Title: Gravitational Wave Explanation of Quantum Mechanics

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Dedicated to the memory of the Mathematician Grete Hermann (1901-1984), for having anticipated John von Neumann and John Steward Bell.

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Abstract

A deterministic interpretation of quantum mechanics is given where the non-local hidden variables of Bell's theorem are in reality Watt-less high-energy gravitational waves with an energy well above the Greisen-Zapetsin-Kuzmin (GZK) cosmic ray energy limit of $5 \cdot 10^{10} GeV$. The gravitational waves are emitted by Schrödinger's "Zitterbewegung" (quivering motion) from pole-dipole particles, where a large positive mass m^+ is gravitationally bound to a likewise large negative mass m^-, with a small excess in the positive mass equal to the positive gravitational binding energy of m^+ to m^-. Setting this mass equal to the mass of an electron, one obtains for the oscillating energy of the Zitterbewegung is equal to $3.31 \cdot 10^{11} GeV$, well above the GZK limit. Support for this hypothesis are the rare cosmic ray events of about the same energy, coming from the Ursa Major constellation which have been detected by the Dugway Proving Ground Cosmic Ray Observatory in Utah.

1. Introduction

Since the creation of quantum mechanics about 100 years ago, there has been an ongoing debate about its interpretation. It was the mathematician Grete Hermann, a PhD student of Emmy Noether, who has been an early opponent to its indeterministic interpretation, contradicting the principle of causality by Kant [1]. Her discussions with Heisenberg and von Weizsäcker have been remembered by Heisenberg [2]. It was Heisenberg's opinion [3] that while the Universe in the Large is ruled by Kant's law of causality, it is in the Small ruled by statistical laws. However, since the law of causality has been of fundamental importance for the discovery of all known laws of nature, it is difficult to believe that it must be abandoned for quantum mechanics. In the words of Einstein, "God does not play dice" (Gott würfelt nicht).

A deeper understanding of the nature of quantum mechanics was discovered by Bell [4], with his famous theorem, ruling out local "hidden variables," but exempting the existence of "non-local hidden variables."

Since non-local hidden variables have not been detected in experiments, neither with energies up to the maximum energy needed with the Large Hadron Collider (LHC), nor with the much higher energies of the cosmic rays, we make the guess that they are gravitational and for energies above the GKZ energy cut off for cosmic rays. In making this guess we follow the recommendation by Feynman to discover new laws of nature [5]:

> "In general we look for a new law by the following process. First we guess it. Then we compute the consequences of the guess to see what would be implied if this law that we guessed is right. Then we compare the result of the computation to nature, with experiment or experience, compare it directly with observation, to see if it works. If it disagrees with experiment it is wrong. In that simple statement is the key to science. It does not make any difference how beautiful your guess is. It does not make any difference how smart you are, who made the guess, or what his name is—if it disagrees with the experiment, it is wrong. That is all there is to it."

2. The Nonrelativistic Schrödinger Equation and the Madelung Transformation

We will first study the mathematical structure of the nonrelativistic Schrödinger equation, followed by the relativistic Dirac equation. A nonrelativistic particle of mass m and velocity v, where $\frac{1}{2}mv^2 \ll mc^2$ (c being the velocity of light), is described by the Schrödinger equation:

$$i\hbar\frac{\partial\psi}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2\psi + U\psi \tag{1}$$

where U is the potential of an externally applied force. Making for (1) the Madelung transformation [6],

$$\begin{aligned} \psi &= \sqrt{n}e^{iS} \\ \psi^* &= \sqrt{n}e^{-iS} \end{aligned} \tag{2}$$

where $n = \psi^*\psi$, and S the Hamiltonian action function, one obtains two coupled equations:

$$\left.\begin{aligned} \hbar\frac{\partial S}{\partial t} + \frac{\hbar^2}{2m}(\nabla S)^2 + U + Q = 0 \\ \frac{\partial n}{\partial t} + \frac{\hbar}{m}\nabla(ns) = 0 \end{aligned}\right\} \tag{3}$$

where

$$Q = \frac{\hbar^2}{2m}\frac{\nabla^2\sqrt{n}}{\sqrt{n}} \tag{4}$$

is called the quantum potential. Setting $v = (\hbar/m)\nabla S$, as in the Hamilton-Jacobi theory of classical mechanics, on obtains from (3),

$$\left.\begin{aligned} \frac{\partial v}{\partial t} + v\frac{\partial v}{\partial \boldsymbol{r}} = -\frac{1}{m}\frac{\partial}{\partial \boldsymbol{r}}[U + Q] \\ \frac{\partial n}{\partial t} + div(n\boldsymbol{v}) = 0 \end{aligned}\right\} \tag{5}$$

the Euler and continuity equation for a friction-less fluid with ordinary U and quantum potential Q. Setting $Q = 0$ and making for (5) the inverse Madelung transformation [7], one obtains the wave equation of classical mechanics:

$$i\hbar\frac{\partial\psi}{\partial t} = -\frac{\hbar^2}{2m}\nabla^2\psi + [U + \bar{Q}]\psi \tag{6}$$

where

$$\bar{Q} = \frac{\hbar^2}{2m}\frac{\nabla^2|\psi|}{|\psi|} \tag{7}$$

is the inverse quantum potential. Unlike the Schrödinger equation (1), (6) is non-linear. This simple fact shows it is the quantum potential that makes the Schrödinger equation a linear wave equation. To estimate the value of the quantum potential (4), we set $\nabla^2 \simeq 1/r_c^2$ in (4), where $r_c = \hbar/2mc$, ½ of the Compton wavelength of a particle with mass m. One finds that

$$Q \simeq mc^2 \tag{8}$$

3. The Dirac Equation

Replacing the nonrelativistic Schrödinger equation with the relativistic Dirac equation, we obtain a clue for the origin of the quantum potential [8]. We will show it has to do with the spin of the Dirac particle. As it was first noticed by Breit [9], the Dirac equation seems to suggest that a particle described by it must move with the velocity of light, in gross contradiction to the observation. In the Dirac equation, the particle velocity is described by the velocity operator:

$$v_{o,p} = \alpha c, \boldsymbol{\alpha} = \{\alpha_1 . \alpha_2 . \alpha_3\} \tag{9}$$

where $\boldsymbol{\alpha}$ are the Dirac matrices. With the expectation value $< \boldsymbol{\alpha} > = 1$, it follows that

$$< v_{o,p} > = c \tag{10}$$

The resolution of this paradox was given by Schrödinger [10] in his famous "Zitterbewegung" (quivering motion) papers. Schrödinger showed that it is the negative energy, and hence the negative mass states of the Dirac equation, which lead to its spin being equal to ½ ħ.

4. The Pole-Dipole Particle

Following Schrödinger's Zitterbewegung (quivering motion) theory of the Dirac electron [10], it was shown by Hönl, Papapetrou [11], and Bopp [12] that a simple "pole-dipole" particle can describe this "Zitterbewegung." Similar to how the hydrogen atom is composed of a particle with a positive electric charge (the proton) and of an electron with an equal but opposite charge, obtains its energy from the electric field interaction, a pole-dipole made of two masses, one positive m^+, and the other m^-, but with $|m^-|=|m^+|$, obtains its interaction energy from the gravitational field set up in between m^+ and m^-. Because the signs of m^+ and m^- are opposite, this gravitational interaction energy is positive, and for energies less than the Planck energy of $\sim 10^{19}$ GeV it can be computed from Newton's law of gravity.

While the equivalence principle of the general theory of relativity outlaws the existence of negative mass particles, which would have to move on "antigeodesics," it does not outlaw pole-dipole particles, with a positive mass pole. There, only the center of mass is moving on a geodesic. For a pole-dipole particle we thus have for the mass of an electron:

$$m = G\frac{|m^{\pm}|^2}{c^2 r} \text{ (Newton's law)} \tag{11}$$

where G is Newton's constant and r is the separation distance between m^+ and m^-. Supplementing (11) with

$$2|m^{\pm}|rc = \hbar \text{ (Bohr's angular momentum quantization principle)} \tag{12}$$

one obtains from (11) and (12)

$$|m^{\pm}| = \sqrt[3]{\frac{\hbar mc}{2G}} = 6 \times 10^{-13} \text{ g} \tag{13}$$

$$r = 3 \times 10^{-26} \text{ cm} \tag{14}$$

and hence

$$|m^{\pm}|c^2 = 3.31 \times 10^{11} \text{ GeV.} \tag{15}$$

5. Emission of Watt-less Gravitational Waves from a Pole-Dipole Particle

According to Schrödinger [10], a Dirac electron executes a luminal helical motion, with the radius of the helix equal to the Compton wavelength of the electron, superimposed by a "Zitterbewegung" with an oscillatory displacement given by (14) equal to $r \simeq 10^{-26}$ cm. This situation resembles a double star, except that one of its components has a negative mass. As for a double star, where the center of mass is on a geodesic, the same must be true here, leading to the emission of high energy gravitational waves by the oscillation of m^+ against m^-, or vice versa, with a wavelength on the order of 10^{-26} cm, modulated by the Compton frequency $mc^2/\hbar$, due to the helical motion of the pole-dipole particle, which is the Dirac particle.

To prevent the Dirac particle from disintegrating due to this emission of gravitational waves, there must be a superposition of a positive energy – positive space curvature wave – and a likewise negative energy – negative space curvature wave. The source of the positive space curvature wave is the energy-momentum tensor of the positive mass m^+ and negative mass m^-. There, the Dirac particle would be accompanied by a Watt-less gravitational wave, giving a plausible explanation for de Broglie's pilot wave hypothesis. In addition, it would explain the particle-wave duality of quantum mechanics, which Feynman believed could never be explained.

To compute the energy loss (and energy gain) by the emission of positive (and negative) energy gravitational radiation, we use Einstein's quadrupole formula [13] for the energy loss of a double star of masses m_1 and m_2, separated by the distance r and orbital frequency ω:

$$-\frac{d\varepsilon}{dt} = \frac{32G}{5c^5}\left(\frac{m_1 m_2}{m_1 + m_2}\right)^2 r^4\omega^6 \tag{16}$$

Setting $m_1 >> m_2 = m$, and $m_1 + m_2 = m_1$, (approximately true since m_1 is almost motion-less), one has for the energy loss (gain),

$$-\frac{d\varepsilon}{dt} = \frac{32G}{5c^5} m^2 r^4\omega^6 \tag{17}$$

We set m = $|m^{\pm}|/2$ as the reduced mass, and furthermore multiply (17) by ½ to average over a sinus wave. For the positive energy loss of m^+ and the negative energy loss of m^-which is equal to the positive energy gain of m^- we have,

$$\mp\frac{d\varepsilon}{dt} = \frac{4G}{5c^5}|m^{\pm}|^2 r^4\omega^6 \tag{18}$$

Setting ω = c/r, we obtain

$$\mp\frac{d\varepsilon}{dt} = \frac{4}{5}\frac{G|m^{\pm}|^2 c}{r^2} \tag{19}$$

Integrating over the time of one revolution and multiplying (19) by r/c, one obtains

$$\varepsilon^{\pm} = \mp\frac{4}{5}\frac{G|m^{\pm}|^2}{r} = \mp\frac{4}{5}mc^2 \tag{20}$$

hence,

$$\varepsilon^+ + \varepsilon^- = 0 \tag{21}$$

Comparing this result with (8), one can see that the quantum potential has its origin in the Watt-less emission of high energy gravitational waves by the pole-dipole particle, not only explaining why the quantum potential makes the Schrödinger equation linear, but also permitting the linear superposition of its solutions.

The independent validity of the calculation is supported by the Work of Redington [14], who showed that Einstein's general theory or relativity has "Literal Rippling Spacetime" solutions, in a time-orthogonal metric, as in Dehnen's time-orthogonal formulation of the general theory of relativity [15].

Comparing (20) and (21) with (8), one can see that the quantum potential given by (4) has its origin in Watt-less gravitational waves from the "Zitterbewegung" of a pole-dipole particle.

6. Astrophysical Evidence

While in cosmic rays of electrically charged particles, energies above the Greisen-Zatsepin-Kuzmin (GZK) limit of $5 \cdot 10^{10} GeV$ are not possible, this limit does not apply to gravitons, and thus to the rarely observed cosmic ray events with an energy of $3.2 \cdot 10^{11} GeV$, well above the GZK limit if they are gravitons released in the breakup of a pole-dipole particle with the energy given by (13). The fact that these events have been observed in a region of Ursa Major suggests they are emitted from a Kerr black hole located in this area of space. The large gravitational fields in the ergosphere of a Kerr black hole would be capable of splitting electrons thereby releasing high-energy gravitons. Through resonance absorption by electrons in the earth's atmosphere, these gravitons could lead to the $\sim 10^{11}$ GeV cosmic rays observed.

7. Comparison with the Copenhagen Interpretation

While in the Copenhagen Interpretation the cause for an event remains unknown, it is here explained to result from the statistics of a stochastic force, of a rapidly oscillating gravitational field, which according to Bell's theorem can be interpreted as a nonlocal hidden variable, but difficult to detect with its very high energy above the GZK limit.

A useful example is the decay of a single radium atom, where the Copenhagen Interpretation can only give an answer about the statistical probability of its decay, if it happens in the next second or the next 10 years, but without providing a cause for its decay. The cause is here the stochastic force of the fluctuating high energy gravitational wave.

Another important example is the quantum entanglement phenomenon, where the Copenhagen interpretation predicts the superluminal connection between entangled particles, even for distances outside the lightcone. In the interpretation given here, the Watt-less gravitational wave emitted by the particle can there still interfere over very large distances, very much as the radio signals received from the Pluto probe, over a distance as large as the diameter of the solar system.

The non-Copenhagen interpretation presented here can also give an explanation of the outcome of the double-slit experiment. This experiment not only has been done with photons and electrons, but also with very large molecules. There then, the high energy osciallting gravitational wave emitted from the molecules guides the molecule on its path through just one slit, with the gravitational wave replacing the hypothetical pilot wave of the deterministic de Broglie-Bohm interpretation of quantum mechanics.

8. The Cause of Uncertainty in the Nonlinearity of Einstein's Gravitational Field Equation

For any wave mechanics, like for acoustic waves, but also (linear) gravitational waves, made up from waveforms $\psi = Ae^{i(kx-\omega t)}$, the Fourier theorem leads to the equations:

$$\begin{aligned} \Delta k \Delta x &\geq 1 \\ \Delta \omega \Delta t &\geq 1 \end{aligned} \tag{22}$$

where Δk and $\Delta\omega$ are the spread in wave number and frequency of a wave package. The problem in the interpretation of quantum mechanics enters by identifying a wave package with a particle of momentum $p = \hbar k$, and energy $E = \hbar\omega$, whereby (22) leads to the two uncertainty relations:

$$\begin{aligned} \Delta p \Delta x &\geq \hbar \\ \Delta E \Delta t &\geq \hbar \end{aligned} \tag{23}$$

requiring in the Copenhagen interpretation a superluminal (relativity-violating) collapse of the wave function. This is different in the de Broglie-Bohm pilot wave interpretation, where one always has real particles, and particles are not wave packages. If the pilot wave is a Watt-less gravitational wave, it can explain all the interference phenomena of a wave. But the question still arises, if everything is deterministic, from where then can come any uncertainty? The answer is from the nonlinearity of Einstein's gravitational field equation. That nonlinearity can lead to a different kind uncertainty has been recognized by Heisenberg [16]: "I might mention a most paradoxical result of this mathematical analysis – the theorem by Bruns. He proved that in an even infinitely close neighborhood of a point where the perturbation theory converges, there must always be other points where the perturbation theory diverges. So, one can say that the points where the perturbation theory converges and those where it diverges form a dense manifold. This result suggests that after a very long time one can never know where the orbit finally will go." Heisenberg's comment was made in the context of Newton's classical equations of motion. Like Einstein's gravitational field equation Newton's equation is nonlinear. The nonlinearity implies that the initial conditions of position and velocity for the emission of gravitational waves by the Dirac equation would have to be more accurately known as a Planck length and the likewise accurate particle velocity at this length. This is impossible, since no instrument can be built of parts that small, and because of the theorem by Bruns, even that would not be enough. This means that there always will be an uncertainty, (and where the Gods can interfere).

It is as if nature wants to avoid the nonlinearity of deterministic classical physics by linear quantum mechanics, which in reality is only statistical and not deterministic.

9. Conclusion

It is shown that the mystery of the Copenhagen interpretation of quantum mechanics, in being the only indeterministic theory of the fundamental laws of nature, may be rooted in the inability to reach particle energies not only higher than what can be reached by man with the largest conceivable particle accelerators, but not even with cosmic rays up to the GZK cut-off at $5 \cdot 10^{10} GeV$. This underlines the importance of gravitational wave research, with energies all the way up to the Planck energy of $10^{19} GeV$. The situation is reminiscent of supersonic fluid dynamics, which for technical reasons remained inaccessible for a long time. Without supersonic fluid dynamics we would have no space rockets, the GPS, or many other things. This reminds me of a remark made by Heisenberg, that it would not make much sense to build ever larger particle accelerators to test elementary particle theories, but rather to go to the much higher energies of cosmic rays. Their much smaller intensity could, in space, be substantially increased with large electromagnetic lenses, requiring a highly developed supersonic space launch technology.

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