Spacetime-based model of EM radiation

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ABSTRACT

A spacetime based model of an electric field and a photon is presented. The model assumes that 4 dimensional spacetime has vacuum fluctuations at all frequencies up to Planck frequency. Gravitational wave theory is used to give insights into electromagnetic (EM) radiation. From gravitational wave equations it is possible to derive the impedance of spacetime and quantify energy propagating in the medium of spacetime. EM radiation is shown to experience the same impedance as gravitational waves. This implies that photons also are waves in the medium of spacetime. The distortion of spacetime produced by a photon is calculated. Experiments are suggested including an experiment that may improve the sensitivity of experiments attempting to detect gravitational waves.

Keywords: spacetime field, photon, electric field, gravitational wave, LIGO, zero point energy, impedance of spacetime

1. INTRODUCTION

The explanation of a photon offered here was originally generated as part of a much larger undertaking which examines the following question: Is spacetime the single energetic field responsible for everything in the universe? Various field theories exist [1] which postulate that each particle has its own field. In these models particles are quantized excitations of a field. However, since the standard model has about 17 different fundamental particles, this approach implies the unappealing prospect of 17 different overlapping fields. Furthermore, this does not even include gravity because gravity is not part of the standard model. Therefore, exploring the possibility that everything in the universe is constructed out of 4 dimensional spacetime requires the starting assumption that there is only one truly fundamental field which is 4 dimensional spacetime. This approach has yielded very interesting results for particles and forces. However, this paper will report specifically on the results relating to photons and electric fields.

The proposal has previously been made that photons are fluctuations in zero point energy [2,3]. However, zero point energy has not been physically described in terms of something more fundamental. Also, a quantifiable physical effect produced by a photon has not been given. This paper will attempt to accomplish these goals by relating everything to 4 dimensional spacetime. Therefore it is necessary to first describe energetic 4 dimensional spacetime before it is possible to describe photons. The proposal is made that spacetime is the single universal field which is responsible for everything in the universe including photons. A book titled The Universe Is Only Spacetime [4] is available online which derives particles, fields and forces from 4 dimensional spacetime. An abbreviated account will be given here of the portion of the book showing how photons and electric fields are derived from the properties of 4 dimensional spacetime. While this may sound like a speculative approach, it generates models and predictions which can be quantified and analyzed mathematically.

2. GENERAL RELATIVITY MODEL OF SPACETIME

When we speak of spacetime, we usually assume that we are in the domain of general relativity (GR). This discipline pictures spacetime as three spatial dimensions plus one time dimension. Events occurring in spacetime are thought of as having a specific spatial location occurring at a specific time. GR showed that spacetime can be curved (warped) by matter or energy. This curvature occurs in a smooth and continuous way. However, according to GR spacetime is also capable of wave propagation. Gravitational waves propagate at the speed of light in the medium of spacetime.

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The WMAP [5] and Planck space missions have established that spacetime is flat on the very large scale of about 3×10^8 light years. From the GR perspective, flat spacetime implies that the universe meets a "critical" density which achieves large scale flat curvature where parallel lines remain parallel indefinitely. Both cosmological observation and theoretical predictions from GR agree that the average energy density of the universe on the large scale appears to equal the "critical" energy of about 10^{-9} J/m^3. This energy density is considered to consist of dark energy, dark matter, baryonic mater and photons. This paper will specifically exclude any discussion of the hypothetical cosmological constant.

3. QUANTUM VACUUM

Quantum mechanics (QM) does not have a formal model of spacetime. However, QM does require a model of the vacuum. In order to perform the incredibly accurate calculations of both quantum electrodynamics and quantum chromodynamics it is necessary to assume that the vacuum is full of activity [6]. Virtual particle pairs are continuously coming into existence and going out of existence. Furthermore, the Lamb shift, the Casimir effect, the correction to the electron's anomalous magnetic dipole moment, all require that vacuum is full of activity (energy) on the very small scale. Even some aspects of the uncertainty principle are traceable to spacial and temporal vacuum fluctuations. An estimate of the energy density of the quantum vacuum can be obtained from field theory. This requires that the vacuum be modeled as being filled with quantum oscillators with energy $E = \hbar\omega/2$. The maximum frequency of these quantum oscillators is equal to Planck angular frequency $\omega_p = (c^5/\hbar G)^{½} \approx 1.8 \times 10^{43}$ s^{-1}. The implied energy density [6] of this zero point energy is about 10^{113} J/m^3.

This energy density is roughly 10^{120} times greater than the "critical" energy density of the universe obtained from GR and cosmological observation. Usually it is assumed that GR must be correct and something unknown must cancel what appears to be the ridiculously high energy density implied by QM. However, to cancel out 10^{113} J/m^3 would require an equally large offsetting effect. Also, it is not possible to merely declare that the large implied energy of the vacuum is impossible according to GR and therefore must not exist. Its existence is required for a large number QM effects.

What structure of spacetime could possibly be compatible with spacetime having the equivalent of harmonic oscillators at all frequencies up to Planck frequency? Furthermore, the implied enormous energy density must not be detectable on the macroscopic scale but still produce the various QM effects. In other words, we are looking for a model of spacetime that satisfies both GR and QM requirements. The answer proposed in the book [4] is that spacetime is a sea of small amplitude, high frequency waves which are modulating both the spatial and temporal properties of spacetime. Such waves are forbidden by GR if they existed on the macroscopic scale governed by GR. Among other problems, they would cause a violation of the conservation of momentum. However these spatial and temporal waves are permitted on the scale governed by QM provided that the displacement of spacetime is so small that they are undetectable as determined by the uncertainty principle. The question of the minimum detectable length measurement (device independent) has been examined [7-12] and found to be equal to Planck length $L_p = \sqrt{\hbar G/c^3}$. Similarly the allowable variation in the rate of time in flat spacetime cannot produce a difference between perfect clocks exceeding Planck time $T_p = \sqrt{\hbar G/c^5}$ [8,9]. Therefore, L_p and T_p sets a quantifiable amplitude for the displacement of spacetime. The maximum spatial displacement is equal to Planck length. The maximum temporal displacement is equal to Planck time. Therefore these waves will be called "Planck length/time waves". Their existence is analogous to virtual particle pairs being permitted provided that they are annihilated in a short time period specified by the uncertainty principle. The difference is that the uncertainty principle permits Planck length/time waves in spacetime to last indefinitely. The case will be made that these waves not only exist in spacetime but are the fundamental property of spacetime. This sea of small amplitude waves is the basic building block of all particles, fields and forces and will be called the "spacetime field". They are also the physical explanation of zero point energy and are essential for the proposed explanation of photons.

4. IMPEDANCE OF SPACETIME

We will temporarily leave the subject of spacetime being a sea of waves and examine a related subject. We can gain an insight into the properties of spacetime by examining the properties that spacetime exhibits when it is propagating a gravitational wave. The reasoning is that a gravitational wave is propagating in the medium of spacetime. If we can determine the implied impedance of spacetime from gravitational wave equations, then this impedance would not only reveal insights into spacetime, but the impedance of spacetime would allow analysis of Planck length/time waves in spacetime. Fortunately the impedance of spacetime Z_s has been determined [13] from analysis of gravitational wave equations:

$$Z_s = c^3/G \approx 4.04 \times 10^{35} \text{ kg/s} \tag{1}$$

One simple example can be given showing how the impedance of spacetime can be derived from gravitational wave equations. There is a universal equation for the intensity $\mathcal{I}$ of waves of any kind which includes wave amplitude A, angular frequency ω, impedance Z and a dimensionless numerical factor k.

$$\mathcal{I} = k\,A^2\omega^2 Z \tag{2}$$

Gravitational wave equations are usually complex because they are nonlinear. However, in the limit of a plane wave and weak gravity the intensity $\mathcal{I}$ of a gravitational wave can be expressed as : $\mathcal{I} = (1/16\pi)A^2\omega^2(c^3/G)$. Comparing this to equation (2), it is obvious that the impedance term is c^3/G. Equation (2) can also be converted into equations for energy density U and energy E in volume V. If we are dealing with waves propagating at the speed of light, then $U = \mathcal{I}/c$ and $E = \mathcal{I}V/c$. This results in the following equations which will be used later.

$$E = kA^2\omega^2 ZV/c \tag{3}$$
$$U = kA^2\omega^2 Z/c \tag{4}$$

Next we will examine the implications of spacetime having a definable impedance. Any medium that exhibits impedance must have elasticity. When a wave propagates in a medium, the medium itself must have the ability to absorb energy and return energy to the wave as it propagates. This elasticity is required for spacetime to propagate gravitational waves. This elasticity is compatible with the idea that spacetime is a sea of Planck length/time waves in spacetime. The passage of a gravitational wave would slightly distort these high frequency waves causing them to slightly change their frequency as they absorb or return energy. The impedance of spacetime is so large that spacetime is a very stiff medium for wave propagation. That is the reason that it is so difficult to detect gravitational waves. Even a large intensity gravitational wave produces a relatively small displacement of spacetime.

In equations (2-4) the amplitude and the impedance must have units which are compatible with the other terms in the equations. When impedance has units of kg/s, then the amplitude term must be dimensionless. The amplitude of gravitational waves are expressed as a dimensionless strain of spacetime. A simplified version if this strain amplitude would be $A = \Delta L/L$ where ΔL is the displacement of spacetime measured over distance L. However, this is just an approximation that presumes that L is much less than the gravitational wavelength ($L << \lambda$). The strain is the slope of a sine wave with maximum displacement of a spatial dimension of ΔL over a wavelength λ. The exact designation of this slope (strain amplitude) is: $A = \Delta L/\lambda\!\!\!^{-}$ where $\lambda\!\!\!^{-} = \lambda/2\pi$ and $\lambda\!\!\!^{-}$ is pronounced lambda bar. It is important to understand the difference between the displacement amplitude of a wave ΔL which has units of length and strain amplitude $\Delta L/\lambda\!\!\!^{-}$ which is dimensionless. Both types of amplitude are important in the discussion of photons to follow.

Zero point energy is usually characterized as harmonic oscillators in the vacuum at a temperature of absolute zero but with energy of $E = \hbar\omega/2$ and energy density of $U = k\hbar\omega/\lambda\!\!\!^{-3}$. It is proposed that Planck length/time waves in spacetime fulfill the characteristics required to be the physical explanation for the abstract idea of "harmonic oscillators at a temperature of absolute zero". We will use equation (4) to test this hypothesis. The substitutions used will be; $A = L_p/ƛ$; $\omega = c/ƛ$; $L_p = \sqrt{\hbar G/c^3}$; $Z = Z_s = c^3/G$.

$$U = \frac{kA^2\omega^2 Z}{c} = k\frac{\hbar\omega}{ƛ^3} \tag{5}$$

Therefore this is a successful test because Planck length/time waves in spacetime plus the impedance of spacetime gives the correct energy density to be zero point energy if the numerical factor k can be shown to be correct. This detail is outside the scope of this paper. The point of this exercise is to establish plausibility that spacetime is filled with a sea if Planck length/time waves. Another proof is the fact that if we set the angular frequency ω equal to Planck angular frequency $\omega_p = \sqrt{c^5/\hbar G}$ then the energy density equals Planck energy density $U = c^7/\hbar G \approx 4.6\times10^{113}$ J/m^3. This corresponds to the QM model of the energy density of the vacuum.

There is another test of the plausibility that spacetime is filled with Planck length/time waves propagating at the speed of light. Gravitational waves propagate in the medium of spacetime and they propagate at the speed of light in all frames of reference. When the Michelson-Morley experiment was performed, it was an attempt to measure motion relative to the ether. The assumption was that light propagated as waves in a hypothetical fluid called the "luminiferous ether" that was assumed to fill the universe. However, no relative motion was able to be detected by Michelson-Morley experiment or numerous more recent experiments. Special relativity postulated that light traveled at the speed of light in all frames of reference and the need for the ether was eliminated. However, that is not the end of the story. If the Michelson-Morley experiment could be repeated using gravitational waves rather than light, no motion could be detected relative to the medium of spacetime. Therefore, spacetime possesses the ability to always make gravitational waves appear to propagate at the speed of light in any frame of reference. This makes sense if spacetime is viewed as a sea of Planck length/time waves propagating at the speed of light. It is impossible to measure motion relative to this type of medium.

The normal way of treating energy density at a particular frequency is to designate the "spectral energy density" which is energy density per unit frequency interval. We will designate this spectral energy density as: $U(\omega)d\omega$. The Planck length/time waves that are the proposed source of zero point energy would have a spectral energy density of zero point energy which is: $U(\omega)d\omega = k(\hbar\omega^3/c^3)d\omega$. As Puthoff [14] comments, "This spectrum with its ω^3 dependence of spectral energy density is unique in as much as motion through this spectral distribution does not produce a detectable Doppler shift. It is a Lorentz invariant random field. Any particular spectral component undergoes a Doppler shift, but other components compensate so that all components taken together do not exhibit a Doppler shift (at least up to the cut off at Planck frequency). It should also be noted that neither cosmological expansion nor gravity alters this spectrum".

The sea of vacuum energy (Planck length/time waves) that is proposed to be the basic structure of spacetime takes on some of the properties that physicists used to attribute to the ether at the beginning of the 20th century. However, there are also some major differences. First, the ether was visualized as an entity which had a separate existence from all other particles, fields and forces. Spacetime is proposed to be the single universal field which generates everything in the universe (all particles, fields and forces). Second, the ether was visualized as having a unique frame of reference. As previously demonstrated, spacetime is a medium without a unique frame of reference. Finally, the ether was abandoned because it simply was not needed. The spacetime field consisting of Planck length/time waves is absolutely essential. It is the single universal field responsible for all forces and particles. Of particular interest to this paper, the energetic spacetime field will be proposed as the medium required for the propagation of photons.

5. CHARGE CONVERSION CONSTANT

We have not completed the background information necessary to proceed with the description of electric fields and photons. Since the premise is that everything in the universe is derived from the spacetime field, the first step is to find an explanation for electrical charge using the properties of spacetime. Usually charge is assumed to be an abstract concept that is not understandable in terms of being explainable in terms of something more fundamental. However, if we are assuming that everything is the result of the spacetime field, then even charge must be explainable as a distortion of spacetime. We merely have to look for an equation which equates charge to a spatial or temporal property of spacetime. Fortunately, this is an easy search. We know that elementary charge e is related to the fine structure constant α as shown: $e = \sqrt{\alpha 4\pi\varepsilon_o \hbar c}$. We will start with the Coulomb force equation between two elementary charges e and make substitutions including Planck length $L_p = \sqrt{\hbar G/c^3}$ and Planck force $F_p = c^4/G$.

$$F_e = \left(\frac{1}{4\pi\varepsilon_o}\right)\left(\frac{e^2}{r^2}\right) = \alpha \left(\frac{L_p^2}{r^2}\right) \mathrm{F_p}$$

We will rearrange terms and work towards defining a new constant with units of meter/Coulomb. This will be called the "charge conversion constant" and designated by the Greek symbol eta *(η)*. A substitution for Planck charge $q_p = \sqrt{4\pi\varepsilon_o \hbar c}$ will also be made.

$$\frac{e^2}{\alpha L_p^2} = 4\pi\varepsilon_o F_p \equiv \frac{1}{\eta^2}$$

$$\eta \equiv \frac{\sqrt{\alpha} L_p}{e} = \frac{L_p}{q_p} = \sqrt{1/4\pi\varepsilon_o F_p} = 8.617 \times 10^{-18}\ \mathrm{m/C} \qquad (5)$$

The proposed charge conversion constant $\eta = L_p/q_p$ will serve as the conversion factor between units that contain charge (Coulomb) and the distortion of spacetime produced by a charged particle or an electric field. Equating charge to length does not seem conceptually understandable if we think of length merely as ordinary ruler length. However, there are various mathematical terms which can have units of length without implying static ruler length. When η has units of meters/Coulomb these meters will be shown to represent a distortion of spacetime with units of length.

Next we will examine the impedance of free space $Z_o \approx 376.7\ \Omega$ using the charge conversion constant η. The impedance of free space Z_o is a physical constant that relates the magnitudes of the electric field $\mathbb{E}$ and the magnetic field strength $\mathbb{H}$ in EM radiation when this EM radiation is propagating through a vacuum.

$$Z_o \equiv \mathbb{E}/\mathbb{H} = \mu_o c = (1/\varepsilon_o c) \approx 376.7\ \Omega \qquad (6)$$

The units of the impedance of free space Z_o are: $\mathrm{m^2 kg/C^2 s}$. Therefore to eliminate the Coulomb squared units using η we must multiply Z_o by $(1/\eta^2) = 4\pi\varepsilon_o c^4/G$

$$\left(\frac{1}{\eta^2}\right) Z_o = \left(\frac{4\pi\varepsilon_o c^4}{G}\right)\left(\frac{1}{\varepsilon_o c}\right) = 4\pi \frac{c^3}{G} = 4\pi Z_s \qquad (7)$$

This is an important insight. Equation (7) says that $Z_o = \mathbb{E}/\mathbb{H}$ corresponds to $4\pi Z_s$ when we use the charge conversion constant $\eta = L_p/q_p$ to convert charge to a property of spacetime. This implies that EM radiation experiences the same impedance ($Z_s = c^3/G$) as gravitational waves (the factor of 4π can be ignored). The implication is that photons are not like corpuscles of energy propagation *through* spacetime, photons are waves propagating *in* the medium of the spacetime field. They are similar to gravitational waves in the sense that both EM radiation and gravitational waves experience the same impedance of spacetime Z_s. The sea of Planck length/time waves that forms the spacetime field gives spacetime elasticity and the property of not being able to detect motion relative to the medium of spacetime.

The next questions are: Why are photons quantized? Why do they have particle-like properties? We are imagining spacetime as a sea of Planck length/time waves at all frequencies up to Planck frequency. These waves possess no angular momentum and can be thought of as being the most perfect superfluid possible. We can get an insight into this superfluid by looking at a Bose-Einstein condensate which is also a superfluid. It is an experimentally observed fact that a Bose-Einstein condensate cannot possess angular momentum. If angular momentum is introduced, the angular momentum is isolated into quantized units which are a function of $\hbar$. The isolated angular momentum vortices in a Bose-Einstein condensate have been experimentally observed [15-17]. It is proposed that fundamental particles are a rotating Planck length/time wave possessing $\hbar/2$ angular momentum. These are analogous to the rotation vortices that exist in the superfluid Bose-Einstein condensate. Photons are propagating waves possessing $\hbar$ of angular momentum. They propagate in a sea of superfluid Planck length/time waves that lack angular momentum. It is the superfluid sea of Planck length/time waves that enforces the quantization of angular momentum. When a photon (a wave possessing angular momentum) propagates through the spacetime field that lacks angular momentum, the photon introduces angular momentum that produces a type of phase change to a small portion of the spacetime field. The spacetime field quarantines angular momentum. This results in photons having quantized angular momentum and a particle-like property. This quantized disturbance propagates at the speed of light and collapses to a single point when the photon is absorbed.

6. PHOTONS IN MAXIMUM CONFINEMENT

We will attempt to develop a model of a photon and an electric field by starting with the simplified case of a photon confined to the smallest volume that will support the photon. If we make an optical resonator with two parallel reflective mirrors, we know that the minimum resonant separation between these mirrors is ½ wavelength (½λ). The minimum diameter waveguide that will transmit circularly polarized light is slightly larger than ½λ. If we combine these we would have a waveguide approximately ½λ diameter with flat reflectors separated by ½λ and oriented perpendicular to the waveguide axis. This will be called a "maximum confinement resonator" and it will be used to simplify the calculation of the properties of a photon.

When EM radiation is freely propagating, the electric and magnetic fields are transverse to the propagation direction and in phase. However, when EM radiation is confined between reflectors, it forms standing waves that have the electric and magnetic fields 90 degrees out of phase. If the reflectors are separated by ½ λ, then the oscillating electric field is maximum, half way between the reflectors and zero at the reflectors. The magnetic field is maximum at the reflectors and zero half way between the reflectors. The lowest order waveguide mode in the maximum confinement resonator described has the radial distribution of the electric field also maximum along the axis of the cylinder and zero at the cylindrical surface. Combining these, the maximum electric field is at the geometric center of the maximum confinement cavity and the electric field is zero at all surfaces. Assuming maximum confinement simplifies the discussion of photons because it stabilizes the distribution and avoids questions about emission pattern, bandwidth and the model of a freely propagating photon. To simplify this even further we will assume a uniform energy distribution across a volume of $k\lambda\!\!\!^{-3}$ and temporarily ignore the numerical factor k. Therefore for a single photon with energy $E = \hbar\omega$ in volume $\lambda\!\!\!^{-3}$ we have energy density $U = \hbar\omega/\lambda\!\!\!^{-3} = \hbar\omega^4/c^3$. We previously determined that for photons they experienced the same impedance as gravitational waves $Z = Z_s = c^3/G$. Combining these equations with equation (4) we can solve for the amplitude term A. Recall that A is a strain amplitude of the form $A = \Delta L/\lambda\!\!\!^{-} = \Delta L\omega/c$. and obtain an insight into the distortion of spacetime produced by a single photon in maximum confinement.

$$U = \frac{A^2\omega^2 Z_s}{c} = \frac{\hbar\omega^4}{c^3}$$

$$A = \sqrt{\left(\frac{\hbar G}{c^3}\right)\left(\frac{\omega^2}{c^2}\right)} = \frac{L_p}{ƛ} = \frac{\Delta L}{ƛ} \quad (8)$$

$$\Delta L = L_\mathrm{p} \quad (9)$$

Therefore, all photons in a maximum confinement resonant cavity produce the same displacement of spacetime which is equal to Planck length (ΔL = L_p). The strain amplitude for photons of different frequency/wavelength is different because the single displacement (L_p) is divided by ƛ which gives different values of $A = L_\mathrm{p}/ƛ$.

If there are multiple photons in maximum confinement, then we will designate the number of photons as $\mathcal{N}$. A similar calculation would show that *n* coherent photons in maximum confinement produce a displacement of spacetime equal to $\Delta L = \sqrt{\mathcal{N}} L_\mathrm{p}$. This is very revealing because it has been shown [7-12] that there is a fundamental limitation, device independent, as to the minimum change in length that can be detected. These calculations show that it should be impossible to detect the wave properties of a single photon because the Planck length distortion of spacetime is undetectable. However, multiple photons produce a distortion of spacetime larger than Planck length and therefore the wave properties of multiple photons should be detectable. This is correct because a single photon's electric and magnetic fields are undetectable but multiple photons produce detectable electric and magnetic fields.

It is also possible to answer another long standing physics question using the example of a photon in maximum confinement. Why is there no amplitude term in the equation $E = \hbar\omega$? This equation seems to imply that a photon must have a particle-like property. If a photon is only a wave, then it seems as if there should be an amplitude term in $E = \hbar\omega$. For example, it should be possible to have two waves of the same frequency but different amplitudes and therefore different energies. The properties of the spacetime field and a photon in maximum confinement can be used to understand $E = \hbar\omega$. We will use the energy equation (4) and substitute the maximum confinement condition of $V = ƛ^3$ along with other previous substitutions.

$$E = kA^2\omega^2 ZV/c = \left(\frac{L_p}{ƛ}\right)^2 \left(\frac{c\omega}{ƛ}\right)\left(\frac{c^3}{G}\right)\left(\frac{ƛ^3}{c}\right) = \hbar\omega \quad (10)$$

The answer is contained in the cancelations that occur in equation (10). The displacement of spacetime is the same for all photons ($\Delta L = L_\mathrm{p}$), but that is only part of the answer. After cancelations, the only remnant of the strain amplitude ($A = L_\mathrm{p}/ƛ$) is $\hbar$ which comes from $L_\mathrm{p}^2 = \hbar G/c^3$. Still $\hbar$ retains the property of amplitude in the sense that $\hbar$ is the spin amplitude which is the same for all photons. Even though equation (10) is for maximum confinement, it carries over to a freely propagating photon as can be seen if the confinement mechanism suddenly disappeared.

7. WHAT IS AN ELECTRIC FIELD?

Physicists normally treat the subject of an electric field as if it is fundamentally unknowable. If the electromagnetic force is assumed to be transferred by the exchange of virtual photons, then sometimes an electric field is visualized as a cloud of virtual photons. However, even this is not a conceptually understandable explanation. What is a virtual photon? How can an electric field have measurable energy density if virtual photons cannot possess measurable energy?

Since there are similarities between gravitational waves and EM radiation, we will start with gravitational waves. If there were reflectors for gravitational waves, then we could imagine capturing a circularly polarized gravitational wave in a maximum confinement cavity similar to the one described for photons. The rotating gravitational wave would produce an effect which would convert a spherical volume into a rotating ellipsoid. One transverse axis would be elongated while the orthogonal transverse axis would be contracted. These offset each other so that a gravitational wave produces no net change in total volume and no change in the rate of time.

If we had a circularly polarized EM radiation (many photons) in maximum confinement, we would have a detectable electric field at the center of this cavity rotating at the photon's angular frequency ω. What is the difference between having confined EM radiation and confined gravitational waves? One obvious difference is that the electric field is different progressing from + to – compared to progressing the opposite direction (– to +). The gravitational wave stretches and compresses two orthogonal dimensions, but any one dimension makes no distinction about propagation direction. There is nothing different progressing left to right or the opposite direction (right to left). If we assume that spacetime is the single universal field, then an electric field must produce an effect which is different going **+** to **–** compared to the opposite direction (**–** to **+**). There are other limitations on the possible model of an electric field. If an electric field produced a rate of time gradient then this would have properties similar to a gravitational field and electrically neutral particles would be accelerated by an electric field. The proposal reached after analysis is that an electric field is a distortion of one spatial dimension of spacetime that results in a slight asymmetric speed of light in opposite propagation directions. One direction would experience a slight increase in the speed of light and the opposite direction would experience a slight decrease in the speed of light. This would produce no net proper volume change or no net rate of time change because the round trip time between the points is unchanged compared to no electric field. This distortion of space would have units of length because the distance between two points would be different depending on the direction of propagation.

The previously calculated distortion of spacetime over distance approximately equal to $\lambda\!\!\!^{-}$ was previously calculated to be $\Delta L = \sqrt{\mathcal{N}} L_p$. Since $L_p \approx 10^{-35}$ m, even confining 10^{30} photons would only produce an effect of $\Delta L \approx 10^{-20}$ m which would still be undetectable by today's technology. However, there is another alternative. The model of an electric field produced by a photon implies that there is a maximum number of photons which could be contained in a given size maximum confinement experiment. It should be impossible to exceed the condition where $\Delta L = \lambda\!\!\!^{-}$ (ignoring a numerical factor near 1). This would effectively be 100% modulation of the properties of the spacetime field. Is this a flaw in the concept? We will calculate the condition that would achieve $\Delta L = \lambda\!\!\!^{-}$. The critical number of photons that hypothetically achieves $\Delta L = \lambda\!\!\!^{-}$ will be designated as n_c and the critical energy is $E_c = n_c \hbar\omega$.

$$n_c = \frac{E_c}{\hbar\omega} = \frac{E_c \lambda\!\!\!^{-}}{\hbar c} \qquad \text{set } \Delta L = \sqrt{n_c} L_p$$
$$\Delta L^2 = n_c L_p{}^2 = \left(\frac{E_c \lambda\!\!\!^{-}}{\hbar c}\right)\left(\frac{G\hbar}{c^3}\right) \qquad \text{set } \lambda\!\!\!^{-} = \Delta L$$
$$\Delta L = \frac{G E_c}{c^4} = \frac{Gm}{c^2} = R_s \tag{11}$$

In equation (11) R_s is the classical Schwarzschild radius for a black hole with energy equal to E_c. This has been converted to the more familiar equation $R_s = Gm/c^2$ which incorporates mass of $m = E_c/c^2$. Therefore, the prediction that it should not be possible to exceed an energy density that would achieve 100% modulation of spacetime turns out to be correct. This is the condition that achieves a black hole which would block further transmission. In fact, this thought experiment also gives insights into the conditions that achieve a black hole. It is not necessary to exceed the 10^{113} J/m^3 energy density of spacetime to achieve a black hole. That is the energy density required if the maximum confinement cavity was Planck length in radius and the EM radiation was at Planck angular frequency. It is only necessary to exceed the energy density of the lower frequency harmonic oscillators (Planck length/time waves in spacetime) at the frequency of the confined EM radiation.

8. MODEL OF A FREELY PROPAGATING PHOTON

Before proceeding, a brief summary is helpful. It has previously been established that a photon must be propagating in the medium of spacetime because it experiences the same impedance as a gravitational wave. Also spacetime has been characterized as an energetic field of Planck length/time waves at all frequencies up tp Planck frequency. This gives the spacetime field a type of energy density that lacks angular momentum and only interacts with our observable universe (fermions and bosons) through QM effects. This vacuum energy is a basic property of the spacetime field which gives spacetime characteristics such as the impedance of spacetime Z_s and a propagation speed equal to the speed of light. Photons are modeled as waves propagating in the sea of Planck length/time waves in spacetime. Since the superfluid properties of vacuum energy cannot possess angular momentum, a wave carrying quantized angular momentum would be like a propagating phase transition. Such a wave in vacuum energy would propagate at the speed of light for all frames of reference. Also, the waves forming a photon have amplitude measured in units of length, because this is related to the strain in spacetime produced by the Planck length difference in opposite propagation directions along the electric field previously discussed.

Waves in spacetime that are responsible for EM radiation are proposed to have propagation characteristics that are similar to the Huygens-Fresnel-Kirchhoff principle in optics. The waves are propagating in the sea of Planck length/time waves that gives spacetime its high energy density. The Huygens principle assumes that every point on an advancing wavefront of an electromagnetic wave is the source of new secondary waves called "wavelets". The Huygens Principle originally required that the wavelets were hemispherical and only radiate into the forward hemispherical direction of the propagation vector. However, a modification of this was made by Gustav Kirchhoff where the wavelets emit into an amplitude distribution of $\cos^2(\theta/2)$ in a *spherical* coordinate system. This distribution has maximum amplitude in the forward direction and zero amplitude in the reverse direction. The result is the classical Huygens-Fresnel-Kirchhoff principle that accurately describes diffraction, reflection and refraction. All the familiar properties of EM radiation are achieved by the coherent addition of wavelets where phase is included and intensity is amplitude squared. This principle also satisfies the conditions described by Feynman's path integral where every possible path is explored and the resultant is the coherent sum of these alternatives.

The Huygens-Fresnel-Kirchhoff principle and the concept of wavelets accurately describes the propagation of many coherent photons in the spacetime field. However, this concept does not explain the QM characteristics of a single photon or two entangled photons. To explain these, we will start with a thought experiment that generates two entangled photons using electron/positron annihilation. This might seem like an exotic example but it actually is the simplest example because it generates two entangled photons without leaving behind particles which can complicate the explanation because they carry away momentum. We will assume that the electron and positron have anti-parallel spin so that the decay produces two entangled photons with anti-parallel spin. This form of positronium annihilation produces two gamma ray photons, each with energy of 511,000 eV. The polarizations and momentums initially are not determined until one photon is absorbed. Then the remaining previously entangled photon will have the orthogonal polarization and opposite momentum.

Some of the mysteries of this process are: 1) How do the two entangled photons keep track of each other? 2) How do they communicate the polarization and momentum information faster than the speed of light? 3) How does the remaining entangled photon achieve the opposite momentum with the required accuracy?

9. SPACETIME BASED MODEL OF TWO ENTANGLED PHOTONS

The spacetime-based model of a fundamental particle is beyond the scope of this article. However, briefly it is a wave in spacetime rotating at the particle's Compton frequency with $\hbar/2$ angular momentum. This rotating wave is isolated by the surrounding sea of waves in spacetime that lack angular momentum and have superfluid properties. Combining an electron and a positron of this model logically leads to the destabilization of both particles resulting in the emission of a wave disturbance into the surrounding wave structure of spacetime. When two of these particles (matter and antimatter) annihilate each other there is a mutual destabilization and a spherical wave disturbance at the particle's Compton wavelength ($\sim 2.4 \times 10^{-12}$ m) radiates away from the location of the annihilation at the speed of light. This annihilation lasts about 1.25×10^{-10} seconds, which is a spherical shell of waves about 10^{10} wavelengths thick ($\sim$ 4 cm thick). The waves are propagating in the medium of the vacuum fluctuations that are the essential characteristics of spacetime.

Figure 1 shows the shell of waves produced by the electron-positron annihilation expanding at the speed of light away from the location where the annihilation took place. We will imagine that this has happened in the QM vacuum devoid of any other obstacles. The expansion takes place by the formation of new wavelets as previously described. The new wavelets add coherently (in phase) in the direction that expands the local wavefront and adds incoherently in all other directions. Wave propagation in the reverse direction (back towards the center) is prevented by wavelet amplitude distribution previously described.

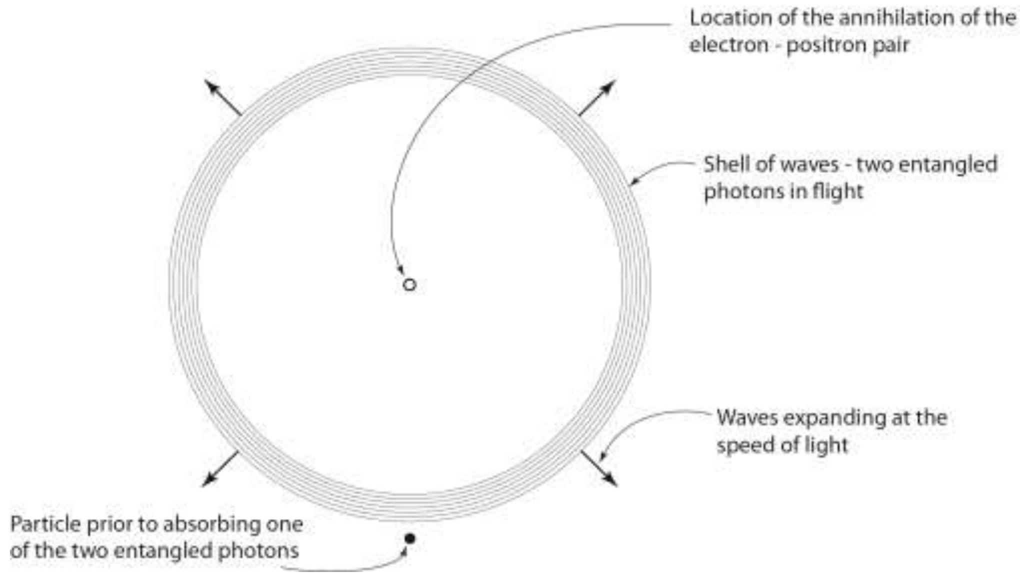

Figure 1 Concentric circles represent the waves in spacetime that form two entangled photons produced by the annihilation of the electron-positron pair [4].

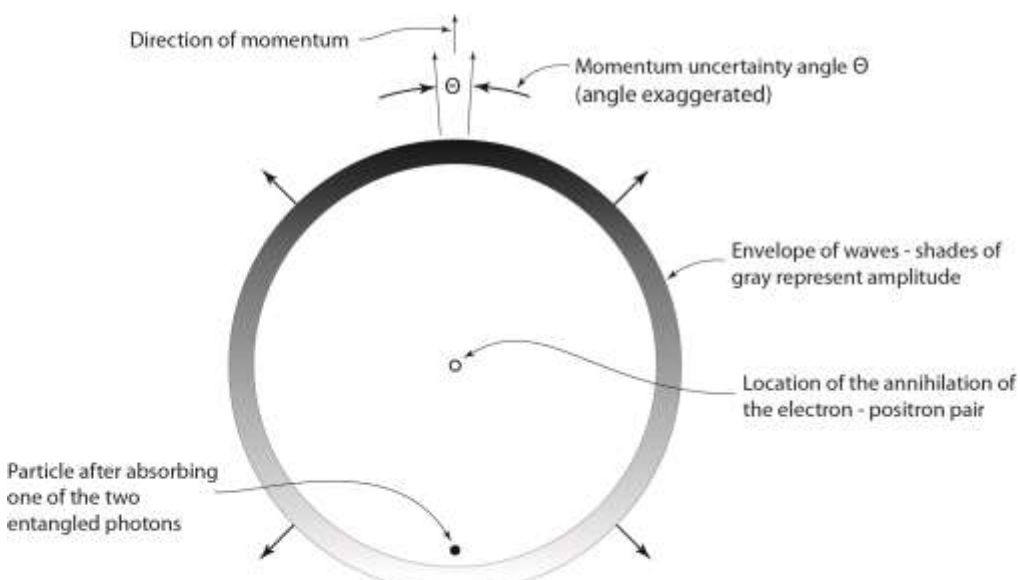

Figure 2 Amplitude distribution (shades of gray) of the surviving photon. This is a picture shortly after the other entangled photon was absorbed by the particle shown [4].

Suppose that the shell of waves expands for one year to a radius of 1 light year before encountering the designated absorbing particle. While the expanding shell of waves represents two entangled photons, only one of these photons is absorbed by the particle. Even though the waves are distributed over a spherical shell one light year in radius, the energy and angular momentum of one of the two entangled photons collapses into the absorbing particle on a process that will be described later

After the absorption of one of the two entangled photons, the characteristic of the remaining photon become obvious. Figure 2 illustrates the remaining photon which is a shell of waves that has expanded past the absorbing particle shown at the bottom of figure 2. In this figure, the wave fronts used to illustrate the wave properties of the photons in figure 1 has been replaced with a gray shading meant to illustrate the relative amplitude of the waves in the remaining photon. The distribution of wave amplitude is strongest (darkest) at the top of figure 2 and the amplitude is zero (no shading) at the bottom of figure 2 representing the direction of the absorbing particle. This is the same amplitude distribution as previously described in the Huygens-Fresnel-Kirchhoff principle. The energy extracted from the two entangled waves by the absorbing particle shown in figures (1, 2) would have the inverse shading. In other words, the absorbed photon would have been black at the bottom of figure 2 and zero shading at the top of figure 2.

Before the adsorption of the first photon, the two entangled photons had the potential to give any momentum vector, any polarization and $\hbar$ angular momentum with any rotational axis to the first absorbing particle. However, after the first entangled photon was removed, all that remained was the properties required to give the opposite angular momentum, the opposite linear momentum and the opposite polarization to the remaining photon. In this model the wave structure of the expanding shell of waves that forms a single photon is not the concentric circles used to represent two entangled photons depicted in figure 1. Instead, the single photon's wave structure must carry a specific angular momentum. The wave structure of a single photon is a 3 dimensional Archimedes spiral [4]. This wave structure carries the correct angular momentum. It permits even a linearly polarized photon to carry orbital angular momentum with a particular rotational direction as required by the conservation of momentum.

The surviving photon also possesses an extremely well defined linear momentum vector with a very small uncertainty angle. At the top of figure 2 there is an angle designated as "momentum uncertainty angle". This angle is set by the uncertainty in the location of the original annihilation event and the uncertainty in the absorption event location. The surviving photon must carry precisely the opposite linear momentum. The calculation is not shown here, but the linear momentum uncertainty angle for the surviving photon with 511,000 eV and r = 1 light year is about 10^{-23} radians.

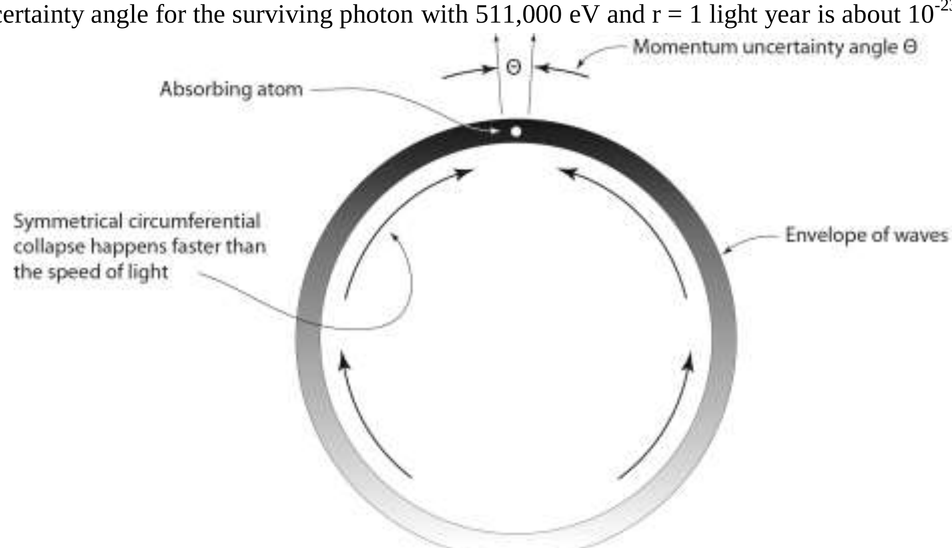

Figure 3 The collapse of the remaining photon into an atom [4]

Figure 3 shows the proposed model of the eventual absorption of the surviving photon. For simplicity, we will assume that it happens shortly after the absorption of the first photon. This means that the radius of the expanding shell of waves is only slightly larger than before. The absorbing atom is designated and it must lie within the volume limited in width by the momentum uncertainty angle. The collapse of the single photon's energy and angular momentum is depicted by the arrows shown in figure 3. These arrows indicate that the collapse proceeds along the circumferential route defined by the envelope of waves. This is an internal collapse happening within a single photon. The photon does not experience time and apparently this collapse can deposit angular momentum and energy happens faster than the speed of light. No information can be communicated faster than the speed of light by this superluminal collapse of the structure of a photon.

This has a great deal of appeal. The momentum transferred to the absorbing body can only have a radial vector relative to the emission uncertainty volume. It would be a violation of the conservation of momentum for there to be a tangential vector component that is larger than the uncertainty limit. This means that the only volume of the photon's wave structure capable of interacting with matter is restricted to the small volume bounded by the momentum uncertainty angle and the thickness of the shell of waves. This is the only volume where the collapse is sufficiently symmetrical to prevent the transfer of detectable transverse momentum. Therefore we would usually ignore the remainder of the shell of waves that lies outside this volume. The portion of the photon waves outside this interactive volume are incapable of transferring the correct momentum and therefore can easily pass through matter without being absorbed. These waves would pass through matter more easily than neutrinos.

When a photon is emitted by an atom there is also a recoil of the atom which defines the momentum uncertainty angle of the photon. This uncertainty angle would be much larger than the entangled photon example. When we have a large number of photons interacting with each other by the wavelet formation previously described, then we would also usually ignore the portion of the wave that lies outside the momentum uncertainty angle for a single photon. However, even these waves outside the momentum uncertainty volume still produce a physical effect because they interact in a way that produces the gravitational field associated with the photon's gravity. However, this is beyond the scope of this paper.

10. PROPOSED GRAVITATIONAL WAVE EXPERIMENT

The value of any new scientific hypothesis is measured in whether it ultimately leads to previously unknown scientific insights and inventions. The model of a photon proposed here is a wave possessing quantized angular momentum propagating in the medium of the spacetime field. Gravitational waves are also propagating in the medium of spacetime. Therefore, what will happen if photons and gravitational waves propagate through the same volume of spacetime? Will there be a measurable interaction? Before attempting to answer these questions, it is helpful to give some background on the current experiments attempting to measure the presence of gravitational waves using laser interferometers.

There are currently several laser interferometer experiments in the world attempting to detect gravitational waves. The largest and most well-known is the LIGO experiments consisting of two Michelson type interferometers located in widely separated parts of the United States. Each interferometer has two 4,000 m long arms in evacuated tunnels. The laser beams are 200 watts at a wavelength of 1.06 µm. The maximum sensitivity occurs at a frequency range between about 60 and 600 Hz. At the high frequency end the optical storage time decreases sensitivity and shot noise is dominant. At the low frequency end various noise sources cause the interferometer mirror surfaces to move minutely. The LIGO interferometers can detect a path length change less than 10^{-18} m at the maximum sensitivity frequency range. Therefore anything that causes the suspended mirror surfaces to move by this minute amount is a source of noise. Seismic noise and even noise induced by radiation pressure on the mirrors become dominant at low frequencies. Therefore, the low frequency noise masks any low frequency gravitational wave signals.

Before attempting to answer the question about the interaction between light and a gravitational wave, we will first look at the simpler case of the interaction between a gravitational wave and matter. For clarity, we designate the propagation direction of a gravitational wave as the Z axis and the transverse directions undergoing length modulation will be designated as the X and Y axis. We will imagine freezing the distortion of spacetime produced by a gravitational wave at the instant that the X axis is undergoing the maximum elongation and the Y axis is undergoing the maximum contraction. A cube made of atoms should react as expected to this distortion of spacetime. It would be elongated along the X axis and compressed along the Y axis. No change would happen along the Z axis. The atoms are exploring all three dimensions simultaneously and should react proportional to the distortion of spacetime.

It is commonly assumed that light should react the same way, but this ignores the proposed mechanism by which light propagates through the spacetime field. Linearly polarized light is a transverse wave that is propagating through the spacetime field by oscillating the properties of one of the 3 spatial dimensions. Even though the electric and magnetic fields of EM radiation are perpendicular, the magnetic field appears to be associated with spin [4] and can be ignored for this analysis. The speed of propagation of the linearly polarized light is determined by the interaction with the spacetime field in the electric field direction. For example, a homogeneous and non-magnetic transparent material such as glass has a single relative permittivity ε at an optical frequency and the single index of refraction n which are related as: $n = \sqrt{\varepsilon}$. Birefringent crystals have different values of permittivity and therefore different indexes of refraction for different linear polarization directions. Suppose that a hypothetical crystal had permittivities ε_x, ε_y ε_z aligned with the X, Y and Z axes. If linearly polarized light had a Z axis polarization direction, then the speed of propagation would be $c/\sqrt{\varepsilon_z}$. The actual propagation direction might be along the X or Y axis, but the speed of propagation is determined by the permittivity in the polarization direction (the Z axis in this case).

The point of this is that when a gravitational wave propagating in the Z direction strains the spacetime field, it is probably slightly changing the relative permittivity ε in the X and Y axis directions. If this is the case, then the gravitational wave will affect the polarization of a beam of light since both the gravitational wave and the light are propagating in the same spacetime field. Furthermore, the X, Y, Z length change measurements made by a beam of light will be polarization dependent and this will not correspond to the X, Y, Z length changes exhibited by a cube of matter. In fact, if vertically polarized light is used in a Michelson interferometer which have both arms in the horizontal plane, then the same polarization direction would be present in each arm. Both arms would therefore experience the same optical path length change and it would be impossible to detect a gravitational wave with this arrangement.

The proposed polarization effect suggests another way of detecting gravitational waves that is both simpler than interferometers and eliminates the notorious sensitivity to vibration of interferometers. Using the polarization effect, the gravitational waves should be detectable using only a single laser beam. The difference in path length produced by the gravitational wave would be between orthogonal linear polarizations in the single beam. A simple example will be given just to illustrate the principle. Suppose that the single laser beam is circularly polarized light and makes multiple reflections to increase its path length similar to an optical delay line. At the output port, the beam is split into orthogonal linear polarizations. Using the previously described axis designations, if the beam propagates along the Z axis, then the beam would be split into X and Y linear polarized components. A gravitational wave with the previously designated X, Y and Z orientations would convert the circularly polarized light into oscillating elliptical polarized light with X and Y elliptical axes. Detectors would monitor each linear polarization and the output signals would be subtracted electronically. The difference in path length for the X and Y linear components would produce amplitude modulation in the two detectors. Subtracting these two signals would produce the output signal. There are other possible designs, so this just illustrates the principles.

11. SUMMARY AND CONCLUSION

A model of the universe has been proposed where 4 dimensional spacetime is the single universal field responsible for everything in the universe (all particles, forces and other fields). The spacetime field is characterized as possessing wave-like fluctuations with spatial displacement equal to Planck length and temporal displacement equal to Planck time. These Planck length/time waves are present at all frequencies up to Planck frequency. With this as background, the following conclusions have been proposed: 1) Gravitational waves propagate in the medium of spacetime and encounter a characteristic impedance of $Z_s = c^3/G \approx 4\times10^{35}$ kg/s. 2) A charge conversion constant $\eta = L_p/q_p \approx 8.6\times10^{-18}$ m/C has been proposed which has units of meters/Coulomb. This relates charge and electric field to a distortion of spacetime. 3) The impedance of free space $Z_o = \mathbb{E}/\mathbb{H} \approx 376.7\ \Omega$ becomes $4\pi Z_s$ when charge is converted to properties of spacetime using the charge conversion constant η. This implies that photons experience the same impedance as gravitational waves. Therefore photons must be a wave propagating in the medium of the spacetime field. 4) Both gravitational waves and photons propagate at the speed of light in all frames of reference. This confirms that the spacetime field has some different properties than the ether which was assumed to have its own frame of reference. However, the spacetime field is a very stiff medium which does propagate light waves. Therefore the spacetime field also possesses some of the properties previously attributed to the ether. 5) A single photon confined in the smallest volume possible produces a Planck length distortion of spacetime oscillating at the frequency of the photon. 6) A proposed model of an electric field is an asymmetric distortion of spacetime where the propagation time between points is slightly different for waves in spacetime if the propagation is in the positive electric field direction compared to the negative electric field direction. However, the round trip distance is unchanged compared to no electric field. 7) This model predicts that there are theoretical energy density conditions where EM radiation would reach a limit demanding 100% modulation of the properties of spacetime. A calculation shows that this limit corresponds to the condition that achieves a black hole. 8) A model of two entangled photons has been proposed. 9) It has also been proposed that gravitational waves should affect the polarization of a beam of light if both the light and the gravitational waves are propagating through the same volume of spacetime. The polarization effect would be vastly less sensitive to vibrations than interferometers. The proposed polarization effect offers alternatives to interferometers for the detection of gravitational waves.

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