Journal of Modern Physics, 2023, 14, 1392-1408
https://www.scirp.org/journal/jmp
ISSN Online: 2153-120X
ISSN Print: 2153-1196

Ontology of Quantum Gravity

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How to cite this paper: Klingman, E.E. (2023) Ontology of Quantum Gravity. *Journal of Modern Physics*, **14**, 1392-1408.
https://doi.org/10.4236/jmp.2023.1411080

Received: September 7, 2023
Accepted: October 14, 2023
Published: October 17, 2023

Abstract

A theory of *Quantum Gravity* based on *Primordial Field Theory* is applied to a fundamental particle, the neutron. The result is compared to the current quantum description of the neutron bouncing in a gravitational field. Our quantum gravity theory yields results in agreement with the Q-bounce experimental data, but ontologically different from quantum mechanics. The differences are summarized and imply that this experiment on a fundamental particle has the potential to radically alter the ontology of field theory.

Keywords

Loop Quantum Gravity, Ontology, Neutron Bounce, Primordial Field Theory, Q-Bounce, Neutron Flux

1. Introduction

Ontology effectively formalizes the reality of physics; the relation is many-to-one: a number of ontologies may correspond to physical reality. A primordial field theory ontological formulation is presented here and contrasted with a quantum mechanical formulation of the bouncing neutron, a key experiment measuring interaction between fundamental field and fundamental particle [1]. Gravity acts on cosmology-scale structure and events, from neutron stars to black holes, to galactic clusters; however, at the root of all, gravity acts on individual particles. Q-bounce experiments are analyzed based on primordial field theory, a recent addition to Loop Quantum Gravity [2] [3], then reviewed, compared, and contrasted with quantum analyses. Future experiments should achieve sufficient precision to choose between alternate ontologies based on data. The plan of this paper (following this introduction) is:

2. Brief introduction to Primordial Field Theory.
3. Review of Quantum Loop Gravity Harmonic Oscillator.
4. Physics of the Bouncing Neutron.

5. Quantum treatment of Neutron Bouncing.
6. Quantum description vs Ontology of Primordial Field.
7. Ontological analysis of Classical vs Quantum theory of reality.

2. Brief Intro to Primordial Field Theory

Every theory of physics assumes a specific understanding of the nature of physical reality; however, the fact that different theories, with varying success, have different ontological models has confused physics for at least a century. Since it is as simple to derive primordial field theory as to present and explain it, we do so here. The underlying assumption, to be contrasted with today's 30+ quantum field theory fields is that in the beginning there was *one* field, the *primordial* field, and nothing else. Analysis proceeds on the basis of *the fundamental principle of self-interaction*: the primordial field only evolves via the equation of self-interaction:

$$\nabla \psi = \psi \psi \tag{1}$$

where ∇ is the *change operator* and ψ represents the field. ψ can be parameterized with scalar ξ or a vector parameter $\boldsymbol{\xi}$ and solved for with the corresponding change operator. Solutions are readily obtained mathematically; $\psi(\xi) = -\xi^{-1}$ and $\psi(\boldsymbol{\xi}) = \boldsymbol{\xi}^{-1}$. The simplest physical interpretation treats the scalar parameter as time *t* and the vector parameter as position $\boldsymbol{r}$. The physics formulated in Hestenes' *Geometric Calculus* [4] has $\psi = G(\boldsymbol{r}) + iC(t)$ and eqn (1) takes the form:

$$(\nabla + \partial_t)(\boldsymbol{G} + i\boldsymbol{C}) = (\boldsymbol{G} + i\boldsymbol{C})(\boldsymbol{G} + i\boldsymbol{C}) \tag{2}$$

which directly leads to Heaviside's dynamicization of Newton's gravity, with energy density ρ of the field expressed as $G^2 + C^2$ and with momentum $\boldsymbol{C} \times \boldsymbol{G} \to \rho \boldsymbol{v}$. This classical physics approach to gravity has been available since 1893, extended by Einstein's $E = mc^2$ (1905), de Broglie $p = \frac{h}{\lambda}$ (1923), and Yang-Mills' (1954) self-interaction term $\left[\partial^{\mu} A^{\nu} - \partial^{\nu} A^{\mu}\right]$. Momentum density $\rho \boldsymbol{v}$ induces circulation of the C-field that is *U*(1) in character, $\exp\left[\frac{i}{\hbar}\left(\boldsymbol{P} \cdot \boldsymbol{x} - \hbar C t\right)\right]$; this *wave-function* represents gravito-dynamical propagation of momentum density $\boldsymbol{p} = \frac{\boldsymbol{P}}{\int \mathrm{d}^3 x} = \frac{m}{\int \mathrm{d}^3 x} \boldsymbol{v} = \rho \boldsymbol{v}$ in gravitational field $\boldsymbol{G}$. The key governing equation is

$$\nabla \times \boldsymbol{C} = -\left(\frac{g}{c^2}\right) \frac{\boldsymbol{P}}{\int \mathrm{d}^3 x} + \left(\frac{1}{c^2}\right) \frac{\partial \boldsymbol{G}}{\partial t}. \tag{3}$$

Here gravitational field $\boldsymbol{G}$ has units of acceleration $\left[\frac{l}{t^2}\right]$ while gravito-magnetic field $\boldsymbol{C}$ has units of frequency $\left[\frac{1}{t}\right]$. A free particle with momentum $\boldsymbol{P}$ induces a circulating C-field.

Gravity theory deals with "microscopic" structure of the universe; stars, black holes, and galaxies, and this statement encapsulates it for many. Despite the fact that every human feels gravity, all day long, with every cell in the body, this is normally swept under the rug; gravitational interaction with elementary particles is for the most part ignored. The *Gravity Probe B* experiment proved the existence of the C-field induced by Earth's rotation. The C-field is thought of as "weak", based on measurements performed near Earth; but Earth's density is quite small. The key aspect of the theory is that it is not based on mass, but *mass density*. Compare to the density of the neutron (**Table 1**).

The ratio of the mass density of the neutron compared to Earth is

$\frac{\rho_n}{\rho_E} = 0.72 \times 10^{14}$. Circulation of the local C-field (the physical instantiation of angular momentum) as a function of local density is $\nabla \times \boldsymbol{C} = \rho \boldsymbol{v}$. When the magnitude of physical variable ρ increases by 14 orders of magnitude, it is worth looking at, so I develop primordial field theory interpretation of Q-bounce experiments.

Key experiments can change opinions: the 1925 Michelson-Gale experiment, establishes the reality of gravity as "local ether", far more useful than the *universal ether* that Michelson-Morley banished. Q-bounce experiments may favor quantum gravity over current quantum mechanics.

3. Brief Review of Quantum Loop Gravity Harmonic Oscillator

In [5] I show that C-field circulation energy has units of mv^2, with natural units $c = g = \hbar = 1$ where c is the speed of light and g is Newton's gravitational constant, with $\boldsymbol{G}$ being the gravitational field. It is easy to show that local energy densities are proportional to

$$\underset{\text{kinetic}}{p^2} = \underset{\text{C-field}}{C^2} \tag{4}$$

This interpretation conforms perfectly to the classical pendulum, which starts at zero momentum in a gravitational potential and falls under the force of gravity, with kinetic energy zero at the extreme displacement from vertical and maximum kinetic energy at zero displacement. Three symmetry diagrams of C-field circulation are shown in **Figure 1**.

The pendulum is displaced to position *x*, raising it in the gravitational field potential, and then released. Gravitational force accelerates the mass, constrained

Table 1. Comparison of Earth's mass density versus neutron mass density.

	Earth	Neutron
Mass	5.97×10^{24} kg	1.67×10^{-27} kg
Volume	~$[6.378 \times 10^6\ \text{m}]^3$	~$[10^{-15}\ \text{m}]^3$
Mass density	$\rho_E = 5.513 \times 10^3$	$\rho_n = 4 \times 10^{17}$

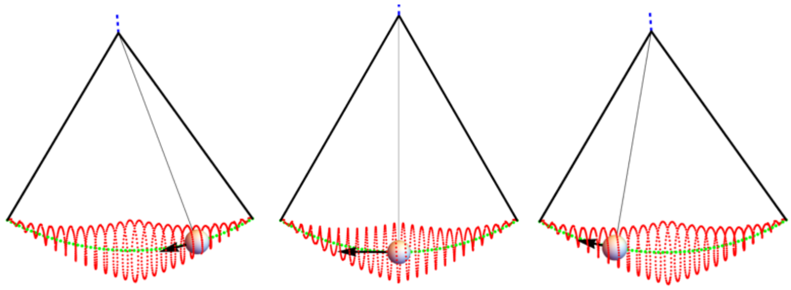


Figure 1. (a) Start of swing; (b) mid-swing; (c) ending swing. The spiral represents the *envelope* of C-field circulation over the path transversed.

by the arm of length L, creating momentum which induces gravitomagnetic field circulation energy, maximum at the lowest point in the field, then decreasing as the mass rises against gravity. Energies involved in relativistic mass include rest mass mc^2 and momentum density $\boldsymbol{p}$. For momentum used in the Hamiltonian, we have $\boldsymbol{P} = m_0\boldsymbol{v} = \int \mathrm{d}^3x \nabla \times \boldsymbol{C}$. Momentum is the volume integral of the C-field circulation induced by momentum density $\boldsymbol{p}$. Temporarily ignore $\frac{\partial \boldsymbol{G}}{\partial t}$; consider only $\nabla \times \boldsymbol{C} = -\boldsymbol{p}$. Force $\boldsymbol{F}$ accelerates rest mass; $\boldsymbol{F} = m_0 a = \mathrm{d}\boldsymbol{P}/\mathrm{d}t$ gives rise to a change in circulation of the C-field:

$$\frac{\mathrm{d}}{\mathrm{d}t}(\nabla \times \boldsymbol{C}) = \frac{-\frac{\mathrm{d}\boldsymbol{P}}{\mathrm{d}t}}{\int \mathrm{d}^3x} \tag{5}$$

The negative sign in Equation (3) is associated with the direction of circulation, that is, momentum density $\boldsymbol{p}$ induces a left-handed circulation about the momentum. However, in the force formula, any negative sign associated with change in momentum density $\mathrm{d}\boldsymbol{p}/\mathrm{d}t$ will have the same meaning as current flow in Lenz's Law of electromagnetic theory. Consider the classic distributor found on gasoline engines in which the collapsing magnetic field induced by flowing electric current is interrupted by mechanically breaking the connection. Lenz's Law states that the direction of the electric current induced in a conductor by a changing magnetic field is such that the magnetic field created by the induced current opposes changes in the initial magnetic field. When the current conductor is broken, change in current is immediate; this large rate of change induces a strong electro-motive force (emf) that tends to keep current flowing in the inductor. A sufficiently strong emf ionizes atoms and produces a "spark", normally timed to ignite fuel in the cylinder near top-dead-center, thus driving the piston down for the power stroke. That is, current flowing in the inductor coil induces a magnetic field sustained by continued current flow. When the flow is interrupted, the collapsing magnetic field induces an electric force that keeps the current flowing.

The dual of electric current density flow in electromagnetism is mass density flow in gravitomagnetism: $\boldsymbol{J} \Leftrightarrow \boldsymbol{P}$ therefore:

$$\nabla \times \boldsymbol{B} \sim \boldsymbol{j} \quad \text{and} \quad \nabla \times \boldsymbol{C} \sim -\boldsymbol{p} \tag{6}$$

implies

$$\frac{\mathrm{d}}{\mathrm{d}t}\left(\nabla \times \vec{B}\right) \sim \frac{\mathrm{d}\boldsymbol{j}}{\mathrm{d}t} \quad \text{and} \quad \frac{\mathrm{d}}{\mathrm{d}t}\left(\nabla \times \boldsymbol{C}\right) \sim -\frac{\mathrm{d}\boldsymbol{p}}{\mathrm{d}t}. \tag{7}$$

The gravitomagnetic dual of Lenz's Law is such that change in momentum (force $\mathrm{d}\boldsymbol{P}/\mathrm{d}t$) induces changed C-field circulation. An electric field $\boldsymbol{E}$ accelerates charged particle, inducing both B-field and C-field circulations. If charge is balanced, $\sum q = 0$, we can mechanically accelerate the mass, producing C-field circulation. When all forces are removed, the mass will essentially "coast" forever, that is, *momentum is conserved*. Yet, per Feynman [6]: *the reason why things coast for ever has never been found out*: "*The law of inertia has no known origin*." But a decrease in momentum generates a corresponding change in C-field circulation compensating for the initial decrease and maintaining momentum: acceleration increases C-field circulation, while deceleration is opposed by the existing circulation. A change in momentum of the free particle is opposed by the corresponding force associated with the change in circulation. The particle is accelerated by the collapsing C-field circulation until the circulation disappears.

4. Physics of the Bouncing Neutron

Gravity holds our moon to the Earth, at a quarter million miles, and pulls neutrons to the Earth over millionths of a meter, with action governed by the same equations.

Consider wave behavior associated with momentum-induced C-field distribution. Local gravity $\boldsymbol{G}$ accelerates the ball towards the Earth; the ball acquires vertical momentum governed by relations:

$$\boldsymbol{P} = m\boldsymbol{v} \quad \text{and} \quad \frac{\mathrm{d}\boldsymbol{P}}{\mathrm{d}t} = m\boldsymbol{G} \quad \text{with states:} \quad \left\{ mGh_0 \Leftrightarrow \frac{1}{2}mv^2 \right\} \tag{8}$$

compatible with relations $v = \sqrt{2Gh_0}$ and $P = \dfrac{h}{\lambda}$.

Figure 2 shows circulation of bouncing ball. The red spiral symbolizes the associated C-field circulation envelope induced by momentum density, $\rho\boldsymbol{v}$.

The mirror is a fixed array structure that does <u>not</u> support rotation at the surface, whereas the impinging massive ball is inducing rotation at an increasing rate.

$$\int \mathrm{d}^3x \frac{\mathrm{d}}{\mathrm{d}t}\left(\nabla \times \boldsymbol{C}\right) \sim \frac{\mathrm{d}\boldsymbol{P}}{\mathrm{d}t} = m\boldsymbol{G} \tag{9}$$

In **Figure 3**, the C-field circulation is represented by the radius of the spiral at time *t*. There is no C-field circulation in the vertical direction at the initial height. The radius of the spiral relates to the momentum at the closest point. From these 2D figures of the bouncing ball it may appear that the shorter wavelengths appear at the top of the bounce, with longer wavelengths at the bottom, however the dynamics behavior of the model exhibits time dependence as the ball moves

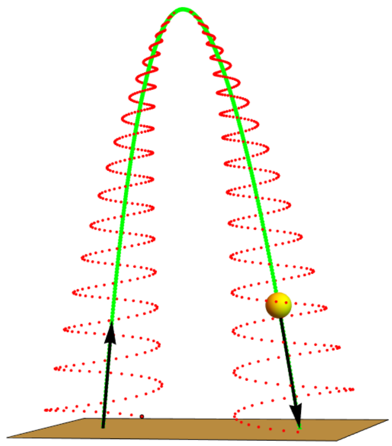
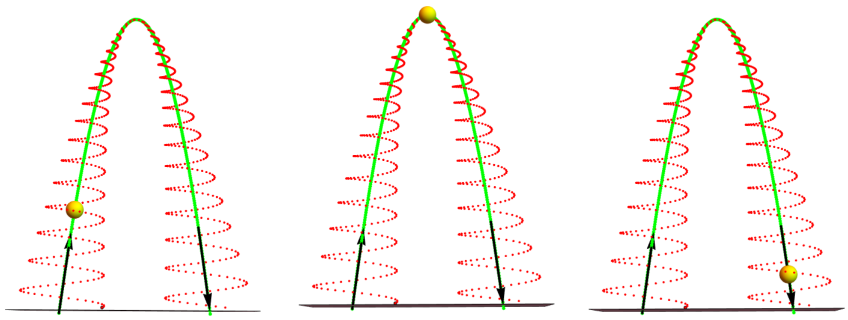


Figure 2. One bounce of a neutron from the mirror to the potential height, and back down.



(a) (b) (c)

Figure 3. (a) The rebounding ball with momentum $-\boldsymbol{p}$ has left-handed circulation of the C-field, as evidenced by the spiral in front of the ball rising in the direction of motion as seen where the path of the C-field circulation eclipsed by the ball. (b) Ball reverses at max height. (c) The falling ball with momentum $\boldsymbol{p}$ shows the left-handed C-field circulation descending.

slowly at the top and quickly at the bottom of the gravity well. Traversal of the path is non-linear in time, with most of the likely measured positions being near the top of the parabola where the ball spends most of its time. This non-linearity affects the apparent wavelength of the C-field spiral, whose associated wavelength actually decreases as the ball nears the bottom. Our eyes key off of the apparent in 2D geometry, but an animated bouncing ball with correct time dependent dynamics adds timing information revealing a dimension beyond the static 2D-information.

4.1. Analysis of the Reflection at Mirror Plane

If reflection in the mirror was based simply on one particle interacting in appropriate fashion with another particle or particles in a lattice…but that is not the case. The impinging massively dense neutron has gravity-driven kinetic energy, stored as circulating C-field, as induced stress ("twist") in the local field traversed by the neutron. The mirror offers a perfect reflecting plane and does not harbor local rotational vortices at its surface. The collision of rotational field and irrotational surface needs to be described. This collision is not considered in quantum treatments.

Consider a very strong C-field, impinging on the surface. What happens when C-field circulation encounters a mirror whose surface does not support rotational flow. We expect the *twisted* field induced by gravitational potential to be zero at the mirror—naively summarized as $\psi(0)=0$. Consider the reflection of an intense vortex laser beam on an overdense laser target. Per Allen *et al.* [7] a Laguerre-Gaussian laser pulse has finite orbital angular momentum (OAM) with relativistic light > 10^{18} W/cm^2 expected on the horizon (in 2016): Zhang *et al.* report [8] that when an intense vortex laser beam is obliquely incidental onto and reflected by an overdense plasma target, the rotational symmetry of the target surface is broken, bringing a considerable correctional effect to the optical reflection law. The rotation carried by strong electromagnetic fields to a surface of a *plasma fluid* of charged particles imparts rotational flow locally to the plasma. In contrast, a weaker gravitomagnetic rotation impinging on a lattice of millions of atoms does not impart rotational energy to the lattice; the coupling is zero.

"…*the Laguerre-Gaussian beam carrying angular momentum* $\boldsymbol{J}_i$ *obliquely impinges on the foil* (*parallel to the z-axis*) *with angle of incidence* θ_{in} *and the reflected beam does not strictly abide by the optical reflection law to propagate in the x-y plane* (*the plane of incidence*) *but deflects slightly towards the +z or −z direction depending on direction of* $\boldsymbol{J}$."

The OAM laser pulse deflects out of the plane of incidence, having forcibly imparted angular momentum to the surface; the deflection angle increases linearly with pulse duration. For a beam *without* OAM, the deflection vanishes since no angular momentum transfers to the surface, experimentally supporting our contention that C-field circulation does *not* penetrate the mirror.

C-field circulation collapses as it reaches the irrotational surface of the mirror. But collapse does *not* mean "go to zero". Instead, wound up stress represented by the induced C-field circulation begins to "unwind", in the opposite circulation direction. Lenz-Law behavior of the unwinding field accelerates the particle in the $-\boldsymbol{p}$ direction. Simultaneous change in sign of circulation $\nabla\times\boldsymbol{C}$ and momentum $\boldsymbol{p}$ preserves the relevant Heaviside Equations (3) and (5), while making complete ontological sense. In short:

- The *gravity phase* of the phenomenon transfers energy from the local G-field potential to the local C-field energy: $\boldsymbol{F}=m\ddot{x}=m\boldsymbol{G}=\frac{\mathrm{d}\boldsymbol{P}}{\mathrm{d}t}$.
- The *anti-gravity phase* of the phenomenon transfers C-field energy into G-field potential energy: $\boldsymbol{F}\sim\int\mathrm{d}^3x\frac{\mathrm{d}}{\mathrm{d}t}(\nabla\times\boldsymbol{C})=-\frac{\mathrm{d}\boldsymbol{P}}{\mathrm{d}t}$.

4.2. Analysis of Dynamics of the Bounce

The physical situation begins with neutron mass, *m*, at rest at height $z=h_0$

above the ground. We assume that momentum is instantaneous, $\boldsymbol{P}(t)=m\boldsymbol{v}(t)$ when the mass is accelerated by the force of gravity. We start with four relations:

$$\text{Energy:}\quad mGh_0=\frac{1}{2}mv^2\Rightarrow v=\sqrt{2Gh_0} \tag{10}$$

$$\text{Newton:}\quad \boldsymbol{P}(t)=m\boldsymbol{v}(t) \tag{11}$$

$$\text{De Broglie:}\quad P=\frac{h}{\lambda} \tag{12}$$

$$\text{Heaviside:}\quad \rho\boldsymbol{v}=\boldsymbol{p}=\nabla\times\boldsymbol{C}\quad \rho=\frac{m}{\int \mathrm{d}^3x} \tag{13}$$

Consider the situation at $z=0$ after fall from $z=h_0$. From Equations (10)-(12) we have:

$$m^2\,2Gh_0=\frac{(2\pi\hbar)^2}{\lambda^2}\Rightarrow h_0\lambda^2=\frac{(2\pi\hbar)^2}{2Gm^2} \tag{14}$$

which we rewrite as $h_0\lambda^2=2\pi^2\left(\frac{\hbar}{mG}\right)\left(\frac{\hbar}{m}\right)$ and divide both sides by $\left(\frac{\hbar}{mG}\right)$ to obtain:

$$\left(\frac{mG}{\hbar}\right)h_0\lambda^2=2\pi^2\left(\frac{\hbar}{m}\right). \tag{15}$$

Since the neutron fell from $h_0>0$ to gain momentum density $\boldsymbol{p}$ the wavelength of the induced C-field circulation is $\lambda>0$, hence: $h_0\lambda^2\equiv vol.>0$.

The dimensionality of $\left[\frac{mG}{\hbar}\right]=\left[\frac{\left(\frac{ml}{t^2}\right)}{\left(\frac{ml^2}{t}\right)}\right]\equiv\left[\frac{1}{lt}\right]$ is the same as C-field circulation: $[\nabla\times\boldsymbol{C}]=\left[\frac{1}{lt}\right]$, so, if we are guided by dimensionality, we might conclude that:

$$\left[\frac{\text{gravity force on neutron}}{\text{quantum of action}}\right]\Rightarrow\left(\frac{mG}{\hbar}\right)\sim\nabla\times\boldsymbol{C} \tag{16}$$

Gravitational force in quantum units implies C-field circulation. Substitute from Equation (16) into (15):

$$(\nabla\times\boldsymbol{C})\cdot h_0\lambda^2=2\pi^2\left(\frac{\hbar}{m}\right) \tag{17}$$

$$\frac{m}{2\pi}\cdot(\nabla\times\boldsymbol{C})\cdot h_0\lambda^2=\frac{h}{2},\quad\left[\equiv\frac{ml^2}{t}\right] \tag{18}$$

which invites interpretation as a flow of rotational inertia. The right hand side of Equation (14) is given in known physical entities, $m,\boldsymbol{G},\hbar$, whose values are: $\hbar=1.054\times10^{-34}$ Joule-sec, $G=9.8\ \mathrm{m/sec^2}$, neutron mass $m=1.675\times10^{-27}\ \mathrm{kg}$, yielding $\left(\frac{\hbar}{m}\right)^2=0.3956\times10^{-14}$ and $2\pi^2/G=2.0142\ \mathrm{sec^2/m}$. Hence:

$h_0\lambda^2 = 8\times10^{-15}\ \mathrm{m}^3$. For simplicity assume that the wavelength $\lambda \sim h_0$, then $\lambda^3 = 8\times10^{-15} \Rightarrow \lambda = 20\ \mu\mathrm{m}$. The general relations are shown in **Figure 4**.

How does our ontological theory compare with experiment? The height of the wave guide, h_0, establishes the energy available, and an absorber above this clips neutrons with greater energy. Our calculation shows wavelength $\lambda > 20\ \mu\mathrm{m}$ when $h_0 < 20\ \mu\mathrm{m}$. The wavelength will not "fit-into" the waveguide: $\lambda(h_0 < 20) > 20\ \mu\mathrm{m}$. Thus, primordial field theory predicts a "flux cutoff" threshold at 20 μm, while Q-bounce experiments prove that there is very little, if any, neutron flux when the waveguide channel is below 20 μm.

A 2012 report: $v_\perp \sim 2\ \mathrm{cm/sec}$ and *mean wavelength* $\lambda = 10\ \mu\mathrm{m}$, which agrees with calculations. Our ontological model of the neutron in gravity produces realistic physical values agreeing with values reported by experiment. Experimental evidence of gravity at interstellar scales, based on gravitational waves from merging neutron stars and black holes, now reaches all the way down to millionths of a meter, a mind-boggling range for experiments on the primordial field. We next investigate the quantum mechanical description of the experiment.

5. The Quantum Treatment of Neutron Bouncing

Within the conceptual framework of quantum theory Nesvizhevsky, *et al.* [9] observed:

"*The probability* $\psi_n^2(z)$ *of finding neutrons at height z has n maxima and* (*n* – 1) *minima with the probability zero in each minimum as for standing waves.*"

Standing waves are a strange image for the primordial field picture of neutrons bouncing in gravity but are built-into the quantum framework. Since any smooth potential is approximately harmonic in the vicinity of a stable equilibrium point, the harmonic oscillator is one of the most important model systems in quantum mechanics, and one of the few quantum-mechanical systems for which an exact, analytical solution is known. The bounce behavior is somewhat similar to a harmonic oscillator, whose states are derived and described in [10]; the analog of the classical oscillator. Oscillator wavefunctions in **Figure 5(a)** are Hermit polynomial-based, generated by *Mathematica* code:

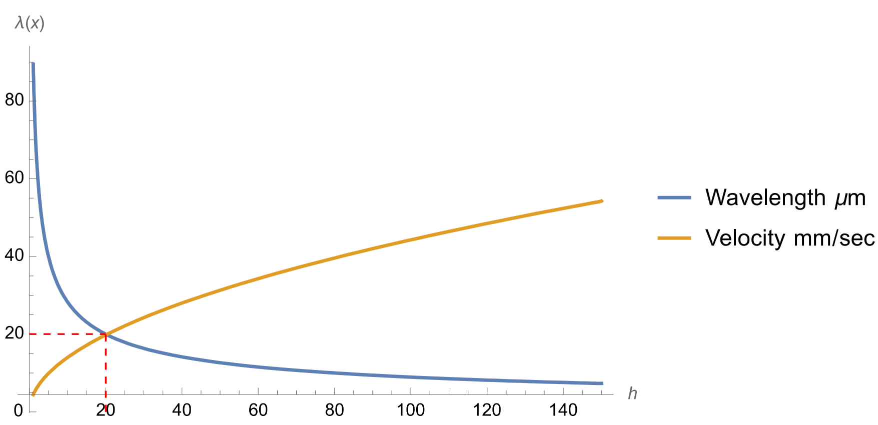
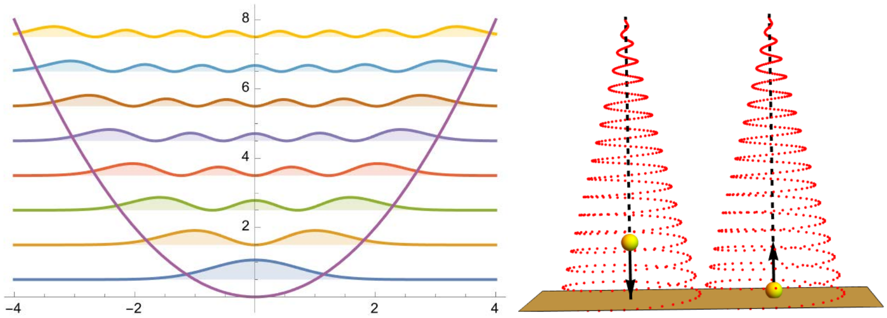


Figure 4. Wavelength as function of height (both in μm), velocity in mm/sec.



(a) (b)

Figure 5. (a) Harmonic Oscillator wavefunctions. (b) Bouncing neutron wavefunctions.

```
f[n_, x_] := Abs[((1/Pi)^(1/4) HermiteH[n, x])/(E^(x^2/2) Sqrt[2^n n!])]^2
Plot[Evaluate@ Append[Table[f[n, x] + n + 1/2,
{n, 0, 7}], x^2/2], {x, -4, 4}, Filling -> Table[n -> n - 1/2, {n, 1, 8}]]
```

C-field-based wavefunctions are shown in **Figure 5(b)**. Aside from the obvious similarity between "bouncing" and "oscillating", physicists see a "particle-in-a-box" paradigm: the oscillator is trapped between potential walls or bounds; the bouncing neutron is trapped between a potential height and a perfectly reflecting mirror; formal quantum treatment of the problems as similar was predictable. In 2000 Westphal formulated a quantum mechanical description of the bounce, reducing the problem of a neutron moving inside the setup to an effective one-particle problem, corresponding to the single-particle time-dependent Schrödinger equation:

$$\frac{-\hbar^2}{2m}\frac{\partial^2\psi}{\partial z^2}+mGz\psi=-i\hbar\frac{\partial\psi}{\partial t}\quad\text{for}\quad z>0 \tag{19}$$

whose solution is

$$\Psi(z,t)=\sum C_n\exp\left(-i\frac{E_n}{\hbar}t\right)\psi_n(z). \tag{20}$$

where ψ_n are solutions of time-independent Schrödinger equation:

$$\left\{\frac{-\hbar^2}{2m}\frac{\partial^2}{\partial t^2}+V(z)\right\}\psi_n=E_n\psi_n \tag{21}$$

The $z>0$ boundary condition is solved by setting $\psi(0)=0$. In addition to the perfectly reflecting mirror, an absorbent ceiling is added, to clip neutrons beyond the certain vertical energy-component, mGh. A neutron falls from an initial height in a gravitational potential, is accelerated by gravity until it strikes a perfectly reflecting mirror with momentum p, then defies gravity to regain its initial height. For neutrons trapped between potential barriers, quantum theory predicts discrete energies. After passing through a first, fixed, waveguide, the mirror is lowered, effectively raising the ceiling. Quantum theory represents what is happening in this region as a superposition of the vertical motions eigenstates; to describe the measurements quantum mechanically one must calculate eigenstates. The key concept of quantum mechanical description is "spatial density distribution", normally given by the square of the wave function, $\psi_n^2(z)$, which establishes local spreading and a momentum distribution. With Figure 6 in mind, Suda, *et al.* [11] note:

"*As is well-known, it is possible to describe this phenomenon using Airy functions.*"

Since the wave function has to vanish at the mirror surface, in 2012, Abele and Leeb [12] noted:

"*…the eigenfunction for this problem are pieces of the same Airy function in the sense that they are shifted in each case in order to be zero at* $z = 0$ *and cut for* $z < 0$."

Figure 7(a) shows the wavefunctions of the harmonic oscillator and a diagrammatic mapping Figure 7(b) into Airy functions in bounce framework.

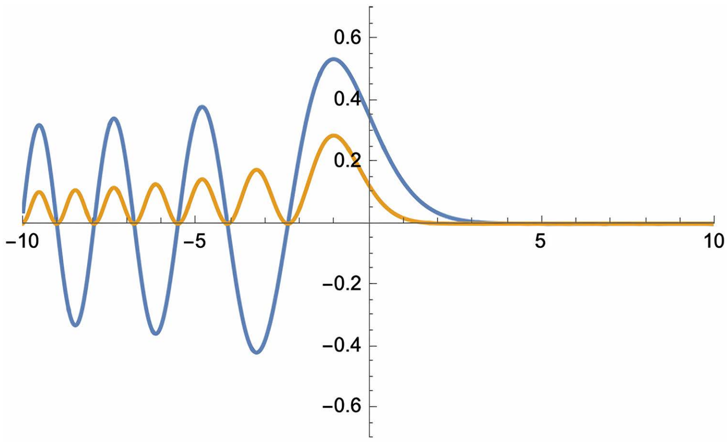


Figure 6. *Mathematica*: *Plot[{AiryAi[x], AiryAi[x]^2}, {x, −10,10}]*. Airy function $Ai(\zeta)$ (blue) and $[Ai(\zeta)]^2$ (orange).

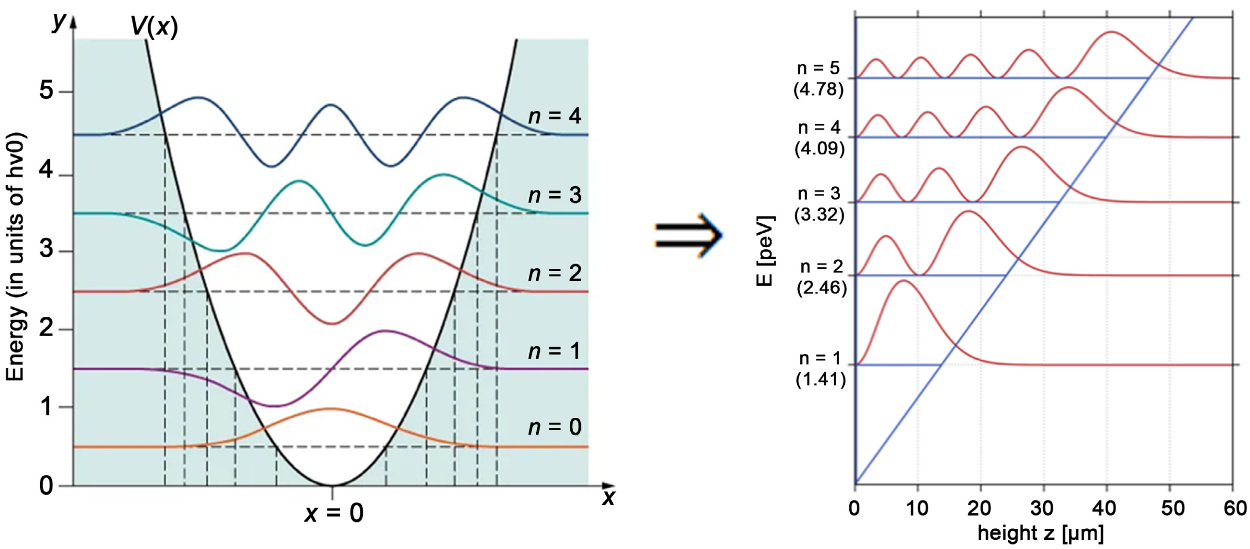
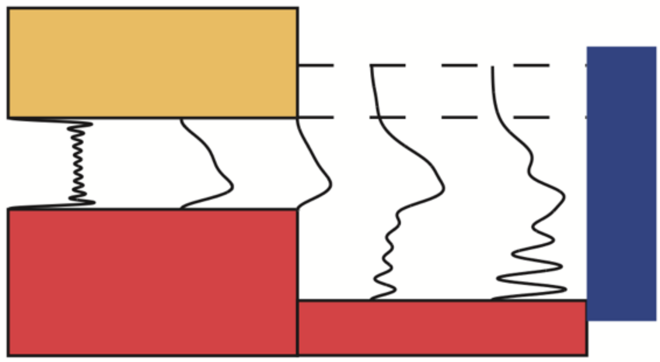


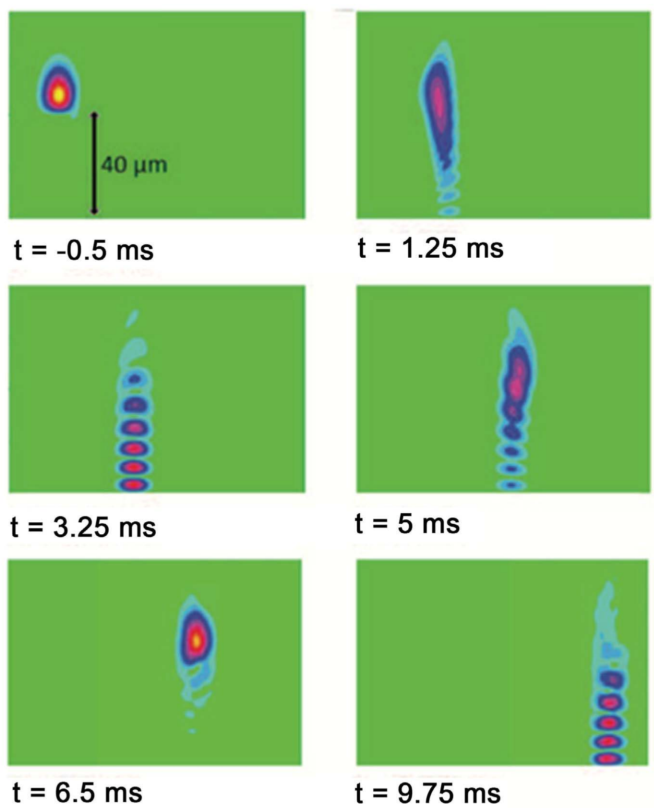
Figure 7. (a) Harmonic oscillator wave functions, (b) AiryAi wave functions, squared to provide spatial density distribution.

With this introduction to a conceptual framework in which Q-bounce QM description was created, we forego the mathematics of the solution—well presented in the literature—and focus on ontological aspects of the model. Figure 8(a) depicts the oscillator wave functions literally as Airy functions, while according to Abele and Leeb, the simulations of Figure 8(b) are such that:

"*it is not possible to tell whether the particle is falling or going up, and the expectation value* $\langle z \rangle$ *of the wave packet remains very close to the time average of the classical trajectory.*"



(a)



(b)

Figure 8. (a) Side view of neutron waveguide, with (yellow) absorber at top, (red) neutron mirror at bottom, and (blue) detector at right. (b) Simulated bouncing based on Airy-based wave function at different time steps.

6. Quantum Description vs Ontology of Primordial Field

Thus, two interpretations of neutrons bouncing in a gravitational field: an ontological interpretation based on primordial field theory, and a quantum description, a wave function of the bouncing neutron, with gravity potential used in Schrödinger's equation, and with Airy function solutions. Westphal's Schrödinger equation used 3D position vector $\boldsymbol{r}$ rather than height *z*. Since "*every eigenfunction of the vertical motion* (*z*) *is multiplied by a plane wave in the x-direction*," we obtain a continuous spectrum in the horizontal plane, but quantized states for the vertical motion. Ontological assumptions of the quantum theorist:

1) Evolution is based on superposition of eigenstates.

2) The neutron "bound" by the gravitational well is conceptually similar to harmonic oscillators.

3) The minima (zeros) of the neutron wave function correspond to oscillator wavefunctions.

4) The wavefunction must vanish at $z = 0$ (the mirror): $\psi(0) = 0$.

5) Energy levels above the first are very closely spaced.

6) Airy function-based neutron wavefunctions travel through the waveguide along the x-axis.

7) The vertically bound states inside maintain the conditions of continuous differentiability.

8) Every eigenfunction of vertical motion (*z*) is multiplied by a plane wave in the x-direction.

One version of the experiment involves several bounces on a mirror, then effectively lowering the mirror a specific amount (27 μm) and modeling the system behavior. In QM this is considered preparation of the system in the lower quantum states, followed by a fall down a step of 27 μm in the g-field. From the perspective of the quantum physicist,

"*The neutron is now in a coherent superposition of several quantum states.*"

A *neutron spectrum enters the waveguide*, and consequent weak statistics make it difficult to add reasonable confidence limits. In particular, a 2003 conclusion of Nesvizhevsky, *et al.*:

"*A clear observation of high quantum states is a more difficult task than that for the lowest quantum state. In order to detect neutron flux showing that the first state is populated, one has to compare an almost zero signal* (*low background*) *with a non-zero effect…to resolve higher levels one has to compare two non-zero and quite close signals.*"

The first step height is the highest one, and step height decreases quite rapidly with state number. *I.e.*: "*the experimental separation of two neighboring levels is more difficult for higher levels.*" Vallee *et al.* [13] observe that:

"*…the energy levels in a gravitational well are closely spaced, making the classical limit ubiquitous in most practical cases and quantum interference effects hardly observable.*"

Finally, the flux count measured across the waveguide gap should be able to distinguish between the primordial field theory neutron and the current quantum model of neutron bouncing. It was noted in 2003 that the neutron count shows that:

"*…the lowest level* [*state*] *is significantly underpopulated, the third level is overpopulated. The reason for such behavior of the level population has yet to be understood.*"

I interpret this to mean that the higher in the potential field the neutron flux is sampled, the higher the count. If so, this supports the primordial field theory interpretation, wherein the locally well-defined mass density spends most of its time in the higher potential, slowest motion regions.

7. Ontological Analysis of Quantum vs Classical Theory of Reality

Physics Today [14]:

"*Sometimes theory and experiment are both correct but do not agree with each other*; *sometimes a wrong theory agrees with experiment. One must therefore be careful not to jump to conclusions.*"

Both Rosu [15]: "*We consider the toy model of a Schrödinger quantum particle bouncing on a perfectly reflecting surface…*", and in 2006, Westphal *et al.*: "*The toy model of a Schrödinger quantum particle bouncing in a linear gravitational field is known as the quantum bouncer.*" The toy model supposes that the horizontal wavefunction is continuous, while the vertical wavefunction description of the bouncing neutron has discrete eigenfunctions. As Santilli states:

"*Quantum mechanics cannot provide a representation of the mean life*, *charge radius*, *and anomalous magnetic moment of the neutron.*"

In agreement with Burton Richter [*Physics Today*, 2006] Santilli views "*contemporary particle physics as* '*theological speculation*'." A relevant quote from E.T. Jaynes [16]:

"*…our present quantum mechanical formalism is not purely epistemological*; *it is a peculiar mixture of describing in part realities of Nature*, *in part incomplete human information about Nature—all scrambled up by Heisenberg and Bohr into an omelet that no one has seen how to unscramble.* (…) *if we cannot separate the subjective and objective aspects of the formalism*, *we cannot know what we are talking about*; *it is just that simple.*"

Despite 100 years of "wave-particle" physics [17] it is still true that quantum physicists don't know what they're talking about. We do NOT know whether the wavefunction is *ontic* or *epistemic*:

"*Does the quantum state represent a state of some physical entity out there in the world, or does it represent instead a state of our knowledge about something out there in the world*?"

If the nature of the quantum state is assumed to represent real physical systems, it is said to be ontic; otherwise, it is considered epistemological. A key resource is Harrigan and Spekkens' [18] categorization of quantum ontological models as ψ-*ontic* or ψ-*epistemic*. Oldofredi and Lopez [19] further show that the H&S categorization "*implicitly assumes that a complete description of a quantum system* (*its ontic state*, λ) *only concerns single individual systems*, *instantiating absolute*, *intrinsic properties*." But Klein [20] [21] argues that a rational basis for such an "individuality interpretation" does not exist; instead he argues quantum theory is a substructure of classical probabilistic physics. Not every quantum theory presupposes that λ represents the state of a single, individual quantum system. Statistical interpretations of quantum mechanics assume that ψ provides a description of the statistical properties of an ensemble of similarly prepared systems.

Ontology Overview

This paper presents one application of primordial field theory, which theory has been applied to Kasner-metric dynamical cosmology, geometrical encoding of energy density, an existence proof for particle "mass gap", and other aspects of reality, with good explanatory power, which is an indirect measure of ontology. The current application addresses major conceptual aspects of physics, potentially resolving century-old issues. Our primordial model of the neutron is ψ-ontic: the neutron is a physically real particle, interacting with the physically real gravitational field, along a physically real trajectory in configuration space, with momentum-density-induced C-field-circulation-based wavefunction. The quantum description of the neutron is a statistical spatial distribution comprised of superposition of eigenstates, in such manner that the simulation (**Figure 8(b)**) of neutron behavior cannot distinguish between up and down motion.

Several papers claim that measured data for $\Delta h < 15\,\mu\text{m}$ strongly contradict classical dependence $N_{CL}(\Delta h)$, but are in good agreement with quantum expectations. This is incorrect. Their logic is that classical *point particles* should be able to penetrate almost any width waveguide, but classical primordial field theory associates a *wave* of C-field circulation with finite de Broglie wavelength, which predicts a non-zero minimum wave guide channel; a cutoff threshold exists at 20 μm and experiments prove that there is very little, if any, neutron flux when the waveguide channel is below 20 μm. **Figure 3** implies the greatest probability of finding a particle is near the height of the gravity well, where it is moving slowest; the spiral-based circulation is maximum at the mirror and zero at the height of the well. Quantum physics does not associate gravitomagnetic circulation with neutrons, so does not view the simple $\psi(0) = 0$ condition from the perspective of the reversal of circulation at the irrotational surface, and consequent reversal of momentum.

We developed a quantum gravity description of the Q-bounce to contrast with the current quantum mechanical treatment. Primordial field theory yields results in agreement with the experiment. This is significant: for a century atom-level physics has been formulated quantum mechanically, mostly Copenhagen, but also other interpretations, almost all of which are based on the de Broglie

$p = h/\lambda$ and *Schrödinger* $\hat{p} = i\hbar\nabla$ relations, while macro physics typically treats systems of countless particles with classical mechanics. The Q-bounce experiment, in its variations, perhaps the only experiment to be described quantum mechanically *and* via primordial field theory, invites an ontological comparison previously unavailable. After a century of quantum confusion, as to *ψ-ontic* or *ψ-epistemic*, the Q-bounce experiment offers a meaningful comparison between theories and corresponding ontological models. We compare: Fields, Physics, Particles, Trajectory, Fundamental aspects:

1) Fields:

Quantum wavefunctions have no energy.

The primordial C-field has/*is* kinetic energy.

2) Physics:

Quantum is formulated on energy eigenstates: $-\hbar^2\nabla^2\psi + V\psi = E\psi$

Primordial field based on momentum density: $\boldsymbol{p} = \nabla \times \boldsymbol{C}$

3) Particle:

Quantum superposition of eigenstates/wavefunctions.

Primordial *real*, *localized*, *non-point* particles, with C-field wavefunction.

4) Trajectory:

Quantum model impossible to describe trajectory, or even direction of path.

Primordial neutron follows classical path, with C-field wave function physics.

5) Fundamental:

Quantum theory is substructure of classical probabilistic physics.

Primordial field substructure arises classically from self-interaction.

This experiment may be the only experiment to date that allows direct comparison between classical and quantum ontology. The primordial field applied to the bouncing neutron yields a test of classical field theory on a fundamental particle typically conceived of quantum mechanically. Review of ontological neutron models, *Primordial Quantum Gravity*, and *Quantum Mechanical*, reveals significant ontological differences between the two, which have not been resolved one way or the other. Anticipated evolution of Q-bounce experiments (both increase in neutron flux and improvements in flux detection instruments) should allow categorical rejection of one or both theories of quantum gravity. If *Primordial Quantum Gravity* wins this theory-contest, it will probably engender the most radical change in physics ontology since 1900.

Conflicts of Interest

The author declares no conflicts of interest regarding publication of this paper.

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