Quantum Time

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Abstract

For 60 years the fact that quantum field formulations of gravity make only non-finite predictions has been a vexing issue in physics. In this paper I propose a slightly new interpretation of the photon in Quantum Electrodynamics, as the quanta of the A^μ field, which advances or retards the phase of charged particles. A new Lagrangian for quantum gravity is proposed, and is demonstrated to be equivalent in the proper approximation to the canonical Lagrangian for quantum gravity. The new proposed Lagrangian makes gravitational red shift manifest, instead of a 2^{nd} order effect. I then interpret the graviton, the quanta of the $h^{\mu\nu}$ field, as a particle which retards the time of a particle. Then, just as Feynman re-interpreted Dirac's negative energy solutions to be positive energy particles traveling backwards in time, we will interpret the gravitational field of virtual particles to be an anti-gravity field. The gravitons from virtual particles are shown to advance the time of a particle. Time is now considered an effect of a background field of these gravitons, instead of a free parameter. The result of this interpretation is that all calculations in Quantum Field Theory become finite, including Quantum Gravity calculations. Applications of this new theory will then be listed, including no time travel, dark energy, inflation, the cosmological constant, and the failure of the cosmic background radiation inhomogeneity to explain the observed distribution of galaxies. When one includes the possibility of Hoyle's continuous creation punctuated by big bangs from time to time, we get a cosmology that allows for the possibility of a very old universe.

I. THE THEORY OF QUANTUM TIME

We are all agreed that your theory is crazy. The question which divides us is whether it is crazy enough to have a chance of being correct. – Niels Bohr

That's the way things come clear. All of a sudden. And then you realize how obvious they've been all along. – Madeleine L'Engle

A. Electrodynamics

We start with Gauss' law,

$$\int \nabla \cdot \vec{E} \, dV = q = \int \frac{q}{V} \, dV \tag{1}$$

Thus, since the volume is not specified,

$$\nabla \cdot \vec{E} = \rho = \frac{q}{V} \tag{2}$$

With our modern eyes, we immediately see a problem: although q is a Lorentz invariant, the volume V is not. If we Lorentz transform this equation to some other boosted frame, V will contract by one factor of γ. In our boosted frame we get a different equation,

$$\nabla \cdot \vec{E} = \frac{\gamma q}{V} = \frac{q}{\sqrt{1 - \frac{v^2}{c^2}} V} \tag{3}$$

Where

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \tag{4}$$

We need to get rid of this γ somehow. The easiest way we can imagine is to just multiply q by the 4-velocity, U^μ. At the same time we remember that the electric field $\vec{E}$ can be derived from a scalar electric potential field ϕ_e, $\vec{E} = \vec{\nabla}\phi_e$, so we can multiply ϕ_e by U^μ to balance the equation. To keep with our program of Lorentz invariance, we promote the vector operator $\vec{\nabla} \equiv (\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z})$ to the 4-vector operator $\Box \equiv (\frac{\partial}{\partial t}, \frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z})$. Now,

$$\Box^2 \phi_e U^\mu = \frac{q U^\mu}{V} \tag{5}$$

We call $\phi_e U^\mu \equiv A^\mu$, the 4-potential, and we call $\frac{qU^\mu}{V} \equiv J^\mu$, the 4-current density. Now we have a relativistic version of Gauss' law,

$$\Box^2 A^\mu = J^\mu \tag{6}$$

This is a simplified version of electrodynamics which is only valid in a particular choice of phase convention. In the rest frame of an electron, A^μ is just (ϕ_e, 0, 0, 0) and J^μ is (ρ, 0, 0, 0) and this reduces to Gauss' law, $\vec{\nabla} \cdot E = \rho$; in other frames moving at different velocities more terms will appear in A^μ and J^μ which correspond to magnetic fields. In order to get the derivatives right, we would write down every possible 2nd order derivative of A^μ, then choose constants which make the theory match experiment. A more correct form is

$$\partial^\nu \partial_\nu A^\mu - \partial^\mu \partial_\nu A^\nu = 4\pi J^\mu \tag{7}$$

The 2nd part, $\partial^\mu \partial_\nu A^\nu$, is the part that can be removed by carefully choosing a phase convention. $\partial^\nu \partial_\nu$ is another way to write $\Box^2$. But we really didn't learn anything extra from that.

B. Gravity

Again, we start with Gauss' law,

$$\nabla \cdot \vec{G} = \frac{m}{V} \tag{8}$$

Importantly, in this equation m is not the rest mass but the effective mass. This time when we Lorentz transform, we get two γs in the numerator, one from the transformation of the volume V and one from the transformation of the mass m,

$$\nabla \cdot \vec{G} = \frac{\gamma^2 m}{V} \tag{9}$$

Again we use the gravitational potential ϕ_g to simplify our equations. This time we have two γs to cancel, so we need to use our 4-velocity trick twice,

$$\Box^2 \phi_g U^\mu U^\nu = \frac{m U^\mu U^\nu}{V} \tag{10}$$

By convention we call $\frac{mU^\mu U^\nu}{V} \equiv T^{\mu\nu}$, where $T^{\mu\nu}$ is the stress-energy density tensor. As with the electrodynamics case above, the derivatives on the left hand side actually get a lot trickier in real life, but again that's a detail that we're not concerned with right now. We'll just note that the place of $\phi_g U^\mu U^\nu$ is taken by $g^{\mu\nu}$ where $g^{\mu\nu}$ is the metric tensor. So our very simplified version of Einstein's field equations are:

$$\Box^2 g^{\mu\nu} = T^{\mu\nu} \tag{11}$$

This is not exactly what Einstein wrote down; his version had a lot more combinations of derivatives, and required a factor 8π in front of the $T^{\mu\nu}$. But again, we're not looking to solve these equations. We're looking for a high-level understanding of them, and the extra details get in the way.

The unfortunate fact that $\Box^2 A^\mu = J^\mu$ so closely resembles $\Box^2 g^{\mu\nu} = T^{\mu\nu}$ has led a regrettable number of scientists to waste a significant portion of their lives looking for some deep connection between the two, a so-called unified field theory. The resemblance between $\Box^2 A^\mu = J^\mu$ and $\Box^2 g^{\mu\nu} = T^{\mu\nu}$ probably has more to do with the fact that their field particles, the photon and the graviton, are massless than to anything else. We won't be chasing unified field theories in this paper. To the contrary, we will be emphasizing Einstein's perspective, that gravity is a description of space-time, while electromagnetism lives in space-time. We will be focusing on the differences in these theories, not their similarities, and this will lead us to a new more functional Lagrangian for quantum field theory.

C. Quantum Mechanics

In 1900, Planck gave us $E = \hbar\omega$. In hindsight, it seems truly remarkable that Einstein did not realize by 1906 that as E is part of the momentum 4-vector this clearly implies the de Broglie relationship $\vec{p} = \hbar\vec{k}$. In fact we had to wait for de Broglie to see it in 1924. These relationships led immediately to Schroedinger's wave equation by simply assuming a plane wave solution then solving for the differential equation:

$$\psi = e^{i(\vec{k}\cdot\vec{x}-\omega t)} \tag{12}$$

Using Planck's and de Broglie's relationships, we have for the same plane wave,

$$\psi = e^{\frac{i}{\hbar}(\vec{p}\cdot\vec{x}-Et)} \tag{13}$$

The derivatives of ψ are now easily calculated,

$$\frac{\partial\psi}{\partial t} = -\frac{i}{\hbar}E\psi \qquad i\hbar\frac{\partial\psi}{\partial t} = E\psi \tag{14}$$

$$\frac{\partial\psi}{\partial\vec{x}} = \frac{i}{\hbar}\vec{p}\psi \qquad -i\hbar\frac{\partial\psi}{\partial\vec{x}} = \vec{p}\psi \tag{15}$$

$$\frac{\partial^2\psi}{\partial\vec{x}^2} = \frac{-1}{\hbar^2}p^2\psi \qquad -\hbar^2\frac{\partial^2\psi}{\partial\vec{x}^2} = p^2\psi \tag{16}$$

Using the classical relationship $E = \frac{p^2}{2m}$ we immediately get Schroedinger's equation,

$$i\hbar \frac{\partial \psi}{\partial t} = -\frac{\hbar^2}{2m} \frac{\partial^2 \psi}{\partial \vec{x}^2} \tag{17}$$

The solutions to Schroedinger's equation are complex waves, which have a phase. We are unable to observe this phase, so we expect that solutions to Schroedinger's equation are indifferent to your particular phase convention. So, for example, we imagine that the entire universe agrees on a new phase convention which results in all solutions being multiplied by $e^{i\chi}$. We check to see if Schroedinger's equation allows this new convention. Suppose ψ is an existing solution of Schroedinger's equation. Then

$$i\hbar \frac{\partial}{\partial t} e^{i\chi} \psi = -\frac{\hbar^2}{2m} \frac{\partial^2}{\partial \vec{x}^2} e^{i\chi} \psi \tag{18}$$

Since χ is a constant, the entire $e^{i\chi}$ just passes through the derivatives and we're ok.

Now let's try something a bit more complicated. We'll let everyone in the universe have their own phase convention. Now our phase function is $e^{i\chi(t,\vec{x})}$. When we multiply ψ by this function, because χ is now a function of $\vec{x}$ and t the derivatives no longer work.

$$\frac{\partial}{\partial t} e^{i\chi(t,\vec{x})} \psi = e^{i\chi(t,\vec{x})} \frac{\partial}{\partial t} \psi + i e^{i\chi(t,\vec{x})} \psi \frac{\partial}{\partial t} \chi(t, \vec{x}) \tag{19}$$

$$\frac{\partial}{\partial \vec{x}} e^{i\chi(t,\vec{x})} \psi = e^{i\chi(t,\vec{x})} \frac{\partial}{\partial \vec{x}} \psi + i e^{i\chi(t,\vec{x})} \psi \frac{\partial}{\partial \vec{x}} \chi(t, \vec{x}) \tag{20}$$

We have an extra term proportional to the gradient of χ. We can fix this by defining "covariant derivatives", $\frac{D}{Dt}$ and $\frac{D}{D\vec{x}}$.

$$\frac{D}{Dt} \equiv \frac{\partial}{\partial t} - i \frac{\partial}{\partial t} \chi(t, \vec{x}) \tag{21}$$

$$\frac{D}{D\vec{x}} \equiv \frac{\partial}{\partial \vec{x}} - i \frac{\partial}{\partial \vec{x}} \chi(t, \vec{x}) \tag{22}$$

Now we'll make a textual substitution.

$$\frac{\partial}{\partial t} \chi(t, \vec{x}) \equiv q\phi \tag{23}$$

$$\frac{\partial}{\partial \vec{x}} \chi(t, \vec{x}) \equiv q\vec{A} \tag{24}$$

Our covariant derivatives are now

$$\frac{D}{Dt} \equiv \frac{\partial}{\partial t} - iq\phi \tag{25}$$

$$\frac{D}{D\vec{x}} \equiv \frac{\partial}{\partial \vec{x}} - iq\vec{A} \tag{26}$$

If we now form Schroedinger's equation using $\frac{D}{Dt}$ instead of $\frac{\partial}{\partial t}$ we have an equation that works with any phase convention anywhere, or equivalently with any definition of ground voltage anywhere.

$$i\hbar \frac{D\psi}{Dt} = -\frac{\hbar^2}{2m}\frac{D^2\psi}{D\vec{x}^2} \tag{27}$$

or equivalently

$$i\hbar \frac{\partial \psi}{\partial t} - iq\phi\psi = -\frac{\hbar^2}{2m}(\frac{\partial}{\partial \vec{x}} - iq\vec{A})^2\psi \tag{28}$$

In order to make Schroedinger's equation compatible with this sense of phase invariance, where each lab gets to set their own phase standard, we had to introduce math which looks just like electro-magnetism. In a sense we have derived the need and use of the electro-magnetic field. Our choice of q as the charge is completely arbitrary. There's nothing here that tells us that charge is quantized or conserved, nor are we assured that there's only one type of charge. Here's what we have learned. Suppose you run your lab at some potential ϕ, some ground voltage different than what I use in my lab. This tells us that your electron wave functions will have their phase advancing at a higher rate than my electrons. Mine advance their phase at the rate $\frac{Et}{\hbar}$ where $E = mc^2$; yours advance at the rate $\frac{(E-q\phi)t}{\hbar}$. The big difference between squirrels running on the 10,000 volt high tension wires and squirrels on the ground is that the squirrels on the wire have their electron wave functions' phase advancing at a higher rate.

D. Photons and Phase

The force on an electron is $\vec{\nabla}\phi$, so now we see that the electric field is actually the gradient of the rate of phase advance in electrons. Since photons are the carrier of the electric field, we also see what photons do: they advance or retard the phase of the electron, depending on the relative sign of the potential and the charge. If the potential field has no gradient, there is no force and no real photons. A force is produced when one side of the electron wave function has its phase advancing at a different rate than another side. When the high tension wire is far from the ground, the phase advances at a consistent rate across the squirrel and she feels no effects. If you run a copper wire up from the ground and touch her, now there is a very intense effect as the electrons try to move quickly in response to the very large gradient.

Traditionally, photons are seen as the quanta of the $\vec{E}\&\vec{B}$ fields, and carriers of energy, momentum, force. We will instead see photons as the quanta of the A^μ field, and carriers of phase changes. This is perhaps a bit new to some, but not groundbreaking or unexpected.

We also see that the magnetic field, which arises from $\vec{A}$, is a relativistic effect. At any point in space-time you can always find a frame of reference where $\vec{A}$ is zero and the field is pure electric potential. That means you can always find a frame of reference at a given point in space-time where the photons are all virtual, since real photons always carry both an electric and a magnetic field. Although the count of electrons and the amount of electric charge is a Lorentz invariant - all observers agree on these numbers - the count of photons is not a Lorentz invariant, so in this sense photons are a side effect of your frame relative to the charge, and don't necessarily have their own independent existence.

The electron wave function is

$$\psi = e^{\frac{i}{\hbar}(\vec{p}\cdot\vec{x}-Et)} \tag{29}$$

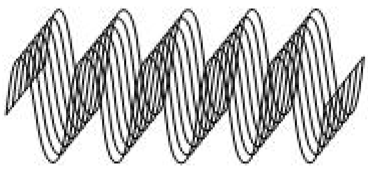

FIG. 1: Electron wave function

$\hbar$ is 6.5×10^{16}eV seconds, and the rest mass of an electron is about 500,000 eV. So an electron at rest at ground potential advances its phase by 2π about 3 times each nanosecond. If the electron is at 120 volts, a common household potential, its phase advance changes by about 1 part in 4,000. $\hbar$ is alternatively $10^{-35}\,\mathrm{kg\,m^2/\,s}$. The electron has a mass of 10^{-30} kg. If the electron is moving at 10^{-5} meters per second, a common household electron speed in AC wires, the frequency change due to the momentum is about 1 part in a billion. So for common lab situations, we can ignore the $\vec{p}\cdot\vec{x}$ term and focus on the $(E+\phi)t$ term. This is normal: special relativity assures us that in most human situations energy is larger than momentum by a factor comparable to the speed of light.

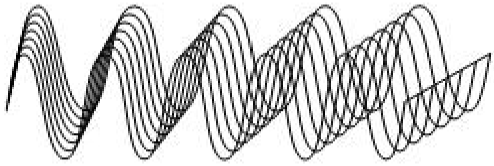

FIG. 2: Electron in a potential field

E. Gravitons and Wave Functions

We've seen that a photon changes the phase of an electron, and it's the phase changes that produce forces. What do gravitons do? To see this, we start with a gedanken (thought) experiment by Einstein. Imagine you have a tall tower; at the top of the tower is a graduate student holding a metal ball. The energy of the ball is $E = mc^2$. On your command, he drops the ball. When the ball hits the ground its energy is $E = mc^2 + \frac{1}{2}mv^2$. The gravitational potential energy at the top of the tower has been converted into kinetic energy. At the base of the tower we have a magic mirror which absorbs the complete energy of the ball and produces in its stead a photon going back up to the top of the tower. At the mirror the photon has the same energy as the ball, $E = mc^2 + \frac{1}{2}mv^2$. When the photon gets to the top of the tower it must have lost energy climbing out of the gravity well, so that when it gets to the graduate student the energy is only $E = mc^2$. If this were not the case, we would have a system that produced free energy forever, perpetual motion.

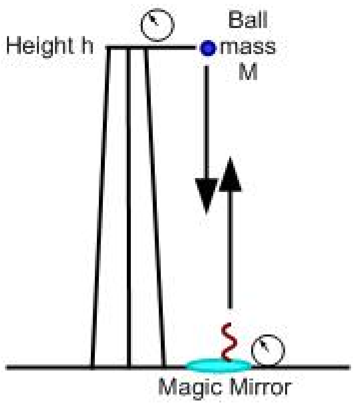

FIG. 3: Tower, Ball and Magic Mirror

Since the photon's energy is related to its frequency by $E = \hbar\omega$, if the photon lost energy it also lost frequency and became red shifted. This is a critical observation: if you want to communicate clock rates, a photon would be a natural way to do this. Since the frequency of the photon drops when climbing out of a gravity well, when you're looking down into a gravity well it appears that clocks run slower. When a photon drops into a gravity well it picks up energy and frequency, so when you look up from inside a gravity well you see clocks above you running faster. How much faster? In our example, a factor of $\frac{mgh}{mc^2} = \frac{gh}{c^2}$.

Imagine the Earth were the only mass in the universe, and the tower were tall enough that the gravitational potential at the top of the tower was immeasurably close to zero. The potential on the ground is $\frac{GM}{rc^2}$, which is $2/3 * 10^{-10} \frac{m^3}{kgs^2} * 6 * 10^{24} kg / 6.4 * 10^6 m * 9 * 10^{16} \frac{m^2}{s^2} = 7 * 10^{-10}$. Notice that the gravitational potential is dimensionless, all observers will agree on this number $7 * 10^{-10}$ regardless of the units they use. On the surface of the Earth, clocks run slow compared to clocks far away from any matter by roughly 1 part in a billion. This is not really very important in everyday timekeeping, except for GPS satellites. Notice that our common household electron had its phase rate changed by 120 volts by about 1 part in 4000; Earth gravity changes the phase rate of the same electron by about 1 part in a billion. Gravity is a very weak force, and the gravity fields in the solar system are very weak fields.

Gravitational fields slow down your clock; for example, on the surface of the Earth by about 1 part in a billion. An observer located far away from any gravitational source would see a clock on Earth running slow by about 22 milliseconds per year. The gradient of this time effect, that is the gradient of the potential, causes passing quantum waves to curve, which we call the force of gravity. Using the full apparatus of General Relativity does not change this fact, all it does is introduce very small extra time effects related to the velocity of the particle. Just as there is a velocity component to A^μ, which we call magnetism, there is a velocity component to gravity, which can be called grativo-magnetics. In fact, Einstein spent a year trying to base General Relativity on time rates, but he failed, as he was not using tensors to calculate the complete time effect. By the time he was using tensors, he had moved on from thinking about time.

In a new interpretation of gravity, we will not consider these time changes to be a side effect of gravity, but rather we will consider the force of gravity to be a side effect of the time changes. By force of habit and for clarity I'll continue to call this force gravity, but it would be more appropriate to call it time. The force of gravity that you feel when standing on the Earth is due to the gradient of the time effect, $\frac{\phi \Delta r}{r}$. You are about 2 meters tall, the radius of the Earth is about 6,400,000 meters. So a clock at the top of your head is running about 1 part in (3 million * 1 billion) faster than a clock at your feet. This minuscule difference in time keeping, about 7 nanoseconds per year, is completely responsible for the force of gravity that you feel: that is, the time difference is responsible for the wave functions of all your electrons, protons, and neutrons being pulled downwards towards the center of the Earth.

We will speak of weak gravitational fields. We calculated that the Earth's gravitational field produces changes at the level of one part in a billion, which surely qualifies as weak. All the gravitational fields in our solar system are similarly weak. In order to find a strong gravitational field we would have to travel to the surface of a neutron star, or to the event horizon of a black hole. We're not going to be concerned in this paper with doing physics on a neutron star or right on top of a black hole, so we'll treat gravitational fields as weak.

F. Calculating with Time Differences

The classical Lagrangian for gravity is the kinetic energy minus the potential energy, $\mathcal{L} = T - V = \frac{1}{2}mv^2 - \frac{GMm}{r}$. We will use a different Lagrangian. In the Lagrangian, the kinetic portion, T, refers to the changes in the wave function due boosts. The potential portion, V, is changes in the wave function due to interactions. So for our new classical Lagrangian, we'll use $\frac{1}{2}mv^2$ for the kinetic portion, and we'll use $E = mc^2$ for the potential portion. The energy of the particle is the classical name for the wave function's frequency; in a gravitational well the frequency will decrease, as shown in our thought experiment above. Our time adjustment will be $d\tau = \sqrt{U^\mu g_{\mu\nu} U^\nu} dt$. We'll consider the equations of motion of a mass m in the temporal (gravitational) field of a mass M. We'll also assume everything is moving very slowly, that is $v \ll c$, so that $U^\mu \approx (1, 0, 0, 0)$.

We can simplify $\sqrt{U^\mu g_{\mu\nu} U^\nu}$ by splitting $g_{\mu\nu}$ into two parts, the metric of special relativity and a portion to account for gravity. $g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$, where, in spherical coordinates,

$$g_{\mu\nu} = \begin{pmatrix} 1 - 2\phi & 0 & 0 & 0 \\ 0 & -(1+2\phi) & 0 & 0 \\ 0 & 0 & -r^2 & 0 \\ 0 & 0 & 0 & -r^2 sin^2\theta \end{pmatrix} \tag{30}$$

$$\eta_{\mu\nu} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -r^2 & 0 \\ 0 & 0 & 0 & -r^2 sin^2\theta \end{pmatrix} \qquad h_{\mu\nu} = \begin{pmatrix} -2\phi & 0 & 0 & 0 \\ 0 & -2\phi & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \tag{31}$$

$$\begin{aligned} \mathcal{L} = T - V &= (\frac{1}{2}mv^2 - E) * \sqrt{U^\mu g_{\mu\nu} U^\nu} && (32) \\ &= (\frac{1}{2}mv^2 - E) * \sqrt{U^\mu (\eta_{\mu\nu} + h_{\mu\nu}) U^\nu} && (33) \\ &= (\frac{1}{2}mv^2 - E) * \sqrt{1 + U^\mu h_{\mu\nu} U^\nu} && (34) \\ &= (\frac{1}{2}mv^2 - E) * (1 + \frac{1}{2}U^\mu h_{\mu\nu} U^\nu) && (35) \\ &= (\frac{1}{2}mv^2 - E) * (1 - \phi) && (36) \\ &= (\frac{1}{2}mv^2 - mc^2) * (1 - \frac{GM}{rc^2}) && (37) \\ &= \frac{1}{2}mv^2 - mc^2 - \frac{GMmv^2}{2rc^2} + \frac{GMm}{r} && (38) \\ & && (39) \end{aligned}$$

We discard the portion $\frac{GMmv^2}{2rc^2}$ as it is small compared to $\frac{GMm}{r}$.

Now,

$$\begin{aligned} \frac{\partial}{\partial v}\mathcal{L} &= mv && (40) \\ \frac{\partial}{\partial r}\mathcal{L} &= -\frac{GMm}{r^2} && (41) \\ \frac{\partial}{\partial t}\frac{\partial}{\partial v}\mathcal{L} + \frac{\partial}{\partial r}\mathcal{L} &= ma - \frac{GMm}{r^2} && (42) \end{aligned}$$

and we have recovered Newtonian gravity.

Now we'll look at a photon approaching the same mass M, with $U^\mu = (1, 1, 0, 0)$. Our time correction for a photon in a gravitational field is

$$d\tau = \sqrt{1 + U^\mu h_{\mu\nu} U^\nu} dt = 1 + \frac{1}{2}U^\mu h_{\mu\nu} U^\nu = 1 - 2\phi \tag{43}$$

Note the factor of 2 in the time correction as compared to the math above. This leads directly to the factor of 2 in the photon deflection about the Sun as compared to the same calculation performed with Newtonian gravity. This is exactly what was measured in 1919 by Sir Arthur Eddington. The factor of 2 is because the gravitational effects of the photon's momentum mc are equal to the gravitational effects of the photon's energy mc^2 and the two contributions add.

G. The Canonical Lagrangian for Quantum Field Theory

We've seen that particle's paths are determined by phase changes in the particle's wave functions. The phase changes are due to changes in the particle's energy. So to calculate the particle's energy as it moves through space, we add up all the energy contributions with a formula called the Lagrangian, which is just the sum of the energy changes. The particle has mass, and this accounts for the basic phase behavior of the particle. The mass term is $\bar{\psi}m\psi$. $\bar{\psi}\psi$ is the amplitude of the particle's wave function at a point in space time, interpreted as the probability of finding the particle there. m is the particle's mass. So $\bar{\psi}m\psi$, when integrated over all space, is just the particle's mass. We have to add in a term that corresponds to the particle's momentum and kinetic energy, which is the term below $\bar{\psi}\gamma^\mu\partial_\mu\psi$. We need a term to account for the energy change when an electron emits or absorbs a photon, which is the term $Q\bar{\psi}\gamma^\mu\psi A_\mu$. Finally we have to add in a factor for the energy and momentum contained in the electro-magnetic field, the energy carried by photons, which is $\frac{1}{4}(\partial^\mu A^\nu - \partial^\nu A^\mu)(\partial_\mu A_\nu - \partial_\nu A_\mu)$. The Lagrangian for relativistic quantum mechanics plus electro-dynamics is

$$\mathcal{L}_{QED} = i\bar{\psi}\gamma^\mu\partial_\mu\psi - \bar{\psi}m\psi + Q\bar{\psi}\gamma^\mu\psi A_\mu - \frac{1}{4}(\partial^\mu A^\nu - \partial^\nu A^\mu)(\partial_\mu A_\nu - \partial_\nu A_\mu) \tag{44}$$

Traditionally if we want to account for gravity, we add some more terms to the energy calculation above. The Lagrangian below holds the normal terms added. The factor $\sqrt{8\pi}\bar{\psi}\psi T^{\mu\nu}h_{\mu\nu}$ accounts for the gravitational attraction between particles, that is when a mass emits or absorbs a graviton. The remaining messy terms account for the energy and momentum of the gravitational field, that is the energy carried by gravitons. At the time of this writing, no one has ever unambiguously seen a graviton - unlike photons which light up our lives, gravitons are so subtle that we haven't caught one in the act so far. None the less, we account for them in our energy bookkeeping.

$$\mathcal{L}_{Gravity} = \frac{1}{2}\partial^\sigma h^{\mu\nu}\partial_\sigma h_{\mu\nu} - \partial_\nu h^{\mu\nu}\partial_\sigma h^\sigma_\mu + \partial_\nu h^{\mu\nu}\partial_\mu h^\sigma_\sigma - \frac{1}{2}\partial_\mu h^\nu_\nu\partial^\mu h^\sigma_\sigma - \sqrt{8\pi}\bar{\psi}\psi T^{\mu\nu}h_{\mu\nu} \tag{45}$$

The messy terms involving derivatives of $h^{\mu\nu}$ are the central problem in building a quantum field theory of gravity. These terms involve gravitons. Photons are the carriers of the electric field, but photons themselves aren't charged, so they mostly don't interact with electric fields or other photons. Gravitons are the carriers of the gravitational field, and gravitons have energy, so gravitons do interact with each other. According to Heisenberg's uncertainty principle, $\hbar = \Delta E \Delta t$, a graviton of quite high energy can pop into existence, so long as it's for a very short time. There is no limit to the energy of such virtual gravitons, so long as their existence is commensurately short. That means there's no limit to the gravitational attraction of the gravitational field. According to the current rules of quantum field theory and this Lagrangian, $\mathcal{L}_{Gravity}$, any mass whatsoever should immediately form a gravitational field of infinite energy density and collapse into a black hole; indeed the vacuum itself should be unstable due to the appearance of virtual gravitons, and the entire universe cannot exist. We cannot simply agree to ignore these terms; that violates the basic laws of nature. We're going to have to find a way to keep them under control.

We won't be using this gravitational Lagrangian again. The portion dealing with gravitational interactions, $\sqrt{8\pi}\bar{\psi}\psi T^{\mu\nu}h_{\mu\nu}$, can be formulated in a better way. Above we noted that there is a red shift associated with climbing out of a gravitational field. With the canonical formulation above, that redshift is not manifest. We would have to calculate an extra term for the interaction of a photon or other particle with a gravitational field. We can do better. The portion dealing with the virtual gravitons, the derivatives of $h^{\mu\nu}$, will be dealt with by finding a method to cut the production of these guys off before they can do any real damage.

H. The Improved Lagrangian for Quantum Field Theory

We also saw above that time slows down in a gravitational field. The equation for the time shift is $d\tau = \sqrt{U^\mu g_{\mu\nu} U^\nu} dt$. We'll make use of this and our new interpretation that gravity is time to show that the canonical gravitational Lagrangian can be deduced from this time shift. We've seen $U^\mu U^\nu$ before, it's $T^{\mu\nu}$ divided by m. $g_{\mu\nu}$ is the metric tensor, which includes the gravitational potential.

Again, for a weak gravitational field we can split $g_{\mu\nu}$ into two parts, the metric of special relativity and a portion to account for gravity, $g_{\mu\nu} = \eta_{\mu\nu} + h_{\mu\nu}$. Again, for slow particles, this leads immediately to a time correction $d\tau = (1 - \phi)dt$

The point of the Lagrangian $\mathcal{L}$ is that we integrate it over the path of the particle to find the total phase change over that path. The total phase change is called the action, S.

$$S = \int d^4x\ (\mathcal{L}_{QED} + \mathcal{L}_{gravity}) \tag{46}$$

$$\psi = e^{-iSt} \tag{47}$$

Canonically, to include gravity in this calculation, we add a term $\sqrt{8\pi}\bar{\psi}\psi T^{\mu\nu}h_{\mu\nu}$ into the Lagrangian $\mathcal{L}$. Instead of considering gravity as an interaction that changes the phase of the particle, we're going to consider it a property of space-time that changes the rate at which time flows. Our equation for the Lagrangian will be

$$S = \int d^3x\ \mathcal{L}_{QED} d\tau \tag{48}$$

$$d\tau = \sqrt{U^\mu g_{\mu\nu} U^\nu} dt \tag{49}$$

Now the gravitational redshift is manifest: if there's a ϕ in $g_{\mu\nu}$, then τ will be slowed appropriately and all our answers will be red shifted. If we wish to calculate a gravitational interaction, we need only split $g_{\mu\nu}$ into $\eta_{\mu\nu} + h_{\mu\nu}$ and consider the result:

$$S = \int d^3x\ (\mathcal{L}_{QED}\sqrt{U^\mu g_{\mu\nu} U^\nu})dt \tag{50}$$

$$S = \int d^3x\ (\mathcal{L}_{QED}\sqrt{U^\mu (\eta_{\mu\nu} + h_{\mu\nu}) U^\nu})dt \tag{51}$$

$$S = \int d^3x\ (\mathcal{L}_{QED}\sqrt{1 + U^\mu h_{\mu\nu} U^\nu})dt \tag{52}$$

$$S = \int d^3x\ (i\bar{\psi}\gamma^\mu\partial_\mu\psi - \bar{\psi}m\psi + Q\bar{\psi}\gamma^\mu\psi A_\mu(1 + \frac{1}{2}U^\mu h_{\mu\nu} U^\nu))dt \tag{53}$$

$$S = \int d^3x\ (i\bar{\psi}\gamma^\mu\partial_\mu\psi - \bar{\psi}m\psi + Q\bar{\psi}\gamma^\mu\psi A_\mu - \bar{\psi}m\psi\frac{1}{2}U^\mu h_{\mu\nu} U^\nu)dt \tag{54}$$

$$S = \int d^3x(i\bar{\psi}\gamma^\mu\partial_\mu\psi - \bar{\psi}m\psi + Q\bar{\psi}\gamma^\mu\psi A_\mu - \bar{\psi}\psi T^{\mu\nu} h_{\mu\nu})dt \tag{55}$$

So we recover the canonical gravitational interaction term by simply neglecting the interaction of $U^\mu U^\nu h_{\mu\nu}$ with $i\bar{\psi}\gamma^\mu\partial_\mu\psi + Q\bar{\psi}\gamma^\mu\psi A_\mu$. By simply including the gravity related time correction, we can deduce the interactions of particles with a gravitational field. It is not popular these days to take Einstein's prescription that gravity is geometry seriously, but I do.

Unfortunately, as the graviton carries gravitational charge (energy), this new Lagrangian seems to have all the same problems with infinity as the previous Lagrangian. Virtual graviton processes that are allowed to go to arbitrary energy will cause arbitrarily large gravitational effects and doom all calculations to produce black holes. We still need some way to cut off these calculations in order to make a finite theory.

I think it noteworthy that QED is an asymptotic theory and suffers from a similar problem with infinities if you try to calculate to 120^{th} order or more. It's also noteworthy that even string theory diverges - although each term is finite, the sum is not. This problem with infinities is spread all through the standard model. We need a way not only to cut off high energy virtual graviton processes, but also to cut off very high order terms in field theory.

I. Time

Now we introduce a new fundamental principle for physics: *Things which happen in this universe have causes which are in this universe.* This may seem like a tautology, as a common definition of universe is the collection of all the things that interact with each other. However it's not obviously true. First, we can consider Aristotle's First Cause, or alternatively the God who said *Let there be light.* Pretty much by definition They were not in this universe before creating it. Second, there are effects in our universe which are still considered mysterious, or at least unconsidered by many. Our primary example will be time. Time moves forwards, always at one second per second, always at the same rate for everyone. If time moved at different rates for different people, we would see gravitational effects and red shifts. We will presume that this fact, that time always moves forwards at the same rate for everyone, has a cause, and that cause is within our universe. This leaves us to search for the cause of the flow of time.

Einstein's equation $G^{\mu\nu} = 8\pi T^{\mu\nu}$ assures us that in the absence of matter there is no time and space, so we expect time and space to be a side effect of matter. In a universe void of matter, Einstein's field equations are the homogeneous $G^{\mu\nu} = 0$. This can be considered a wave equation so perhaps there could be gravitational waves, although I have no idea where their energy would come from. Also the metric would be indeterminate - there is no unambiguous way to speak of length or duration. So the fact that time moves forwards is either a property of the matter in our universe, or it's a violation of our principle, that things which happen in this universe have causes which are in this universe. Our task will be to find the material source of this time effect.

What was it like before the Big Bang, before matter appeared and created space and time? Was the universe completely empty? Not necessarily: *In the absence of time we are left with the changeless, since change can take place only in time. And since smallness and dividedness can exist only in space, in the absence of space we are left with the infinite, the undivided.* – John Dobson

J. Virtual Particles

We're all used to the approximation that $\sqrt{1+\epsilon} \approx 1+\frac{\epsilon}{2}$. Less familiar is that $\sqrt{-1+\epsilon} \approx i - i\frac{\epsilon}{2} \approx -i + i\frac{\epsilon}{2}$. We'll be using this.

Virtual particles have different wave functions than real particles. Instead of traveling waves

$$\text{Real Particle Wave Function}: \quad \psi = e^{\frac{i}{\hbar}(\vec{p}\cdot\vec{x}-Et)} \tag{56}$$

the virtual particle wave function is more like

$$\text{Virtual Particle Wave Function}: \quad \psi = e^{-\frac{E}{\hbar}t} \tag{57}$$

How do we know this? The virtual particle only lives for a time t such that $\hbar \geq Et$. The particle must decay before it gets caught. How do we get such a wave function? The action S of the virtual particle is

$$S = \int d^3x \, (\mathcal{L}\sqrt{U^\mu \eta_{\mu\nu} U^\nu})dt \tag{58}$$

Virtual particles are off mass shell and travel faster than light - that is, virtual particles travel on space-like paths, not time-like paths. This means the question of whether a virtual particle is matter or anti-matter is frame dependent: as Feynman has noted, "One man's virtual particle is another man's virtual anti-particle."

Since virtual particles travel faster than light, $U^\mu \eta_{\mu\nu} U^\nu = -1$ and $\sqrt{U^\mu \eta_{\mu\nu} U^\nu} = -i$. We have a choice in roots, and for consistency we choose the negative root. The action S is $-iE$; the particle has imaginary energy. When we plug this action into the wave function $\psi = e^{-iSt}$ we get the decaying wave function $\psi = e^{-Et}$. Had we chosen the positive root the wave function diverges and can only be normalized to exist in the infinitely far future. We're not interested in such particles.

If we take a normal Lagrangian and integrate it from the frame of a virtual particle, we get another interesting result.

$$S = \int d^3x \ (\mathcal{L}_{QED}\sqrt{U^\mu g_{\mu\nu} U^\nu})dt \tag{59}$$

$$S = \int d^3x \ (\mathcal{L}_{QED}\sqrt{-1 + U^\mu h_{\mu\nu} U^\nu})dt \tag{60}$$

$$S = \int d^3x \ (\mathcal{L}_{QED}(-i + iU^\mu h_{\mu\nu} U^\nu)dt \tag{61}$$

$$S = -i \int d^3x \ (\mathcal{L}_{QED}(1 - U^\mu h_{\mu\nu} U^\nu)dt \tag{62}$$

$$S_{Virtual} = -i \int d^3x(i\bar{\psi}\gamma^\mu \partial_\mu \psi - \bar{\psi}m\psi + Q\bar{\psi}\gamma^\mu \psi A_\mu + \bar{\psi}\psi T^{\mu\nu} h_{\mu\nu})dt \tag{63}$$

$$\psi = e^{-iSt} = e^{\int d^3x \mathcal{L}_{QED} + \bar{\psi}\psi T^{\mu\nu} h_{\mu\nu} dt \ t} \tag{64}$$

From the frame of the virtual particle, the real particle seems to decay - this is of course an artifact of the decay of the virtual particle itself. However, the gravitational interaction has changed sign compared to our previous equation,

$$S_{QED+Gravity} = \int d^3x(i\bar{\psi}\gamma^\mu \partial_\mu \psi - \bar{\psi}m\psi + Q\bar{\psi}\gamma^\mu \psi A_\mu - \bar{\psi}\psi T^{\mu\nu} h_{\mu\nu})dt \tag{65}$$

The gravitational force between the virtual particle and the real particle is repulsive; this means that the virtual particle is driving the time factor of the real particle forwards, not backwards. It's been well known for nearly 100 years that there's no such thing as anti-gravity, but then it was well known for 1,000 years that the Earth was flat. Here it is: anti-gravity. The time effects of anti-gravity are what makes the entire universe run.

Immediately after the big bang, the universe was filled with virtual particles, all putting out these gravitational fields that drive time forwards, as opposed to normal gravitation fields that drive time backwards. Since the virtual particles lived a short time, these fields had beginnings and endings - small quanta of positive time. Some time after the big bang interactions started resulting in the production of real matter, energy was pulled out of the virtual background field, and the universe expanded and cooled. None the less, these quanta of positive time have stayed with us in a background field, recognizable by the fact that all particles always move forwards in time.

What of the virtual particles themselves? It must be remembered that each virtual particle sees itself as a normal particle. In the frame of the virtual particle, it seems to be stationary. Any real particles would seem to be traveling faster than light compared to the virtual particle. In addition, if our real coordinate system is oriented so that we see the virtual particle traveling in the x direction, then any virtual particles traveling in the y or z directions will also seem to be virtual particles to our x virtual particle. So initially, immediately after the big bang when essentially all the particles were virtual, a third of all particles are seen as gravitationally attractive and moving time backwards to a given particle, and two-thirds are seen as gravitationally repulsive and moving time forwards to the same particle. Thus even in the complete absence of real particles, virtual particles will still have their clocks pushed net forwards and will decay.

We now see that our integrals $\int \mathcal{L} dt$ are not in fact integrals over a parameter t, but in fact are summations over the impact of these time quanta. Interactions are assumed to happen only while one of these gravitons is changing the time, as in the absence of time we are left with the changeless. The integral should have another term to account for this background field. We guess that the distribution of these positive time quanta have a roughly gaussian distribution centered about some very small time, like 10^{-35} seconds. The action integrals should then have a factor to account for the integral of this distribution. This could be approximated by simply cutting off the integrals at 10^{-35} seconds, or by adding a convergence factor, perhaps something like

$$\frac{t^2}{10^{-70} + t^2} \tag{66}$$

The normalization factor 10^{-35} is a guess meant to indicate a rough order of magnitude. We chose 10^{-35} as an arbitrary number which is close to the Planck time,

$$\sqrt{\frac{\hbar G}{c^5}} \approx 5 * 10^{-44} s \tag{67}$$

This term will make all the integrals in Quantum Field theory converge. Because the action integral has a logarithmic divergence, the details of the distribution of the quanta are not important to the numerical results of QED. Unfortunately, this also means that QED numerical results are very insensitive to the details of this distribution and QED results cannot be used to estimate it. A more precise estimate of the distribution would come perhaps from arguments about the total energy in the Big Bang and how long until most of that energy was converted to real particles. Feynman frequently noted that nearly any cutoff in the integrals would cause convergence and eliminate the need for renormalization;

the trick was to find a cutoff that was Lorentz invariant. This cutoff, 10^{-35} seconds, is not Lorentz invariant, but that's because it refers to a field of background radiation in the universe: it's no more invariant than the 3° cosmic background radiation.

This cutoff will also mean that extremely high order Feynman diagrams are extremely unlikely - this cutoff is also a cutoff in energy and therefore in the order of calculations that are necessary to achieve any particular precision. QED calculations are known to start to diverge around 120^{th} order or so; this cutoff, 10^{-35} seconds, means we never get to that order.

Finally, since time is now considered an effect of this background radiation, going "backwards in time" means undoing the effects of a myriad of these interactions. As time is no longer a free parameter, but rather a side effect of quantum gravity, there is no such thing as time travel. I apologize profusely to all science fiction fans. Time travel leads to either unresolvable paradoxes or a requirement for an infinite number of parallel universes. The "closed curves" around black cylinders and such are simply regions where the negative time gravitons received from the nearby mass equals the positive time gravitons received from the rest of the universe; these "closed curves" are closed in the sense of having no net phase advancement over the course of the curve, but they do not indicate that you can collide with yourself or travel back in time and warn yourself about that girlfriend. Similarly, at the Schwarzchild radius of a black hole time stops as the negative time gravitons from the black hole exactly equal the positive time gravitons from the rest of the universe. After crossing the Schwarzchild radius the particle's velocity goes to faster than light compared to the outside universe, and the particle's time axis gets rotated 90°, so that what we think of as the particle's r axis becomes the particle's t axis, and what we had though of as the particle's t axis becomes a normal space axis.

Historically renormalizability has been used as a test in physics, a reality check as it were. Indeed, Glashow, Salam and Weinberg did not receive their Nobel Prize until t'Hooft and Veltman had shown their electro-weak theory was renormalizable. I consider it an undesirable side effect of the theory of Quantum Time that now nearly any quantum field theory can be shown to converge. Like many, I consider the Standard Model to be a low energy approximation of some more fundamental theory, and I consider renormalizability to be a good reality check that a new theory is a good approximation. It is regrettable, in my opinion, that the tool necessary to make quantum gravity calculations finite is a quantum mechanical sledge hammer instead of a more subtle quantum scalpel.

K. Inflation, the Cosmological Constant, and Continuous Creation

Immediately after the Big Bang, the local universe was filled with virtual particles. Any real particles would be gravitationally repulsed at very high accelerations. This repulsion would represent a very large cosmological constant. As the big bang cooled, more and more of the energy would go into more and more real particles, causing the number of virtual particles to decline and their average energy to also decline, and slowing the expansion dramatically. In the current much cooler universe, the relatively small number and energy of virtual particles will continue to cause some repulsion, modeled by a smaller cosmological constant.

This continued light-duty inflation has been observed as an acceleration in the expansion of the universe. The cause of this expansion has been labeled "dark energy," but I propose it to simply be an artifact of continued vacuum polarization. This continued expansion of the universe is proposed as the reason that the cosmic background radiation is currently homogeneous to roughly 1 part in 10,000. The smoothness of the cosmic background radiation is at a level where it is unable to explain the observed distribution of galaxies in the universe. 13 billion years of light-duty inflation ago, the cosmic background radiation would have been considerably more inhomogeneous, with brighter areas that could explain much of the current galaxy distribution.

The continued virtual processes in our universe will continue to produce new real particles from time to time, *ex nihilo*, as has already been observed in our accelerators. Since Penzias and Wilson first observed the 3° cosmic background radiation it's been fashionable to say the Big Bang theory is proven and Continuous Creation was wrong; however the history of physics teaches us that whatever the math allows seems to happen. Now that real particle production has been observed in our accelerators it seems obvious that both theories are correct. It's been estimated that production of real matter need only be at the level of .3 atoms per cubic kilometer per year to keep the universe continuously filled in spite of the current expansion. Unfortunately, in a universe where the expansion and cooling are accelerating, real particle production would be required to rise, yet predicted to fall. It's more likely that the actual particle creation number is lower than the required number, and a more accurate model of our universe is one of continuously accelerating expansion, with spontaneous continuous creation of matter filling in some of the new empty areas, and bangs happening from time to time to fill in the rest. This universe can have a density well below the critical density for flat space, just as has been observed, and still continue to have observable matter in it due to continued creation. Some of the observable galaxies may well predate the big bang of 13.7 billion years ago, and some may be the result of condensation of new matter created well after the big bang. Such a cosmology would leave the question of the age and size of the universe indeterminate and perhaps unknowable.

The story of modern science is one of humanity fighting against the scientific notion that we are not at the center of the universe. Copernicus and Galileo moved the center of the universe from the Earth to the Sun and suffered for their opinions. George Gamow moved the center of the universe to a point outside the universe itself with his Big Bang theory, but still left us in the position of being part of the original, only and singular act of creation. Perhaps our big bang was not at all the only one, and there's nothing special at all about our position in the universe - we're not even a part of a singular act of creation, but a part of one of uncountably many.

II. APPENDICES

A. Physical Units

We choose units so that $c = \hbar = \sqrt{G} = 1$.

For historical reasons, we measure time and space with different units: time in seconds, based most likely on a typical heartbeat, and length in feet, the average length of a Roman Centurian's foot, or meters, the length of a pendulum with a half-period of one second. These units just cause confusion when working with relativity, so we will set c, the speed of light, equal to 1. This means we're measuring space and time in the same units, but does not specify that unit. For example, a foot of time is about a nano-second. A meter of time is about 3 nano-seconds. Velocities are unitless and are considered a fraction of the speed of light. A velocity of 1 is 186,000 miles per second, or 300,000,000 meters per second. A velocity of 10^{-7} is about 100 kph, about 60 mph.

Einstein tells us that $E = mc^2$, so energy and mass will now have the same units, pounds or kilograms or ergs. Planck tells us that $E = \hbar\omega = h\nu$. We will choose to set $\hbar = 1$, so this tells us that energy and mass are measured in units of "per second" or "per meter." Acceleration also has units of "per second" or "per meter," and $F = ma$ tells us that force has units of "per second^2" or "per meter^2." We now have only one unit to choose, and everything will be measured in terms of that unit.

Coulomb's law tells us that $F = \frac{e^2}{r^2}$. Since force has dimensions of "per meter^2" and the $\frac{1}{r^2}$ term has dimensions of "per meter^2," e, the charge on the electron, is unitless, and so is the fine structure constant $\frac{e^2}{4\pi} = \frac{1}{137}$. Similarly, Newton tells us that $F = \frac{GmM}{r^2}$, so GmM must also be unitless. Mass has units of "per meter," so G has units of "meters^2," and $\sqrt{G}$ has units of "meters". By setting $G = 1$ we arrive at a fundamental unit of length in our universe. In MKS units $G = \frac{2}{3} * 10^{-10} \frac{m^3}{kg\, s^2}$. $\frac{G}{c^3} = \frac{1}{4} * 10^{-35} \frac{s}{kg}$. Now, we multiply by $\hbar = 1.05 * 10^{-34} \frac{kg\, m^2}{s}$. $\frac{G\hbar}{c^3} = 2.6 * 10^{-70} m^2$. Finally, the square root of this number $\sqrt{\frac{G\hbar}{c^3}} = 1.6162 * 10^{-35} m$. This will be our fundamental unit of length and time, which we will call the Planck, abbreviated as P. We can live with just one fundamental unit, but for convenience sake we will define one additional unit. Our mass and energy unit will be $\frac{\hbar}{c\, P} = \sqrt{\frac{\hbar\, c}{G}} = 2.1765 * 10^{-8} kg$, which will call the Stone, abbreviated as E. The Stone is sometimes called the Planck mass. Note that the Stone is simply 1 / Planck. Wherever we use Stone, we could write Planck^{-1}.

B. Unit Conversion Tables

1	2	3
4	5	6
7	8	9

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Biography

Mark Lawrence received his BS in Engineering in 1979 from Caltech. He used to house sit for Richard Feynman and get into arguments with Fred Hoyle when he came around to visit. Mark now regrets those arguments. Mark spent from 1979 to 1998 writing first computer graphics software, then engineering analysis software, then neural network software. From 1998 to 2001 he was a graduate student in Physics at the University of Southern California, and also wandered around a bit taking classes at UC Davis, UCLA, and Caltech. In 2004 he started making motorcycle windshields on his home made computer guided laser cutter. In 2006 he was granted custody of his three teenage sons, who had by then been diagnosed with ADHD, given prescriptions for various psycho-active drugs, and flunked out of school. Since then he's been working on getting his sons back on track and building up his business, with a certain degree of success: Richard, his oldest son and now a Senior physics major at UC Davis, helped edit this paper and check the math for consistency. Mark has been working on this theory in his spare time since 1985. Mark believes fervently that this work could never have been done in the context of working as a professor of physics. No government agency supported this work in any fashion whatsoever. No animals were harmed during the writing of this paper.

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