\nu$ in Equation (50) and scaling $\gamma^\nu \rightarrow \gamma^\nu / \hbar$, we obtain:

$$\phi^{R/L}(\gamma_\mu) = e^{-i\hat{L}_\mu \gamma^\mu / \hbar} \phi^{R/L}(\gamma_\mu = 0), \quad (54)$$

Applying periodic conditions on the rotations of the spatial part $i = 1, 2, 3$, for bosonic representation, we have,

$$\phi^{R/L}(2\pi) = e^{-i\hat{L}_i 2\pi / \hbar} \phi^{R/L}(0) \equiv e^{-i2\pi n_i} \phi^{R/L}(0), \quad (55)$$

then,

$$\hat{L}_i = n_i \hbar \quad (56)$$

in the same manner for fermionic representation $\phi^{R/L}(2\pi) = -\phi^{R/L}(0)$:

$$\hat{L}_i = (n_i + 1/2) \hbar \quad (57)$$

Which are the quantization of angular momentum.

5. The Extended Poincaré Group Representation

The Poincaré group in this new formulation becomes,
Poincaré group = extended Lorentz symmetry group $\times$ translation symmetry group.
which we call the *extended Poincaré group*. Then, every particle representation is composed of two states:

$$|\phi\rangle = |S_\mu\rangle \otimes |p_\mu = (E, \vec{p})\rangle, \quad (58)$$

$|S_\mu\rangle$ is the spin state (due to rotation symmetry):

$$\phi_s^{R/L}(\gamma_\mu) = e^{-iL_\mu \gamma^\mu / \hbar} \phi_s^{R/L}(\gamma_\mu = 0), \quad (59)$$

$|p_\mu = (E, \vec{p})\rangle$ is the state of energy-momentum (due to translation symmetry):

$$\phi_p^{R/L}(r_\mu) = e^{-ip_\mu r^\mu/\hbar} \phi^{R/L}(r_\mu = 0), \quad (60)$$

For example, for a non-relativistic ($p_\mu \approx (E, \vec{0})$) scalar particle, the quantum state is $|\phi\rangle = |(0,0)_{\hbar,0}\rangle \otimes |p_\mu = (E,0)\rangle$: $|S_\mu = (0,0)_{\hbar,0}\rangle$ is the scalar representation state, substitute in Equation (59), we obtain:

$$\begin{aligned} \phi_s^{R/L}(\gamma_\mu) &= e^{-i(L_0\gamma^0/\hbar + \vec{L}\cdot\vec{\gamma}/\hbar)} \phi^{R/L}(\gamma_\mu = 0) \\ &= e^{-i(L_0\gamma^0/\hbar)} \phi^{R/L}(\gamma_\mu = 0) \\ &= e^{-i\gamma^0} \phi^{R/L}(\gamma_\mu = 0) \end{aligned} \quad (61)$$

where $L_0 = I\hbar$, a quantized angular momentum. $|p_\mu = (E,0)\rangle$ is the particle energy-momentum representation state, substituting in Equation (60) we obtain,

$$\begin{aligned} \phi_s^{R/L}(\gamma_\mu) &= e^{-i(Et/\hbar + \vec{p}\cdot\vec{r}/\hbar)} \phi^{R/L}(\gamma_\mu = 0) \\ &= e^{-i(Et/\hbar)} \phi^{R/L}(\gamma_\mu = 0) \\ &= e^{-i(\omega t)} \phi^{R/L}(\gamma_\mu = 0) \end{aligned} \quad (62)$$

where $E = \hbar\omega$ is the quantized energy. The rotation ω is in the $U^{R/L}(1)$ space while the particle is moving along the time coordinate satisfying $\omega t = \gamma^0$. This explains the origin of this weird angular frequency that causes the interference pattern in the famous double-split experiment. in total,

$$|\phi\rangle_T = |(0,0)_{\hbar,0}\rangle \otimes |p_\mu = (E,0)\rangle = e^{-i(\omega t + \gamma^0)} \phi^{R/L}(0) \quad (63)$$

Hence, every particle in the universe is a *complex wave* ! in space time, which is just the wave function ψ known from quantum mechanics, first described by Schrodinger, i.e., $\phi_T \equiv \psi$

6. Derivation of Quantum Mechanics Postulates

6.1. Postulate 1: State Postulate

A quantum system is completely described by a state vector (also called a *ket*), denoted as $|\phi\rangle$ in a complex Hilbert space. The state encodes all the information about the system. These states also have spin.

The derivation: The representation space is a Hilbert space by definition. Its representation states are the state vectors $|\phi\rangle$, and the representation type is the spin, i.e., scalar representation (spin 0), vector representation (spin 1), and spinor representation (spin 1/2). All the representations are unitary by definition, hence $\langle\phi|\phi\rangle = 1$, by the inner product $\langle\phi_1|\phi_2\rangle$ of this Hilbert space.

6.2. Postulate 2: Time Evolution Postulate

The time evolution of a closed system is described by a unitary transformation on the initial state.

$$|\phi\rangle = e^{-iEt/\hbar} |\phi_0\rangle, \quad (64)$$

The derivation: This is driven by the solution in Equation (62)

6.3. Postulate 3: Observable Postulate

Every observable (like position, momentum, energy) is represented by a Hermitian operator $\hat{O}$ acting on the Hilbert space. The possible outcomes of measuring the observable are the eigenvalues of this operator.

The derivation: Let f be a functional on a particle state ϕ , it can be represented by the Riesz representation theorem [7] of the internal product as:

$$\langle \phi | f \rangle = f(\phi) \quad (65)$$

Therefore, $|f\rangle$ lies in some representation of the extended Lorentz symmetry, and it can be written as,

$$f = e^{-i\hbar O^\nu j_\nu^{R/L}} \quad (66)$$

$O^\nu \equiv \gamma'^\nu$ are angles of rotation in the extended Lorentz symmetry, defining: $\hat{O} := O^\nu j_\nu^{R/L}$ a hermitian matrix or operator ($j_\nu^{R/L}$ are hermitian).

$$f = e^{-i\hbar \hat{O}} \quad (67)$$

finding the eigenvalues of $\hat{O}$:

$$\hat{O}|\phi_\lambda\rangle = \lambda|\phi_\lambda\rangle \quad (68)$$

Where $|\phi_\lambda\rangle$ is the eigenvector. then,

$$f|\phi_\lambda\rangle = e^{-i\hbar\lambda}|\phi_\lambda\rangle \quad (69)$$

acting on the state $\langle r_\mu |$ gives:

$$\begin{aligned} \langle r_\mu | f | \phi_\lambda \rangle &= \langle r_\mu | e^{-i\hbar\lambda} | \phi_\lambda \rangle \\ [f(\phi_\lambda)](r_\mu) &= e^{-i\hbar\lambda} \phi_\lambda(r_\mu) \end{aligned} \quad (70)$$

$$(71)$$

Therefore, the dynamics or the evolution of the state $|\phi_p\rangle$ is exclusively determined by the eigenvalue λ . hence, it is the only observable which can be extracted ("observed") from Equation (68) by projecting on $\langle \phi_\lambda |$:

$$\langle \phi_\lambda | \hat{O} | \phi_\lambda \rangle = \langle \phi_\lambda | \lambda | \phi_\lambda \rangle = \lambda \quad (72)$$

which is known as the expectation value.

Then every diagonalizable operator (hermitian) $\hat{O}$ can be decomposed into its eigenvalues' subspaces by the spectrum theorem,

$$\hat{O} = \lambda_i \sum_i |\phi_{\lambda_i}\rangle \langle \phi_{\lambda_i}|, \quad (73)$$

$|r_i\rangle \langle r_i| = P_i$ is the projection operator satisfying $P_i^2 = P_i$. where $|\phi_{\lambda_i}\rangle \in H^i$ are its orthonormal eigenvectors in the eigenvalue subspaces $\hat{O}|\phi_{\lambda_i}\rangle = \lambda_i|\phi_{\lambda_i}\rangle$. The unit matrix operator I is defined as ($\lambda_i \equiv 1$):

$$\hat{O} = \sum_i |\phi_{\lambda_i}\rangle \langle \phi_{\lambda_i}| = I, \quad (74)$$

Finding the expectation value of ϕ :

$$\begin{aligned}\langle \phi | \hat{O} | \phi \rangle &= \langle \phi | \hat{O} I | \phi \rangle = \sum_i \langle \phi | \hat{O} | \phi_{\lambda_i} \rangle \langle \phi_{\lambda_i} | \phi \rangle = \sum_i \lambda_i \langle \phi | \phi_{\lambda_i} \rangle \langle \phi_{\lambda_i} | \phi \rangle \\ &= \sum_i \lambda_i |\langle \phi | \phi_{\lambda_i} \rangle|^2 = \sum_i \lambda_i P(\lambda_i) = \langle \lambda \rangle,\end{aligned}\quad (75)$$

where we used $|\langle \phi | \phi_{\lambda_j} \rangle|^2 := P(\lambda_j)$ is the probability that the state $|\phi\rangle$ collapses into $|\phi_{\lambda_i}\rangle$ which is addressed postulate 5 6.5,

6.4. Postulate 4: Composite Systems Postulate

For two quantum systems with Hilbert spaces $\mathcal{H}_1$ and $\mathcal{H}_2$, the state space of the combined system is the tensor product:

$$\mathcal{H} = \mathcal{H}_1 \otimes \mathcal{H}_2, \quad (76)$$

A *sub-postulate* is the **Symmetrization postulate**(Pauli exclusion principle) : The wavefunction of a system of N identical particles (in 3D) is either totally symmetric (Bosons) or totally antisymmetric (Fermions) under interchange of any pair of particles.

The derivation: Let H, K be Hilbert spaces. Let $H \otimes K = h \otimes k : h \in H, k \in K$. Define an inner product $\langle \cdot, \cdot \rangle$ on $H \otimes K$ by:

$$\langle h_1 \otimes k_1, h_2 \otimes k_2 \rangle = \langle h_1, h_2 \rangle_H \langle k_1, k_2 \rangle_K, \quad (77)$$

With respect to this inner product, $H \otimes K$ is a Hilbert space called the Hilbert space direct product of H and K .

Therefore, if $|\phi_1\rangle \in H, |\phi_2\rangle \in K$ are two representations, then $|\phi_1\rangle \otimes |\phi_2\rangle$ is a representation in the Hilbert space $H \otimes K$.

This can be generalized by induction to: if $|\phi_i\rangle \in H^i$ are representations, then $\otimes_i |\phi_i\rangle$ is a representation in the Hilbert space $\otimes_i H_i$.

The exchange of states is anti-symmetric for fermions and symmetric for bosons, due to the innate properties of rotation of these representations:

$$|\phi\rangle = e^{-i\hbar\gamma^\nu j_\nu^{R/L}} \quad (78)$$

If $j_\nu^{R/L} \in$ the spinor representation, the exchange (rotation) will be antisymmetric. If $j_\nu^{R/L} \in$ the vector representation, the exchange (rotation) will be symmetric. Hence, the sub-postulate is reproduced.

6.5. Postulate 5: Measurement Postulate

When a measurement of an observable $\hat{O}$ is made on a system in a state $|\phi\rangle$:

- The result is one of the eigenvalues λ_n of $\hat{O}$.
- The probability of getting λ_n is:

$$\mathbf{P}(\lambda_n) = |\langle \lambda_n | \phi \rangle|^2, \quad (79)$$

- $|\lambda_n\rangle$ is the eigenstate corresponding to the eigenvalue λ_n .
- After measurement, the system collapses (according to Copenhagen's interpretation [14–17]) into the state $|\lambda_n\rangle$ corresponding to the measured eigenvalue.

The derivation: Let H, K be Hilbert spaces. Let $H \oplus K = h \oplus k : h \in H, k \in K$, define an inner product $\langle \cdot, \cdot \rangle$ on $H \oplus K$ by:

$$\langle h_1 \oplus k_1, h_2 \oplus k_2 \rangle = \langle h_1, h_2 \rangle_H + \langle k_1, k_2 \rangle_K, \quad (80)$$

With respect to this inner product, $H \oplus K$ is a Hilbert space called the Hilbert space of the direct sum of H and K . Therefore, if $|\phi_1\rangle \in H^{r_1}, |\phi_2\rangle \in H^{r_2}$ are representations, then also $|\phi_1\rangle \oplus |\phi_2\rangle$ is a representation in the Hilbert space $H^{r_1} \oplus H^{r_2}$.

The operator $\hat{\mathbf{O}}$ is defined in $\oplus_i H^i$ Hilbert space in the same manner :

$$\hat{\mathbf{O}}|R\rangle = \left(\bigoplus_{i=1}^N \hat{O}_i\right)\left(\bigoplus_{i=1}^N |r_i\rangle\right) = \bigoplus_{i=1}^N (\hat{O}_i |r_i\rangle), \quad (81)$$

where $\hat{\mathbf{O}} = \bigoplus_{i=1}^N \hat{O}_i$.

defining an orthonormal basis of $\oplus_i H^i$:

$$|V\rangle = \sum_i^N \alpha_i |V_i\rangle \quad (82)$$

where $|V_i\rangle = |0\rangle \oplus |0\rangle \dots \oplus |v_i\rangle \oplus |0\rangle$ and $\delta_{ij} = \langle V_i | V_j \rangle$. Then the operator can be written as:

$$\hat{\mathbf{O}} = \lambda_i \sum_i |V_i\rangle \langle V_i|, \quad (83)$$

and the identity operator,

$$I = \sum_i |V_i\rangle \langle V_i|, \quad (84)$$

Given the following representations states :

$$\begin{aligned} |R_\mu\rangle &= \bigoplus_{i=1}^N |r_\mu^i\rangle \\ |P_\mu\rangle &= \bigoplus_{i=1}^N |p_\mu^i\rangle, \end{aligned} \quad (85)$$

where $|r_\mu^i\rangle := \alpha_i |x_\mu^i\rangle; |p_\mu^i\rangle := \beta_i |k_\mu^i\rangle$ lives in *one-dimensional* Hilbert spaces with the orthonormal basis $|x_\mu^i\rangle; |k_\mu^i\rangle$. These states have $(N!)$ degeneracy by swabbing the direct sum order. Applying unitarity,

$$\begin{aligned} 1 &= \langle R_\mu | R_\mu \rangle = \sum_{i=1}^N \langle r_\mu^i | r_\mu^i \rangle_{H_{r_i}} = \sum_i |\alpha_i|^2 \\ 1 &= \langle P_\mu | P_\mu \rangle = \sum_{i=1}^N \langle p_\mu^i | p_\mu^i \rangle_{H_{r_i}} = \sum_i |\beta_i|^2, \end{aligned} \quad (86)$$

defining the following vectors:

$$\begin{aligned} |R_\mu^i\rangle &= |0\rangle \oplus |0\rangle \dots \oplus |r_\mu^i\rangle \oplus |0\rangle \\ |P_\mu^i\rangle &= |0\rangle \oplus |0\rangle \dots \oplus |p_\mu^i\rangle \oplus |0\rangle, \end{aligned} \quad (87)$$

The representations in Equation (85), then can be written,

$$\begin{aligned} |R_\mu\rangle &= \sum_{i=1}^N |R_\mu^i\rangle \\ |P_\mu\rangle &= \sum_{i=1}^N |P_\mu^i\rangle, \end{aligned} \quad (88)$$

Their internal product is :

$$\langle R_\mu | P_\mu \rangle = \sum_{i=1}^N \langle r_\mu^i | p_\mu^i \rangle_{H_{r_i}} = \sum_{i=1}^N \alpha_i^* \beta_i, \quad (89)$$

using $\langle r_\mu | p_\mu \rangle = p_\mu(r_\mu) = \exp(-ip_\mu r_\mu / \hbar) p_\mu(r_\mu = 0)$ from Equation (36) we have,

$$\begin{aligned} \langle R_\mu | P_\mu \rangle &= P_\mu(R_\mu) = \sum_{i=1}^N \langle r_\mu^i | p_\mu^i \rangle_{H_{r_i}} \\ P_\mu(R_\mu = 0) \exp(+iP_\mu R^\mu / \hbar) &= \sum_{i=1}^N p_\mu^i(r_\mu^i = 0) \exp(+ip_\mu^i r^{i\mu} / \hbar) \\ &= \sum_{i=1}^N \langle r_\mu^i = 0 | p_\mu^i \rangle \exp(+ip_\mu^i r^{i\mu} / \hbar), \end{aligned} \quad (90)$$

which is the *superposition principle* of quantum mechanics. now, projecting on a state $|R_\mu^k\rangle = |0\rangle \oplus |0\rangle \dots \oplus |r_\mu^k\rangle \oplus |0\rangle$ gives,

$$\langle R_\mu^k | P_\mu \rangle = \sum_{i=1}^N \langle r_\mu^k = 0 | p_\mu^i \rangle \exp(-ip_\mu^i r^{i\mu} / \hbar), \quad (91)$$

by Equation (89), $\langle r_\mu^k = 0 | p_\mu^i \rangle \neq 0$, only for $i = k$, we obtain:

$$\begin{aligned} \langle R_\mu^k | P_\mu \rangle &= \sum_{i=1}^N \delta_k^i \langle r_\mu^i = 0 | p_\mu^i \rangle \exp(-ip_\mu^i r^{i\mu} / \hbar) \\ &= \langle r_\mu^k = 0 | p_\mu^k \rangle \exp(-ip_\mu^k r^{k\mu} / \hbar) \\ P_\mu(R_\mu^k) &= p_\mu^k(r_\mu^k = 0) \exp(-ip_\mu^k r^{k\mu} / \hbar), \end{aligned} \quad (92)$$

which is the *collapsed state* (Copenhagen's interpretation) into r_μ^k Hilbert space. Calculating the amplitude of the wave function,

$$\begin{aligned} \langle P_\mu | R_\mu^k \rangle \langle R_\mu^k | P_\mu \rangle &= \langle p_\mu^k | r_\mu^k = 0 \rangle \langle r_\mu^k = 0 | p_\mu^k \rangle = |\langle r_\mu^k = 0 | p_\mu^k \rangle|^2 \\ \Rightarrow |P_\mu(R_\mu^k)|^2 &= |p_\mu^k(r_\mu^k = 0)|^2 = |\alpha_k^* \beta_k|^2, \end{aligned} \quad (93)$$

summing over k , and using the identity operators, $\sum_k |R_\mu^k\rangle \langle R_\mu^k| = I$, we obtain,

$$\begin{aligned} \sum_k \langle P_\mu | R_\mu^k \rangle \langle R_\mu^k | P_\mu \rangle &= \langle P_\mu | P_\mu \rangle = 1 \\ \Rightarrow \sum_k |P_\mu(R_\mu^k)|^2 &= \sum_k |p_\mu^k(r_\mu^k = 0)|^2 = \sum_k |\alpha_k^* \beta_k|^2 = 1, \end{aligned} \quad (94)$$

which is the famous *Max Born's rule of probability*. It has a probabilistic nature because the projection (the quantum measurement) on the state $\langle R_\mu^k | \in \{ \langle R_\mu^i | \}_{i=1}^N$ is probabilistic; choosing one state out of N similar states has N combinations :

$$N = \frac{N!}{1!(N-1)!} \quad (95)$$

Every projection has a weight (amplitude) of $|p_\mu^k(r_\mu^k = 0)|^2$ to project on it. The collapse isn't unitary because the observer picks a random state $\langle R_\mu^k |$ and discards the others,

$$P_\mu(R_\mu) \neq P_\mu(R_\mu^k) \quad (96)$$

If the observer can build a measurement apparatus that projects the state onto the superpositions of the position of the apparatus $\langle R_\mu | = \sum_i^N \langle R_\mu^i |$ instead, the collapse will not happen! This means if there is a direct sum of observers, $\{ |R_\mu^i \rangle \}_i$ the collapse never happens, which is similar to the *many worlds interpretation* of Hugh Everett [18–20]:

$$P_\mu(R_\mu) = \sum_k P_\mu(R_\mu^k) \quad (97)$$

This is the unitary evolution of this direct sum of universes by the Equation (90). These universes are not so real, as one may think, they are just different representations of the same extended Lorentz group (the only invariant part to all representations).

7. The Most General Representation States

postulates 4 + 5 give the most general Hilbert space built as :

$$H_G = \alpha_j \bigoplus_j \left(\bigotimes_{i_j} H^{i_j} \right)^j, \quad (98)$$

Which is a polynomial spanning of the space of "Hilbert spaces ". The representations states in H_G , $|V_G\rangle \in H_G$, are composed of a superposition/ direct sum ($\bigoplus_j$) of multi-particle ($\bigotimes_{i_j}$) states. In case the states are entangled, i.e., $\bigotimes_{i_j} H^{i_j}$ Don't have a separable basis, $\bigotimes_{i_j} H^{i_j} \in \text{span}\{\bigotimes_{i_j} e_i\}$ the states are then written as

$$|V\rangle = \bigoplus_{j=1}^N \alpha_j |v^1, v^2 \dots v^j\rangle^j, \quad (99)$$

Which is the *entanglement*.

8. The Quantum action and Feynman's path integral formulation

The Hamiltonian $\mathcal{H}$ is related to the Lagrangian L by [2]:

$$\mathcal{H} = P_i \dot{r}_i - L \quad ; \quad i = x, y, z, \quad (100)$$

where P_i is the momenta. Multiplying the two sides by dt :

$$\mathcal{H}dt = P_i dr_i - Ldt, \quad (101)$$

The Lagrangian is given by $L := E_K - qV$; the Hamiltonian is given by $\mathcal{H} = E_K + qV$. qV is the potential energy. E_K is the kinetic energy. For a free particle $qV = 0$, gives: $L = \mathcal{H} = E_K$ the action is given by : $dS = Ldt$; substituting in Equation (101) gives,

$$E_K dt - P_i dr_i = -dS, \quad (102)$$

For a massless particle, the kinetic energy equals the total energy of the particle: $E = (mc^2 + E_K) = 0 + E_K = E_K$. Then Equation (102) becomes:

$$Edt - P_i dr_i = -dS \quad (103)$$

$$\Rightarrow -P^\mu dr_\mu = dS, \quad (104)$$

where $P_\mu := (E, \vec{P})$. For a massless particle moving in a field A_μ , the potential energy is $V = qA_0$ and the particle's four-energy-momentum is $p_\mu = P_\mu - qA_\mu$, substitute in Equation (103) gives,

$$-p^\mu dr_\mu = dS, \quad (105)$$

Boosting (rotation in extended Lorentz symmetry) to the rest frame gives:

$$\begin{aligned} dS &= -(p_0, \vec{0})(dt, \vec{0}) = -p_0 dt = -(E - q\Delta A_0)dt = -(E - V) = -Ldt \\ &\Rightarrow E - V = L, \end{aligned} \quad (106)$$

And we retrieved the Lagrangian back. So the *Legendre transformation is just the extended Lorenz transformation!*

Therefore, we will define the action accordingly as follows:

$$-p_\mu r^\mu = S, \quad (107)$$

Or in basis notation :

$$-j_\mu^{R/L} p_\nu^\mu r^\nu = j_\mu^{R/L} S^\mu = S^{R/L}, \quad (108)$$

And its differential in the case of p_ν^μ constant:

$$-j_\mu^{R/L} p_\nu^\mu dr^\nu = j_\mu^{R/L} dS^\mu = dS^{R/L}, \quad (109)$$

For simplicity, assigning $S^R = S^L$ using the symmetry of the right-handed and left-handed. Substituting the quantized momentum $p^\mu = \hbar\omega^\mu$ and the relation for angular velocity: $\omega_\mu^\nu dr_\nu = d\gamma_\mu$ by Equation (51) gives:

$$-\hbar\omega_\mu^\nu dr_\nu = \hbar d\gamma_\mu = ds_\mu, \quad (110)$$

thus,

$$\frac{ds_\mu}{\hbar} = d\gamma_\mu, \quad (111)$$

Making the re-scaling $\hbar\gamma_\mu \rightarrow \gamma_\mu$ gives:

$$ds_\mu = d\gamma_\mu \rightarrow s_\mu = \gamma_\mu, \quad (112)$$

Hence, the action is nothing more than the particle's *rotation angles* of the extended Lorenz symmetry!. These angles are equivalent to Action-angle coordinates [8] used in classical mechanics!

Substituting Equation (111) in Equation (54) gives,

$$\phi^{R/L}(r_\mu) = e^{\frac{-ij_\nu^{R/L} S_\nu}{\hbar}} \phi^{R/L}(r_\mu = 0) = e^{\frac{-iS^{R/L}}{\hbar}} \phi^{R/L}(r_\mu = 0), \quad (113)$$

which is the familiar *quantum action!*

Every quantum action is a translation in space-time by the energy-momentum operator, see Equation (49):

$$e^{\frac{-idS^{R/L}}{\hbar}} = e^{\frac{-ip_\mu dr^\mu}{\hbar}} = \hat{T}(r_\mu^0 + dr_\mu) \quad (114)$$

performing successive translation $r = \sum_j d^j r$:

$$\begin{aligned} \prod_j e^{\frac{-id^j S^{R/L}}{\hbar}} &= \prod_j e^{\frac{-ip_\mu d^j r^\mu}{\hbar}} = \prod_j \hat{T}(r_\mu^0 + d^j r_\mu) \\ e^{\frac{-i \int dS^{R/L}}{\hbar}} &= e^{\frac{-i \int p_\mu dr^\mu}{\hbar}} = \hat{T}(r_\mu^0 + r_\mu) \\ e^{\frac{-iS(r_\mu, p_\mu)}{\hbar}} &= \hat{T}(r_\mu^0 + \int dr_\mu) \end{aligned} \quad (115)$$

which in total gives a translation in some path $l = \int dr_\mu$, so assuming all the possible paths (via superposition) gives the Feynman's path integral formulation of quantum mechanics.

$$\phi^{R/L}(r_\mu)_T = \int_{\text{all the possible paths}} e^{\frac{-iS^{R/L}}{\hbar}} \phi_0^{R/L} \quad (116)$$

9. Discussion

The description of quantum mechanics, as shown, can be replaced by a description of a classical scalar field charged under local extended Lorentz symmetry and its corresponding gauge fields. This simple classical treatment reproduces all the quantum mechanics postulates and techniques. The quantum operators are derived according to this new view, and the exclusive role of their eigenvalues in the evolution of the particle is deduced; hence, they are the only observables in nature. We gave examples of the classical derivation of energy-momentum, the four-position, the angular momentum operators, and their eigenvalues. The Planck constant $\hbar$ finally got a meaning: the quantized charge of the local Lorentz symmetry. The quantization of energy-momentum is derived, including the famous relations $E = \hbar\omega$, $\vec{p} = \hbar\vec{k}$, which are just the kinetic energy of the gauge fields of the extended Lorentz symmetry. The quantum action is also derived naturally from this description. The angles of the extended Lorentz symmetry were shown to be just the quantum action. The superposition and wave-function collapse are explained as the direct sum of many similar representations of the extended Lorentz symmetry. The universe we live in is shown to be just a representation space of the extended Lorentz symmetry, hence the Hilbert space of quantum mechanics, instead of the classical real world we use in classical mechanics. The different representations of the extended Lorentz symmetry are the elementary particles we observe in nature. The classification of the elementary particle into bosons, fermions, and scalars is just a different representation of this symmetry.

10. Conclusions

Quantum mechanics can be totally replaced by a classical field charged under the Lorentz symmetry group of space-time with a simple extension. The angles of the extended Lorentz symmetry are the quantum action. The conserved charge is the Planck constant, and gauge fields carry the observed quantized energy-momentum. All the quantum postulates can be derived naturally, easily, and consistently from this description, hence proving the full theory with its weird phenomena. The extended Lorentz symmetry also explains the origin of the speed of light, the dimension of space-time, and the Minkowski metric.

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