Journal of High Energy Physics, Gravitation and Cosmology, 2024, 10, 1551-1563
https://www.scirp.org/journal/jhepgc
ISSN Online: 2380-4335
ISSN Print: 2380-4327

On Scalar Planck Waves

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How to cite this paper: Nash, L. (2024) On Scalar Planck Waves. *Journal of High Energy Physics, Gravitation and Cosmology*, **10**, 1551-1563.
https://doi.org/10.4236/jhepgc.2024.104087

Received: June 14, 2024
Accepted: September 27, 2024
Published: September 30, 2024

Abstract

The sound of space-time at the large scale is observed in the form of gravitational waves, which are disturbances in space-time produced by wavelike distortions (or kinks) in the gravitational field of an accelerating parcel or distribution of energy. In this study, we investigate a hypothetical wave mode of quantum space-time, which suggests the existence of scalar Planck waves. According to this hypothesis, the sound of quantum space-time corresponds to kinks propagating in the gravitational displacement field of an oscillating energy density. In evaluating the emission of scalar Planck waves and their effect on the geometry of space-time, one finds that they not only transport a vanishingly small amount of energy but can also be used to simulate gravity.

Keywords

Scalar Planck Waves, Quantum Space-Time Dynamics, Gravitational Waves, Gravitational Displacement Field, Artificial Gravity

1. Introduction

One of the most interesting predictions of the general theory of relativity is the existence of gravitational waves [1]. The idea that a perturbation of the gravitational field should propagate as a wave is, in some sense, intuitive. Einstein showed that the existence of gravitational radiation in the form of gravitational waves is a natural consequence of the general theory of relativity. He was able to show that in the limit of small disturbances from Euclidean space-time (or Minkowski space), his field equations gave way to a linear wave equation that has plane wave solutions which are transverse (metric) distortions of Minkowski space traveling at a characteristic speed equal to that of light, properties that electromagnetic waves also possess. In many ways, gravitational waves have been determined to behave similarly to electromagnetic waves; however, one should be careful in stretching this analogy too far.

The Planck lattice model of space-time [2] introduces a hypothetical wave mode of quantum space-time that has not been contemplated until now. In this work, the disturbance of Minkowski space is generated by a scalar perturbation of the metric [3], with the hope that gravitational displacement waves will emerge in the same way that gravitational waves are produced by a tensor perturbation of the metric in Einstein's derivation of the wave equation in empty space [4] [5]. Because gravitational waves are derived from tensor perturbations of the Minkowski metric, they are tensor space-time (or Einstein) waves. On the other hand, gravitational displacement waves arise from scalar perturbations of the Minkowski metric at the Planck scale; consequently, they are scalar quantum space-time (or Planck) waves[1].

Gravitational waves were essentially introduced when Newton's theory of gravitation was replaced by the general theory of relativity, and it was shown by Einstein that they transport information about the evolution of an accelerating parcel or distribution of energy through space. Similarly, when a distribution of energy oscillates relative to its center of gravity, the information about this dynamic change in energy density should propagate in the form of waves as well.

During the passage of gravitational waves, the structure of space-time itself oscillates [7]. To put this more precisely, the proper time taken by light to travel between two fixed points in space oscillates. Thus, when they propagate the geometry of space-time, and consequently the proper distance between space-time points, changes in time. Similarly, scalar Planck waves cause zero-point deformations of the Planck lattice to change in time as they propagate at light speed away from the radiating source. Because scalar Planck waves warp space-time geometry [8] at the Planck scale, it may be possible to prove their existence by generating a uniform gravitational field [9] from a given distribution of oscillating light.

2. Scalar Perturbation of Minkowski Space

The question naturally arises as to whether scalar waves of the Planck lattice can occur as solutions of Einstein's field equations in the same way that gravitational waves can occur. In the linearized approximation appropriate for regions of space-time where the gravitational curvature is small, the metric can be written as[2]

$$g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}, \tag{1}$$

where the perturbation

$$h_{\mu\nu} = \eta_{\mu\nu}\phi \tag{2}$$

is a scalar perturbation with $\phi = \phi(r,t)$ being a scalar field and $h_{\mu\nu} \ll 1$ everywhere in space-time. Thus, the scalar perturbation is a small deviation from the Minkowski metric $\eta_{\mu\nu} = \mathrm{diag}(-1,1,1,1)$ which acts on the geometry of space-time through zero-point deformations of the Planck lattice [2].

The Einstein field equation in empty space-time [10] is given by

[1]A scalar component of gravitational radiation is also foreseen in extended theories of gravity [6].

[2]For the equations presented in this study G is the gravitational constant, $h = 2\pi\hbar$ is Planck's constant, and c is the speed of light in vacuum, unless otherwise stated.

$$G_{\mu\nu} = R_{\mu\nu} = 0\,. \tag{3}$$

To first order in $h_{\mu\nu}$ the Ricci tensor is

$$R_{\mu\nu} = g^{\alpha\beta} R_{\alpha\mu\beta\nu} = \frac{1}{2}\left(\partial_\alpha \partial_\nu h^\alpha_\mu - \Box h_{\mu\nu} + \partial_\mu \partial_\alpha h^\alpha_\nu - \partial_\mu \partial_\nu h\right), \tag{4}$$

where $\partial_\mu = \partial / \partial x^\mu$, $\Box \equiv \partial^\mu \partial_\mu = \nabla^2 - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}$ is the d'Alembertian in Euclidean space-time, and $h = h^\mu_\mu = \eta^{\mu\nu} h_{\mu\nu}$ is the trace of $h_{\mu\nu}$ using the Minkowski metric. Inserting Equation (2) into Equation (4) yields

$$R_{\mu\nu} = -\left(\eta_{\mu\nu} \Box + 2\partial_\mu \partial_\nu\right)\phi/2\,.$$

Combining this result with Equation (3), one obtains the wave equation for scalar Planck waves in Minkowski space [11] [12]

$$\Box \phi = 0\,, \tag{5}$$

which has the form of the familiar equation of motion for waves traveling in empty space with velocity *c*. This result demonstrates that wavelike solutions of the linearized Einstein field equations do exist for scalar perturbations of the Planck lattice. Note that the d'Alembertian operator in Equation (5) ensures that the solutions admitted by the scalar Planck wave equation are Lorentz invariant scalars and are therefore manifestly observer or coordinate independent. Because the geometry of undulating gravitational displacement fields [2] traveling along gravitational field lines resembles waves on a string or in water, scalar Planck waves are *transverse* in nature, as expected for a radiation field. Furthermore, because the distance between equilibrium positions of the Planck unit cells is constant, the Planck lattice behaves like an incompressible fluid, which generally prevents the existence of longitudinal waves.

Let us now take a mechanical approach and show from Hooke's law[3], in one space dimension, that for small perturbations of the event nodes of the Planck lattice, the corresponding equation of motion for the gravitational displacement fields along a gravitational field line has the form of a wave equation. Imagine an array of Planck unit cells interconnected by rigid massless rods of length Δr as shown in **Figure 1**. The zero-point displacement of each event node has a spring constant *k*.

Here, the dependent variable $\phi(r)$ measures the amplitude of the zero-point displacement at *r*, such that $\phi(r)$ represents the magnitude of the disturbance (i.e., strain) that is traveling in a perfectly elastic medium. The average force exerted by the Planck lattice on the gravitational displacement field at location $r + \Delta r$ is

$$F_H = k\left[\phi(r + 2\Delta r, t) - 2\phi(r + \Delta r, t) + \phi(r, t)\right]. \tag{6}$$

According to Newton's second law of motion, the average force imparted to the gravitational displacement field is

[3]In the theory of elasticity, Hooke's law approximates the behavior of certain materials, stating that the amount by which a material body is deformed (the strain) is linearly related to the force causing the deformation (the stress).

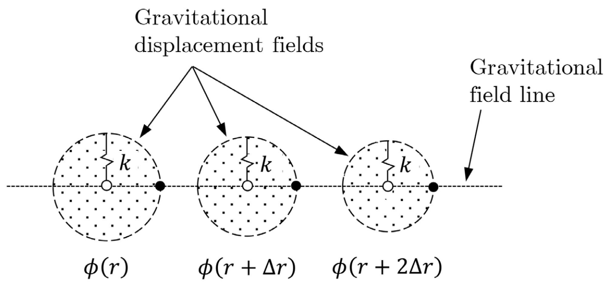

Figure 1. Event nodes indicated by the small filled circles are displaced from the center of their Planck unit cells, which are indicated by the small empty circles at the center of each gravitational displacement field.

$$F_N = ma(t) = \frac{\varepsilon}{c^2}\frac{\partial^2}{\partial t^2}\phi(r+\Delta r,t), \tag{7}$$

where $m = \varepsilon/c^2$ denotes the average energy (or inertial mass) of the gravitational displacement field at $r+\Delta r$. The equation of motion for the gravitational displacement field at location $r+\Delta r$ is determined by equating these two forces:

$$\frac{\partial^2}{\partial t^2}\phi(r+\Delta r,t) = \frac{kc^2}{\varepsilon}\left[\phi(r+2\Delta r,t) - 2\phi(r+\Delta r,t) + \phi(r,t)\right]. \tag{8}$$

The event nodes along the gravitational field line form an array of N gravitational displacement fields of total energy $E = N\varepsilon$ evenly spaced over a distance $L = N\Delta r$ with a total spring constant $K = k/N$. It follows that we can write Equation (8) as:

$$\frac{\partial^2}{\partial t^2}\phi(r+\Delta r,t) = \frac{KL^2c^2}{E}\left[\frac{\phi(r+2\Delta r,t) - 2\phi(r+\Delta r,t) + \phi(r,t)}{\Delta r^2}\right]. \tag{9}$$

As $N \to \infty$, $\Delta r \to 0$, and assuming smoothness at the macroscopic scale one obtains

$$\frac{\partial^2\phi(r,t)}{\partial t^2} = \frac{KL^2c^2}{E}\frac{\partial^2\phi(r,t)}{\partial r^2}. \tag{10}$$

The Planck lattice behaves as a linear elastic material with stiffness K given by

$$K = E_P A/L,$$

where A represents the cross-sectional area of the Planck unit cell and E_P is the modulus of elasticity of the Planck lattice. The wave equation becomes

$$\frac{\partial^2\phi(r,t)}{\partial t^2} = \frac{E_P ALc^2}{E}\frac{\partial^2\phi(r,t)}{\partial r^2}. \tag{11}$$

AL corresponds to a Planck volume of length L that contains the event node perturbations of the Planck lattice. Hence

$$ALc^2/E = 1/\varrho,$$

where ϱ is the energy density of the gravitational displacement fields. Thus, our wave equation reduces to

$$\frac{\partial^2\phi(r,t)}{\partial t^2} = \frac{E_P}{\varrho}\frac{\partial^2\phi(r,t)}{\partial r^2}. \tag{12}$$

The speed of a transverse stress or gravitational displacement wave in the Planck lattice is $\sqrt{E_P/\varrho}$. Because scalar Planck waves travel at the speed of light through the Planck lattice, Equation (12) is equivalent to Equation (5).

Suppose we have a wave moving radially away from the center of gravity of an oscillating spherical energy density of radius *R*. The simplest solution of the wave equation for the Planck lattice has the form

$$\phi(r,t) = A\sin k(r - ct), \quad (13)$$

where $A = \frac{a_P}{2}\sqrt{\frac{R_S}{R}}$ is the amplitude of the wave which is equal to half the zero-point displacement of an event node [2], $k = 2\pi/\lambda$ is the spatial frequency of the wave, also called the wave number, $a_P = \sqrt{\hbar G/c^3} \approx 10^{-33}$ cm is the Planck length, and $R_S = 2GM/c^2$ is the Schwarzschild radius of the oscillating energy density.

3. Emission of Scalar Planck Waves by Superpositions of Oscillating Light

Consider an isolated optical system in which a spherical distribution of light oscillates radially relative to its center of gravity. In much the same way that kinks in the gravitational field travel along gravitational field lines [13], kinks in the gravitational displacement field travel along the gravitational field lines of an oscillating distribution of energy, as well. Hence, as the photons of the oscillating light shell travel outward, they produce kinks in the gravitational displacement field that travel outward from the light shell at the speed of light. Similarly, as the photons of the oscillating light shell travel inward, they produce kinks in the gravitational displacement field that travel toward the center of the light shell at the speed of light (see **Figure 2**). It should be noted that in general, gravitational waves are produced by a changing quadrupole moment [10]. Because the quadrupole moment of the energy distribution is zero, our spherical oscillating light shell does not radiate gravitational waves.

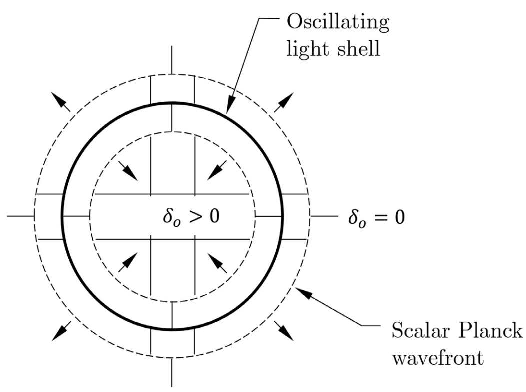

Figure 2. Scalar Planck waves are formed by kinks in the gravitational displacement field (solid lines) propagating away from an oscillating spherical light shell.

In accordance with the mechanics of waves, it can be readily shown that because the amplitude of scalar Planck waves is much smaller than the wavelength $A < a_P \ll \lambda$, they carry an extremely small amount of energy [14]. For a detailed examination of this assertion, we first consider an element of energy of the gravitational displacement field, such that $\Delta m = h\nu/c^2$. As the energy propagates through empty space, each energy element of the gravitational displacement fields is driven radially inward and outward at the same frequency as the wave. Each energy element of the gravitational displacement fields can be modeled as a simple harmonic oscillator with a constant linear energy density given by

$$\mu = \Delta m/\Delta x = \frac{h}{a_P c\lambda}, \tag{14}$$

where $\Delta x = a_P$ denotes the length of each energy element of the gravitational displacement field. The total energy associated with a wavelength is the sum of the kinetic and potential energies K_λ and U_λ, respectively. Thus,

$$\varepsilon_\lambda = K_\lambda + U_\lambda = \frac{2\pi^2 hc}{a_P}\left(\frac{A}{\lambda}\right)^2, \tag{15}$$

where $K_\lambda = U_\lambda = \pi^2 \mu A^2 \nu^2 \lambda$ [14] and A denotes the amplitude of the wave. The radial thickness of the light shell is much smaller than its outer radius $\Delta r \ll R$; therefore, the lower limit of the wave amplitude within the light shell is approximately

$$A \geq \delta_o/2 = \frac{a_P}{2}\sqrt{\frac{R_S}{R}}, \tag{16}$$

where $\delta_o = a_P\sqrt{R_S/R}$ is the zero-point deformation [2] of the Planck lattice and $R_S = 4\pi a_P^2 N/\lambda$ is the Schwarzschild radius of the light shell with N being the number of photons it contains.

The wavelength of the scaler Planck waves is equal to twice the radial thickness of the oscillating light shell $\lambda = 2\Delta r$. Combining Equation (16) with Equation (15) yields

$$\varepsilon_\lambda \geq \left(\frac{\pi^3 a_P^3}{2\Delta r^2 R}\right) Nh\nu, \tag{17}$$

for the lower limit of the total energy of the scalar Planck waves per oscillation of the light shell.

We now pose the problem of calculating the overall radiation of scalar Planck waves originating from the system [15]. To answer this question, we first ask ourselves how many event nodes can fit on the outer surface of the oscillating light shell. This can be determined approximately from

$$N_P \approx S/a_p^2 = 4\pi(R/a_P)^2, \tag{18}$$

with $S = 4\pi R^2$ as the outer surface area of the spherical oscillating light shell. Thus, the total energy of the gravitational radiation emitted by the distribution of light per oscillation is given by

$$\mathcal{E}_\lambda = 2N_P\varepsilon_\lambda \approx \left(\frac{4\pi^4 a_P R}{\Delta r^2}\right) Nh\nu . \tag{19}$$

A factor of two was added to account for waves emitted from both the inner and outer surfaces of the oscillating light shell, which is assumed to be nearly equal for $\Delta r \ll R$.

Finally, the total energy divided by the period of total emission of radiation energy per oscillation T_λ, gives the energy loss (per unit time) of the oscillating light shell due to the emission of scalar Planck waves. To this end, we can write

$$P_\lambda = \mathcal{E}_\lambda / T_\lambda \approx \left(\frac{2\pi^4 a_P c R}{\Delta r^3}\right) Nh\nu , \tag{20}$$

where $T_\lambda = 2\Delta r/c$ is the period of the scalar Planck waves. It follows that the lifetime of an isolated oscillating light shell can be computed as

$$\tau = \left(\frac{E}{\mathcal{E}_\lambda}\right) T_\lambda \approx \frac{\Delta r^3}{2\pi^4 a_P c R}, \tag{21}$$

where $E = Nh\nu$ is the total energy of the light shell. It can be readily shown for a light shell of frequency ν, that its minimum radial thickness follows from Heisenberg's uncertainty principle [16], where the uncertainty in position Δx and frequency $\Delta\nu$ of a photon are related by the following equation:

$$\Delta\nu\Delta x \geq \frac{c}{4\pi}. \tag{22}$$

By letting $\nu\Delta r > c/4\pi$, the lower limit of the lifetime of the light shell is

$$\tau > \frac{c^2}{128\pi^7 a_P \nu^3 R} \approx 10^5 \text{ years} , \tag{23}$$

for $\nu = 10\text{ GHz}$ and $R = 1\text{ km}$. This result shows that the maximum energy loss due to the radiation of scalar Planck waves for an optical system, such as a spherical oscillating light shell is extremely small for frequencies of light, where $\nu < 10\text{ GHz}$ and $R < 1\text{ km}$. Accordingly, with regards to scalar Planck radiation, once the distribution of light is set in motion it may oscillate almost indefinitely.

4. Gravitational Effects of Scalar Planck Waves

The zero-point displacement of the Planck lattice produced by an oscillating ring of light composed of N_γ photons, of radius R, is

$$\delta_{o,\gamma} = t_P\sqrt{2GM_\gamma/R} , \tag{24}$$

where $M_\gamma = N_\gamma h\nu/c^2$ is the photon energy. If N_s superpositioned oscillating rings of light are such uniformly distributed to form a cylindrical shell of oscillating photons, it follows that at a given point along the axis of the light shell, the corresponding zero-point displacement of the Planck lattice is

$$\delta_o = N_s\delta_{o,\gamma} . \tag{25}$$

Since an acceleration field is produced in the direction of increasing zero-point displacement [2], let the zero-point displacement along the axis of the cylindrical light shell be defined by the relation

$$\delta_o(z) = t_P\sqrt{2gz}\ , \tag{26}$$

where $z > 0$ is the coordinate along the axis of the light shell, $g > 0$ is an acceleration constant, and $t_P = a_P/c$ is the Planck time. Equating Equations (25) and (26) gives

$$N_s(z) = \frac{1}{a_P}\sqrt{\frac{gRz}{2\pi N_\gamma \nu c}}, \tag{27}$$

for the number of superpositions of N_γ photons as a function of the *z*-coordinate of the cylindrical light shell. It follows that the energy density distribution along the axis of the light shell is given by the equation:

$$e(z) = \frac{1}{2\pi R}\left(\frac{\partial E}{\partial z}\right) = \frac{\hbar}{2a_P}\sqrt{\frac{gN_\gamma \nu}{2\pi Rcz}}, \tag{28}$$

with $E = N_S N_\gamma h\nu$ being the total energy of the oscillating light shell. The energy density distribution and Planck strain [2] (in units of nanostrain nε) are plotted in **Figure 3** for a 3 kHz cylindrical light shell 0.50 m tall.

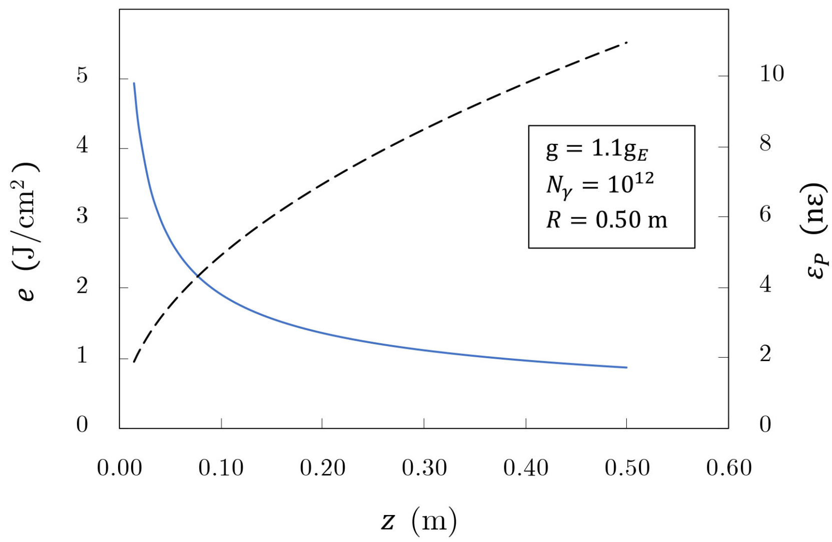

Figure 3. The photon energy density (solid curve) and Planck strain (dashed curve) profiles of an oscillating cylindrical light shell configured to radiate scalar Planck waves that generate a uniform anti-gravitational field 1.1 times stronger than the gravity of Earth.

The corresponding metric of empty space-time in the (t,z) coordinate system inside the cylindrical light shell is given by the following equation [2]:

$$ds^2 = -c^2dt^2\left(1-\left(\delta_o/a_P\right)^2\right) + dz^2\left(1-\left(\delta_o/a_P\right)^2\right)^{-1}, \tag{29}$$

where $\delta_o = t_P\sqrt{\frac{2GM_E}{R_E+z}+2gz}$ is the zero-point displacement of the Planck lattice produced by the Earth and the distribution of scalar Planck waves generated by the oscillating light shell. Since $z \ll R_E$, Equation (29) can be written as[4]

$$\mathrm{d}s^2 \approx -c^2\mathrm{d}t^2\left(1-\frac{R_{S,E}}{R_E}-\frac{2\Delta \mathrm{g}z}{c^2}\right)+\mathrm{d}z^2\left(1-\frac{R_{S,E}}{R_E}-\frac{2\Delta \mathrm{g}z}{c^2}\right)^{-1}, \tag{30}$$

where $\Delta \mathrm{g}=\mathrm{g}-\mathrm{g}_E$, $R_{S,E}=2GM_E/c^2$, and $\mathrm{g}_E=GM_E/R_E^2$ is the acceleration due to gravity on Earth.

In general, the geodesic equation for a parcel of energy in a gravitational field simplifies when the motion can be approximately described by classical mechanics. In which case, the strength of the gravitational field is small, its rate of change is negligible, and the velocity of the parcel of energy is small compared with that of light. The simplified geodesic equation has the form

$$\frac{\mathrm{d}^2x^\mu}{\mathrm{d}s^2}+\Gamma^\mu_{\alpha\beta}\frac{\mathrm{d}x^\alpha}{\mathrm{d}s}\frac{\mathrm{d}x^\beta}{\mathrm{d}s}=0 .$$

For small velocities, $c\mathrm{d}t/\mathrm{d}s \approx 1$ is much larger than the derivatives of the space components. Thus, the dominant components of the geodesic equation are

$$\frac{\mathrm{d}^2x^\mu}{\mathrm{d}t^2}+c^2\Gamma^\mu_{tt}=0, \tag{31}$$

where index $t=0$. Provided that the Γ^μ_{tt} are not negligible. The time component

$$\Gamma^t_{tt}=\mathrm{g}_{tt}\frac{\mathrm{d}\mathrm{g}_{tt}/\mathrm{d}t}{2c},$$

is negligible in the classical limit of fields which vary slowly with time. Because the acceleration of the gravitational field of the cylindrical light shell is in the *z*-direction only, the dominant component of the geodesic equation in the classical limit is given by

$$\frac{\mathrm{d}^2z}{\mathrm{d}t^2}+c^2\Gamma^z_{tt}=0, \tag{32}$$

where index $z=3$. The expression of the Christoffel symbols in terms of the metric is

$$\Gamma^z_{tt}=\frac{1}{2}\left(\frac{\partial \mathrm{g}_{zt}}{\partial t}+\frac{\partial \mathrm{g}_{zt}}{\partial t}-\frac{\partial \mathrm{g}_{tt}}{\partial z}\right).$$

Since $\mathrm{g}_{zt}=0$, the geodesic Equation (32) becomes

$$\frac{\mathrm{d}^2z}{\mathrm{d}t^2}=\frac{c^2}{2}\frac{\partial \mathrm{g}_{tt}}{\partial z}, \tag{33}$$

where g_{tt} is the coefficient $-\left(1-R_{S,E}/R_E-2\Delta \mathrm{g}z/c^2\right)$ in the metric defining $\mathrm{d}s^2$. Therefore, the equation of motion of a particle in the gravitational field produced by the Earth and the scalar Planck waves of the oscillating light shell is

[4]This approximation removes the component of the metric responsible for the tidal forces of Earth's gravitational field. This is acceptable because the light shell contains a very small region of the gravitational field produced by Earth, which is approximately constant near the surface of Earth.

$$\frac{d^2z}{dt^2} = \Delta g, \tag{34}$$

which is just Newton's law of motion in a uniform gravitational field[5]. Thus, we have sufficiently shown that the oscillating light shell can be configured to generate a uniform[6] anti-gravitational field [17] [18] as illustrated in **Figure 4**.

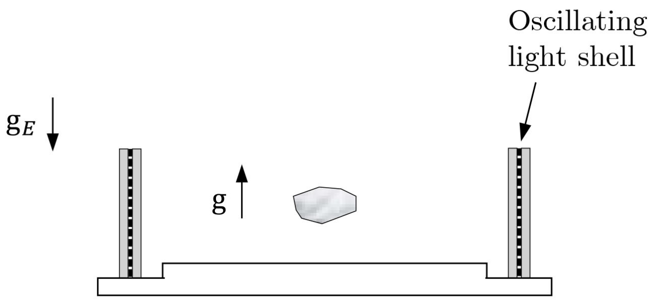

Figure 4. A stone, inside an oscillating cylindrical light shell, falling upward against the gravitational pull of Earth with an acceleration $\Delta g = g - g_E > 0$.

The curvature of space-time is quantified by the Riemann curvature tensor. All the components of the curvature tensor for the metric of space-time inside the cylindrical light shell are exactly zero [19]. Thus,

$$R^{\mu}_{\nu\alpha\beta} = 0 . \tag{35}$$

This implies the existence of a system of coordinates such that the metric is everywhere inside the light shell equal to the Minkowski metric. Consequently, it immediately follows that the geometry of spacetime produced by the scalar Planck waves of the oscillating light shell is indeed intrinsically flat. Therefore, the gravitational effects of the scalar Planck waves that one observes are due to an accelerated frame of reference, like that of an elevator accelerating downward, and not to a gravitating body [20].

Einstein's general theory of relativity is a geometric theory of gravity, where gravitational phenomena are viewed as reflecting the underlying curvature of space-time. An invariant interval is related to the coordinates of the space-time manifold through the metric in the form of

$$ds^2 = g_{\mu\nu} dx^{\mu} dx^{\nu} .$$

For $dz = 0$ this reduces to

$$ds^2 = g_{tt} c^2 dt^2 ,$$

and the knowledge that the invariant interval is the proper time interval

[5]As presented in **Figure 4**, for $\Delta g > 0$, the equation of motion (34) corresponds to that of a particle freely falling upward (or accelerating) away from Earth.

[6]Because scalar Planck waves are envisioned to pass through one other without interference, the diameter of the light shell must be equal to an integral number of half-wavelengths of the emitted scalar Planck waves to ensure the amplitude of the gravitational displacement field within the light shell is uniform.

$ds^2 = -c^2 d\tau^2$, leads us to the following expression:

$$d\tau = dt\sqrt{1 - \frac{R_{S,E}}{R_E} - \frac{2\Delta gz}{c^2}}. \quad (36)$$

This result implies that clocks situated at different *z*-coordinates in the combined gravitational fields of the cylindrical light shell and the Earth run at different rates. By letting $v = \sqrt{2\Delta gz} < c$, Equation (36) becomes with $\Phi_E = -GM_E/R_E$ and $\beta = v/c$:

$$d\tau = dt\sqrt{1 + 2\frac{\Phi_E}{c^2} - \beta^2}, \quad (37)$$

which is the equation for time dilation due to uniform (unaccelerated) relative motion between two frames of reference with one located on the surface of Earth $r = R_E$ and the other an arbitrarily large distance from Earth $r' \gg R_E$.

5. Summary and Conclusions

The detailed investigations carried out in this study successfully demonstrate that Einstein's field equations admit wave solutions of the Planck lattice for a scalar perturbation of the Minkowski metric. Moreover, in accordance with Hooke's law we determined from a mechanical perspective that scalar perturbations of quantum space-time led to gravitational displacement waves. Heisenberg's uncertainty principle was then used to show that the lower limit of the rate of energy transported by scalar Planck waves is inversely proportional to the cubed frequency of an oscillating energy density.

In general, owing to the intrinsic connections between the event nodes of the Planck lattice, the displacement of one or more event nodes from their equilibrium positions due to an oscillating energy density gives rise to a set of waves propagating through the Planck lattice. The wave amplitude is determined by the zero-point displacements of the event nodes from their equilibrium positions. A quantum mechanical interpretation of these Planck lattice waves results in what may be referred to as gravitational phonons [21], which are quantized sound waves of the Planck lattice. Because Planck lattice waves are scalar waves, gravitational phonons are scalar quasiparticles with spin zero, representing the wave-particle duality of quantum space-time. The detection of gravitational phonons would not only provide compelling empirical evidence for the discrete lattice structure of quantum space-time, but also the existence of scalar Planck waves.

Theoretically, scalar Planck waves can be used to generate artificial gravity. The approach developed in this study warped spacetime at the Planck scale in such a way as to produce a field of acceleration similar to that of Earth, excluding tidal effects [22] [23]. The geometry of such a space-time is said to be intrinsically flat. This implies that the resulting gravitational field is due to an accelerated reference frame, as in the case of a uniformly accelerating elevator, and not due to a parcel or distribution of energy. Therefore, the oscillating light shell, described in the previous section, produces an artificial curvature in space-time, unlike the real curvature of space-time produced by a gravitating parcel or distribution of energy. Although it was determined that the number of photons necessary to generate an artificial gravity field that is ten percent stronger than Earth's gravity was on the order of 10^{35} photons, the total relativistic mass of the distribution of light was significantly smaller than that of Earth. Thus, if our conception is correct, scalar Planck waves can in principle be used to artificially warp space-time by an observable amount, which would serve to indirectly confirm their existence, as well as help validate our Planck lattice theory of quantum space-time dynamics.

Conflicts of Interest

The author declares that he has no known competing financial interests or personal relationships that could have influenced the work reported in this study.

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