

Time Evolution of Particle in Quantized Gravitational Field

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Abstract

Through this article, an attempt has been made to propose a heuristic method to determine wave evolution in a quantized gravitational field. In this paper, propagation of particles in a quantized gravitational field is studied. Instead of quantizing the gravitational field into superposition of plane wave solutions, here at a certain point in spacetime, the all-possible values of the field due uncertainty of the gravitational field at that point due to uncertainty in momentum and position of the particle curving spacetime is assigned a probability using the derived rules in the paper. The interaction between other fields and the gravitational field is determined by superimposing all possible solutions what the field would be like in every possible geometry of the curved spacetime with uncertainty of the gravitational field at that point due to uncertainty in momentum and position of the particle curving spacetime.

Keywords: Physics of gravity; Gyroscopic forces of electron rotation; Temperature dependence

Introduction

Renormalization is needed for integrating over internal x in Feynman diagrams, But it can avoid it in finding a quantum theory of gravity, if we use general relativity's original view of curvature in spacetime cause gravity instead of gravitons. Here, we study evolution of a field in each of the geometries for each mass equivalence eigen-sates of the particle curving spacetime's at every spacetime point separated by light like intervals from a given point. This process is repeated for all point in spacetime for an observer.

Due to uncertainty in position and momentum of the particle curving spacetime, there will be uncertainty in the geometry of spacetime at every point.

Now by using conditional probability theory we can get the particle evolution in each of the possible geometries but in probability, not probability density, ie, we need phase retrieval. So, now an iterative algorithm can retrieve its phase if we have the probability of all possible eigenstates of its momenta.

Field evolution in quantized gravitational field

Using Schwarzschild metric, we get $x^1 = r$

Then, the geodesics equation becomes [1,2]

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$$\frac{d^2r}{d\tau^2} = - \left[\frac{R_s c^2}{2r^3} (r - R_s) (v^r)^2 + \frac{R_s}{2r} \left(\frac{1}{r - R_s} \right) (v^r)^2 + (r - R_s) (v^\theta)^2 + (r - R_s) \sin^2 \theta (v^\phi)^2 \right] \quad (1)$$

Where, $R_s = \frac{2GM}{c^2}$

We know that,

$$g = \frac{d^2r}{d\tau^2} - a_c \quad (2)$$

where g is the proper acceleration seen by the observer.

We know,

$$\begin{aligned} a_c &= \frac{v_\perp^2}{r} \\ &= \frac{\left(\frac{rd\theta}{dt} \right)^2 + \left(\frac{r \sin \theta d\phi}{dt} \right)^2}{r} \\ &= r \left(\frac{d\theta}{dt} \right)^2 + r \left(\frac{\sin \theta d\phi}{dt} \right)^2 \\ &= r \left(\frac{d\theta}{d\tau} \frac{d\tau}{dt} \right)^2 + r \left(\frac{\sin \theta d\phi}{d\tau} \frac{d\tau}{dt} \right)^2 \\ &= (r - R_s) (v^\theta)^2 + (r - R_s) \sin^2 \theta (v^\phi)^2 \quad (3) \end{aligned}$$

Therefore,

$$g = - \frac{R_s c^2}{2r^3} (r - R_s) (v^r)^2 - \frac{R_s}{2r} \left(\frac{1}{r - R_s} \right) (v^r)^2 \quad (4)$$

A change in curvature of spacetime at a point in spacetime due to change in position of particles should be causally connected by light like spacetime interval. The change in curvature of spacetime at a point (x_0, t_0) in spacetime due to wave packet must be

causally connected by light like spacetime interval, i.e, $\Delta x = c\Delta t$. Therefore, the wave packet at $x_0 + x, t_0 - \left| \frac{x}{c} \right|$ to induce the change in curvature of spacetime at x_0, t_0 .

The absolute value of time interval is taken as negative value of time interval will imply effect precedes the cause.

Let's assume there is a particle A at (x_0, t_0) and another particle B at $\left(x_0 + x, t_0 - \left|\frac{x}{c}\right|\right)$, the particle at (x_0, t_0) which will be accelerated due to gravity by a value $g(x) = -\frac{R_s c^2}{2r^3}(r - R_s)(v^t)^2 - \frac{R_s}{2r}\left(\frac{1}{r - R_s}\right)(v^r)^2$, whose value is dependent on the distance of separation.

If the particle B's probability to exist at $x_0 + x, t_0 - \left|\frac{x}{c}\right|$ rather than some probability less than 1 to exist at $x_0 + x, t_0 - \left|\frac{x}{c}\right|$, let's say probability $\mathbb{P}\left(x_0 + x, t_0 - \left|\frac{x}{c}\right|\right)$ for the particle B to exist at $\left(x_0 + x, t_0 - \left|\frac{x}{c}\right|\right)$ then the probability of particle A being accelerated by $\frac{d^2 x^\mu}{d\tau^2}$ must be $\mathbb{P}\left(x_0 + x, t_0 - \left|\frac{x}{c}\right|\right)$ as we know $\frac{d^2 x^\mu}{d\tau^2}$ depends on mass equivalence of the other particle $M_{rel} = m^2 + \frac{p^2}{c^2}$ and distance of separation x . Since, here M_{rel} is constant, probability of $\frac{d^2 x^\mu}{d\tau^2}$ will only depend on the probability of the distance to separation between the particles equal to x [3,4].

By Born rule, we know

$$\mathbb{P}\left(x_0 + x, t_0 - \left|\frac{x}{c}\right|\right) = \mathbb{P}(g(x)) \quad (5)$$

$$= \lim_{\delta x \rightarrow 0} \int_{x_0 + x - \delta x}^{x_0 + x + \delta x} \left\langle \Psi \left| x_0 + x, t_0 - \left|\frac{x}{c}\right|\right\rangle \left\langle x_0 + x, t_0 - \left|\frac{x}{c}\right| \right| \Psi \right\rangle \times \frac{1}{\sqrt{1 - \frac{2GM}{c^2 x}}} dx$$

Since proper length in change with distance of separation, the term $\frac{1}{\sqrt{1 - \frac{2GM}{c^2 x}}}$ is multiplied.

Since we know sum of probability of all possibilities should be 1, therefore a condition must be set

$$\int_{-\infty}^{\infty} \left\langle \Psi \left| x_0 + x, t_0 - \left|\frac{x}{c}\right|\right\rangle \left\langle x_0 + x, t_0 - \left|\frac{x}{c}\right| \right| \Psi \right\rangle \frac{1}{\sqrt{1 - \frac{2GM}{c^2 x}}} dx = 1 \quad (6)$$

To get,

$$\int_{-\infty}^{\infty} \left\langle \Psi \left| x_0 + x, t_0 - \left|\frac{x}{c}\right|\right\rangle \left\langle x_0 + x, t_0 - \left|\frac{x}{c}\right| \right| \Psi \right\rangle \frac{1}{\sqrt{1 - \frac{2GM}{c^2 x}}} dx = 1$$

We can set the normalizing constant

$$= \frac{1}{\int_{-\infty}^{\infty} \left\langle \Psi \left| x_0 + x, t_0 - \left| \frac{x}{c} \right| \right\rangle \left\langle x_0 + x, t_0 - \left| \frac{x}{c} \right| \right| \Psi \right\rangle \frac{1}{\sqrt{1 - \frac{2GM}{c^2 x}}} dx}$$

Let's say there are N number of spacetime co-ordinates $\left(x_0 + x, t_0 - \left| \frac{x}{c} \right| \right)$ where $\left\langle x_0 + x, t_0 - \left| \frac{x}{c} \right| \right| \Psi \right\rangle$ is non-zero, i.e., the

probability of the particle B described by Ψ_B has a non-zero chance of existing at $x_0 + x, t_0 - \left| \frac{x}{c} \right|$. Let the position co-ordinates

that satisfy the above criterion be $x_0 + x_1, x_0 + x_2, x_0 + x_3, \dots, x_0 + x_n$. Besides it, on taking into account the uncertainty in

momentum of the particle B at time coordinates $t_0 - \left| \frac{x_1}{c} \right|, t_0 - \left| \frac{x_2}{c} \right|, t_0 - \left| \frac{x_3}{c} \right|, \dots, t_0 - \left| \frac{x_n}{c} \right|$, we can say there are number of

momentum eigenvalues $a_1, a_2, a_3, \dots, a_n$ at time $t_0 - \left| \frac{x_1}{c} \right|, t_0 - \left| \frac{x_2}{c} \right|, t_0 - \left| \frac{x_3}{c} \right|, \dots, t_0 - \left| \frac{x_n}{c} \right|$, respectively [5].

Since there is an uncertainty in momentum of the particle B, the mass equivalence of particle B be uncertain. The probability of a

mass equivalence eigenstate is $\lim_{\delta p \rightarrow 0} \int_{\sqrt{M_{rel}^2 c^2 - m^2 c^2} - \frac{\delta p^\mu}{2}}^{\sqrt{M_{rel}^2 c^2 - m^2 c^2} + \frac{\delta p^\mu}{2}} \left| \left\langle \sqrt{M_{rel}^2 c^2 - m^2 c^2} \right| \Psi \right\rangle^2 dp$ of the particle B.

Thus, probability of the particle A being accelerated by $g(x, M_{rel})$ is equal to

$$\frac{\lim_{\delta x \rightarrow 0} \int_{x_0 + x - \frac{\delta x}{2}}^{x_0 + x + \frac{\delta x}{2}} \left\langle \Psi \left| x_0 + x, t_0 - \left| \frac{x}{c} \right| \right\rangle \left\langle x_0 + x, t_0 - \left| \frac{x}{c} \right| \right| \Psi \right\rangle \frac{1}{\sqrt{1 - \frac{2GM}{c^2 x}}} dx}{\int_{-\infty}^{\infty} \left\langle \Psi \left| x_0 + x, t_0 - \left| \frac{x}{c} \right| \right\rangle \left\langle x_0 + x, t_0 - \left| \frac{x}{c} \right| \right| \Psi \right\rangle \frac{1}{\sqrt{1 - \frac{2GM}{c^2 x}}} dx} \quad (7)$$

he probability of particle B being at $x_0 + x, t_0 - \left| \frac{x}{c} \right|$

$$\lim_{\delta x \rightarrow 0} \int_{\sqrt{M_{rel}^2 c^2 - m^2 c^2} - \frac{\delta p}{2}}^{\sqrt{M_{rel}^2 c^2 - m^2 c^2} + \frac{\delta p}{2}} \left| \left\langle \sqrt{M_{rel}^2 c^2 - m^2 c^2} \right| \Psi \right\rangle^2 dp$$

the probability of particle B being at Possessing momentum $\sqrt{M_{rel}^2 c^2 - m^2 c^2}$ at time $t_0 - \left| \frac{x}{c} \right|$

Let there be a particles particle A at x_0, t_0 . As mentioned earlier there are N number of spacetime co-ordinates $\left(x_0 + x, t_0 - \left| \frac{x}{c} \right| \right)$

where $\left\langle x_0 + x, t_0 - \left| \frac{x}{c} \right| \middle| \Psi \right\rangle$ is non zero. Since there is uncertainty in momentum, at time

$$t_0 - \left| \frac{x_1}{c} \right|, t_0 - \left| \frac{x_2}{c} \right|, t_0 - \left| \frac{x_3}{c} \right| \dots t_0 - \left| \frac{x_n}{c} \right|,$$

let's say there are $a_1, a_2, a_3, \dots, a_n$ number of momentum eigenvalues at time $t_0 - \left| \frac{x_1}{c} \right|, t_0 - \left| \frac{x_2}{c} \right|, t_0 - \left| \frac{x_3}{c} \right| \dots t_0 - \left| \frac{x_n}{c} \right|$, respectively. Therefore, there are $a_1 + a_2 + a_3 + \dots + a_n$ possible values of $g(x, M_{rel})$ which will have a non-zero probability by

which the particle can be accelerated towards $x_0 + x$ in time interval $\lim_{dt \rightarrow 0} d\tau = \sqrt{1 - \frac{R_s}{x}} dt$. Therefore, particle A will have a non-zero probability of existing in all possible coordinates $\left(x_0 + g(x, M_{rel}) \lim_{dt \rightarrow 0} d\tau^2 + v \lim_{dt \rightarrow 0} d\tau \right)$ after the time interval $\lim_{dt \rightarrow 0} d\tau$.

If particle A described by Ψ_A has uncertainty in position such that it could be at two positions r and s at time t_0 simultaneously such that $\left| \langle r, t_0 | \Psi_A \rangle \right|^2 + \left| \langle s, t_0 | \Psi_A \rangle \right|^2 = 1$. In such a case, particle A will be accelerated by all values of $g(x, M_{rel})$ at r and by $g(y, M_{rel})$ at s bearing a non-zero probability. Since there are $a_1 + a_2 + a_3 + \dots + a_n$ and $b_1 + b_2 + b_3 + \dots + b_m$ possible values of $g(x, M_{rel})$ which particle A at r and s respectively will be accelerated by, in time interval $\lim_{dt \rightarrow 0} d\tau = \sqrt{1 - \frac{R_s}{x}} dt$. Thus, there are $(a_1 + a_2 + a_3 + \dots + a_n) \times (b_1 + b_2 + b_3 + \dots + b_m)$ possible particle evolution since at r, there are ways the particle can evolve in time and at s, there are $(b_1 + b_2 + b_3 + \dots + b_m)$ ways the particle can evolve in time and $a_1 + a_2 + a_3 + \dots + a_n + b_1 + b_2 + b_3 + \dots + b_m$ maximum number of possible locations where particle A can have non-zero probability of existing after time interval $\lim_{dt \rightarrow 0} d\tau$ [6,7].

To determine wave evolution in 1 dimension, first we divide the X axis into infinite infinitesimally small segments such that the mean position of the i^{th} segment is termed as ${}^i x_0$ and points from ${}^i x_0$ be labelled as ${}^i x_0 + {}^i x$ and let ${}^i M_{rel}$ be one of the mass

equivalence eigenvalue of Ψ_B at $t_0 - \left| \frac{{}^i x}{c} \right|$ [7].

Let's say using the above-mentioned rules, we get to know that the part of the wave in the 1,2,3,4... i^{th} segment can evolve in time interval $\lim_{dt \rightarrow 0} d\tau$ in $N_1, N_2, N_3, N_3 \dots N_i$ number of ways respectively, i.e., the part of the wave in the i^{th} segment can be accelerated by all values of $g({}^i x, {}^i M_{rel})$ towards ${}^i x_0 + {}^i x$ where for distance of separation from the i^{th} segment ${}^i x$, the

condition $\left\langle {}^i x_0 + {}^i x, t_0 - \left| \frac{{}^i x}{c} \right| \left| \Psi_B \right\rangle\right.$ is non-zero is satisfied [1].

Let's define a scenario as a possible particle time evolution in time interval $\lim_{dt \rightarrow 0} dt$ in which the part of the wave in each of the segments is translated from its initial position by $g({}^i x, {}^i M_{rel}) \lim_{dt \rightarrow 0} dt \tau({}^i x)^2 + v \lim_{dt \rightarrow 0} dt \tau({}^i x)$ where $g({}^i x, {}^i M_{rel})$ is any of the values by which the part of the wave in the i^{th} can be accelerated towards can be.

This can be written in form of an equation as:

$$\lim_{dt \rightarrow 0} \langle t + dt | \Psi \rangle = \lim_{dt \rightarrow 0} \sum_1^i \hat{T}_i \left\{ \left[g(x) d\tau(x) + v_{group} \right] d\tau(x) \right\} \langle {}^i x_0, t_0 | \Psi_A \rangle \quad (8)$$

Where,

$$\hat{T}(S)\psi(x) = \sum_{n=0}^{\infty} \frac{1}{n!} \left(S \frac{\partial}{\partial x} \right)^n \psi(x) = \psi(x + S)$$

Here the $\hat{T}_i \left\{ \left[g(x) d\tau(x) + v_{group} \right] d\tau(x) \right\}$ translates only the part of the wave solutions of the field in i^{th} segment by any of the possible values of $g({}^i x, {}^i M_{rel})$.

Probability of a possible wave evolution, let's say scenario Q:

$$\mathbb{P}(\text{scenario } Q) = \prod_{i=1}^{\infty} \mathbb{P} \left[g({}^i x, {}^i M_{rel}) \right] \quad (9)$$

Let $\lim_{dt \rightarrow 0} \langle t_0 + dt | \Psi_{\text{scenario } Q} \rangle$ be the field after a time interval $\lim_{dt \rightarrow 0} dt$ in scenario Q and be normalized by a normalizing co-efficient $C_{\text{scenario } Q}$ as due to uncertainty in acceleration in each of the segments; in some scenarios the part of the wave solutions of the field in, let's say the j^{th} segment accelerates faster than the part of the wave solutions of the field in any of the segments prior to it and end up out of phase with each other at, say x, which arises the need for normalization [7].

Probability of the particle A to possess momentum p due to this scenario contributing to overall probability of particle A have momentum $p = \sqrt{M_{rel}^2 c^2 - m^2 c^2}$ after time interval $\lim_{dt \rightarrow 0} dt$

$$\mathbb{P}(\text{scenario } Q) C_{\text{scenario } Q}^2 \left| \langle t_0 + dt, \sqrt{M_{rel}^2 c^2 - m^2 c^2} | \Psi_{\text{scenario } Q} \rangle \right|^2 \quad (10)$$

of the particle A to exist in the co-ordinate x due to this scenario contributing to overall probability of particle A being at x after time interval $\lim_{dt \rightarrow 0} dt$

$$\mathbb{P}(\text{scenario } Q) C_{\text{scenario } Q}^2 \left| \langle t_0 + dt, x | \Psi_{\text{scenario } Q} \rangle \right|^2 \quad (11)$$

Therefore,

$$\begin{aligned} & \text{Resultant} \left| \langle t_0 + dt, \sqrt{M_{rel}^2 c^2 - m^2 c^2} | \Psi \rangle \right|^2 \\ &= \sum_{Q=1}^{\text{Total number of possible scenarios}} \mathbb{P}(\text{scenario } Q) C_{\text{scenario } Q}^2 \times \left| \langle t_0 + dt, \sqrt{M_{rel}^2 c^2 - m^2 c^2} | \Psi_{\text{scenario } Q} \rangle \right|^2 \quad (12) \end{aligned}$$

$$\text{Resultant} \left| \langle t_0 + dt, x | \Psi \rangle \right|^2 = \sum_{Q=1}^{\text{Total number of possible scenarios}} \mathbb{P}(\text{scenario } Q) C_{\text{scenario } Q}^2 \times \left| \langle t_0 + dt, x | \Psi_{\text{scenario } Q} \rangle \right|^2 \quad (13)$$

III Creation and Annihilation Operators in Quantized Gravitational Field

In case of any free field, we can directly apply the same principle to get its time evolution in a quantized gravitational since quantum fields are superposition of wave solutions.

But in case of an interacting field theory, we need to take into note redshift of each frequency node of the field in every possible scenario. Using the above derived rules, we can retrieve what would the frequency node look like in a quantized gravitational field. After superimposing all the nodes, we can get to know how the field would look like in a quantized gravitational field.

$$E(x) = -\nabla \left\{ \frac{1}{4\pi} \int dx' \frac{1}{|x' - x|} \left[e\psi^+ \psi + \nabla \cdot \dot{A}(x', t) \right] \right\} \quad (14)$$

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For example, let's take the interacting electric field

$$E(x) = -\nabla \left\{ \frac{1}{4\pi} \int dx' \frac{1}{|x' - x|} \left[e\psi^+ \psi + \nabla \cdot \dot{A}(x', t) \right] \right\} \quad (14)$$

We can see $E(x)$ depends on ψ and A . Since we know $\psi(x)$, let us see what the field A induced by the fermion is like:

$$A_\mu = \sum_k \sum_{\lambda=1}^2 C_\mu(k, \lambda) \left[e^{-ik \cdot x} a(k, \lambda) + e^{-ik \cdot x} a^\dagger(k, \lambda) \right] \quad (15)$$

The contribution of the frequency node \mathbf{k} of the field A_μ to the field is $\sum_{\lambda=1}^2 \epsilon_\mu(\mathbf{k}, \lambda) [e^{-ik \cdot x} a(\mathbf{k}, \lambda) + e^{-ik \cdot x} a^\dagger(\mathbf{k}, \lambda)]$

As we know in a gravitational field, waves are redshifted by gravity,

$$\lambda_r = \frac{\lambda_\infty}{\sqrt{1 - \frac{2GM}{c^2 r}}} \quad (16)$$

where λ_∞ and λ_r are wavelength at infinitely far away from the particle and at distance r away from the particle.

Therefore, momentum of the wave at distance r away from the particle will be

$$p_r = \frac{h \sqrt{1 - \frac{2GM}{c^2 r}}}{\lambda_\infty} \quad (17)$$

Since $\frac{h}{\lambda_\infty}$ is the momentum in absence of a gravitational field, therefore,

$$p_r = p \sqrt{1 - \frac{2GM}{c^2 r}} \quad (18)$$

Let $r = |x' - x|$.

Substituting value of r in the above equation,

$$p_r = p \sqrt{1 - \frac{2GM}{c^2 |x' - x|}} \quad (19)$$

Therefore, in a gravitational field,

$$e^{-ik \cdot x} \rightarrow e^{ik \cdot \sqrt{1 - \frac{2GM}{c^2 |x' - x|}} \cdot x} \quad (20)$$

As we know the uncertainty in the geometry of the space time as mentioned earlier due to uncertainty in momentum and position of the particle as mentioned in the second section of the article. Let us say, at the point $x'_1, x'_2, x'_3 \dots$ at time t , there are $N_1, N_2, N_3 \dots$ spacetime geometries, each with a certain probability of it.

After that, we need to find the modulus of the amplitude of that frequency node of the field in both momentum and position spaces of each of the $N_1 \times N_2 \times N_3 \dots$ scenarios using the earlier derived rules and sum up all the modulus of the amplitude of that frequency node over all possible scenarios in both spaces to get the resultant amplitude of that frequency node of the field in both spaces. Then using the Gerchberg-Saxton algorithm, we can retrieve the field in the momentum space $\langle k | A_\mu | 0 \rangle$ for both the creation and the annihilation part which can be used to get the field in position space [8].

$$\langle x | A_{\mu,\lambda}^+ | 0 \rangle = \sum_k \langle x | A_{\mu,\lambda}^+ | 0 \rangle e^{-ik \cdot x} \quad (21)$$

$$\langle x | A_{\mu,\lambda}^- | 0 \rangle = \sum_k \langle x | A_{\mu,\lambda}^- | 0 \rangle e^{-ik \cdot x}$$

Summary of the Above Derived Rules

Let me explain the above-mentioned method, suppose the range over which the excitation in the field, i.e., particle A is non-zero be divided into 3 segments such that these segments have negligible width **FIG.1**.

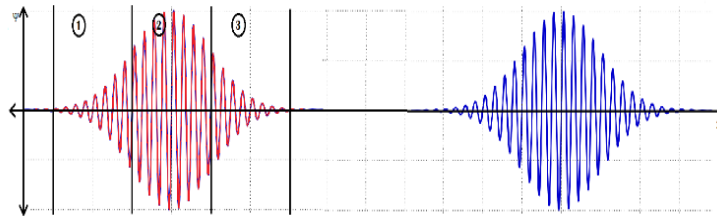


FIG. 1. The range over which the excitation in the field

Using the above-mentioned rules, one can find the possible values of acceleration due to gravity with their associated probability for a particle in segment 1, 2 and 3. Suppose there was n, m and o number of values by which a particle could be accelerated, if present in any of the segments respectively. Similarly, part of the field in each of the segments is accelerated by any of the possible value of acceleration it could undergo in that segment for time interval $\lim_{dt \rightarrow 0} dt$. To get the probability of this field evolution, the probability of the value of acceleration the part of the field in each of the segments is multiplied. Then, the field in this field evolution after time interval $\lim_{dt \rightarrow 0} dt$ is normalized and its contribution to the overall probability of the particle existing at a point x is the sum of probability of the field evolution and the squared modulus of the field in that scenario.

Since, there are n, m and o number of values by which a particle could be accelerated, if present in any of the segments respectively, there are $(m \times n \times o)$ number of possible field evolutions. The overall probability of the particle existing at a point x is the sum of probabilities of all $(m \times n \times o)$ number of possible field evolutions. Similarly, the overall probability of the particle having momentum p is also determined. Then the Gerchberg Saxton algorithm is used to retrieve the field. To increase accuracy of the method, one needs to increase the number of segments the range over which the excitation in the field, i.e., particle A is non-zero.

Similarly, for a particle self-interacting with itself in the gravitational field, we space into infinite infinitesimally small segments. The part of the field Ψ_A of the particle A in the i^{th} segment at (x_0, t_0) will be accelerated by the above mentioned rules, but values of $g(x, M_{rel})$ will depend on Ψ_A . The part of the field in i^{th} segment will be accelerated by $g(x, M_{rel})$ whose values depend on x

(the distance and separation) and the mass equivalence eigen values at time $t_0 - \left| \frac{x}{c} \right|$.

When $x=0$,

We know that the part of the field in i^{th} segment will interact with itself, i.e., it will be accelerated towards itself, thus, $gd\tau^2$ can be

ignored in $\lim_{dt \rightarrow 0} \int \int_{-\infty}^{\infty} \hat{T} \left\{ \left[g(x) d\tau(x) + v_{group} \right] d\tau(x) \right\} \langle x, t | \Psi \rangle \delta(x-y) dx dy$. Therefore, it will be equal to

$\lim_{dt \rightarrow 0} \int \int_{-\infty}^{\infty} \hat{T} \left[v_{group} d\tau(x) \right] \langle x, t | \Psi \rangle \delta(x-y) dx dy$, when $x=0$ for all self-interactions **FIG.2**.

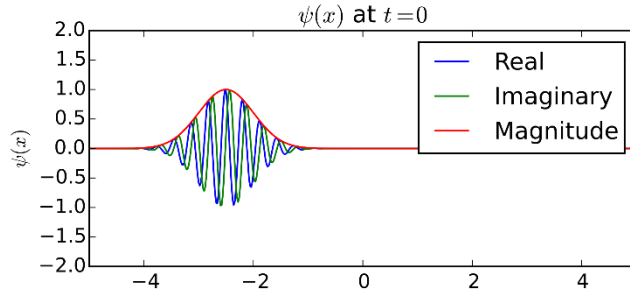


FIG. 2 To study energy conservation due to self-interaction, let's imagine an excitation in the field in vacuum

We can see that the wave function is non-zero over the range $(-4,0)$ at $t=0$. The part of the wave function at -4 will be accelerated in forward direction due to self-interaction. The scenario in which the part of the wave function will be accelerated the least is when $x=0$, in which it will be translated by $\lim_{dt \rightarrow 0} v_{group} d\tau(x)$. The part of the wave function at 0 gets translated the most is when $x=0$, as in other scenario we can see it will be accelerated in the direction opposite to its motion [9].

Therefore, the particle after time interval $\lim_{dt \rightarrow 0} dt$ will have a probability to exist over the range

$$\left[-4 + v_{group} d\tau(x), v_{group} d\tau(x) \right].$$

Since $|\Psi_A|^2$ is non-zero over the range $\left[-4 + v_{group} d\tau(x), v_{group} d\tau(x) \right]$, there Ψ_A will also be non-zero over it. Since the wavelength of the particle does not change, we can say conservation will not be violated due to self-interactions since

$$E = hf = h \frac{v_{group}}{\lambda}.$$

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