Taking the Mechanics out of Space-Time and Putting it Back into Quantum Mechanics

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Abstract. One of the basic postulates of fundamental physics that is ingrained in our thinking is that the photon is an elementary particle that can be represented as a mathematical point, with spin-1, but without radial extension. According to General Relativity, gravity influences the motion of light, not by acting on light itself, but by directly acting on a dynamic four-dimensional space-time continuum through which the point-like photon passively propagates. Here I present an alternative explanation of the effect of gravity on light based on the rotational as well as translational motions of the photon. By taking the mechanics out of the description of space-time, and putting it back into the quantum mechanics of light, I show that the deflection of starlight, the *experimentum crucis* in favor of General Relativity over Newtonian mechanics, can be explained using Newton's Law of Gravitation, Euclidean space and Newtonian time. This treatment has the advantage over General Relativity in encompassing the dynamical properties of photons that were neither known to Newton nor employed by Einstein. This interpretation, which is also applicable to the understanding of gravitational lensing, the Global Positioning System, the gravitational red shift, and black holes, may lead to a deep or "ultimate" understanding of the nature of reality.

Using Newton's Law of Gravitation and treating light as a heavy body, Soldner [1] calculated that the deflection of starlight by the sun would amount to 0.84 arcseconds. After completing the General Theory of Relativity, Einstein [2] predicted that the magnitude of the deflection of starlight by the sun would be twice as great or 1.75 arcseconds (Figure 1). While Soldner considered gravity to act dynamically on light propagating through Euclidean space and Newtonian time, Einstein considered matter to warp a dynamic space-time continuum so that the apparent force of gravity was actually a result of the action of matter on the geometry of space-time through which the point-like photons submissively propagated.

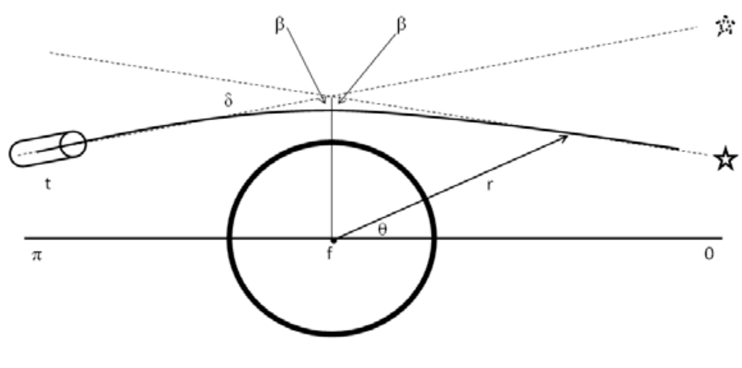

Figure 1. The deflection of starlight. The solid line extending from the actual position of the star to the telescope is described by the equation of motion of the trajectory of starlight which gives

the dependence of r upon θ. The predicted trajectory, evaluated from 0 to π radians, is given by equation 22.

Realizing that he could use the deflection of starlight by the sun to test the veracity of the General Theory of Relativity, Eddington organized an expedition to test the General Theory by observing the position of stars during a total solar eclipse. In such a test, the positions of the stars in the field near the sun that are visible during a solar eclipse are compared with the positions of the same stars observed when the sun's gravity no longer influences the starlight traveling from the stars to the earth. *Caeteris paribus*, the difference in the positions of the stars is attributable to the gravitational deflection of starlight.

On 29 May 1919, British expeditions observed the deflection of starlight during a solar eclipse [3]. The magnitude of the deflection was consistent with General Relativity, and since then, the gravitational bending of light by the sun has been considered to be one of the crucial observations in support of the assumption that the space-time continuum is dynamic and warped by matter. By taking into consideration dynamical properties of light unknown to Newton and not employed by Einstein, I can explain the observed "double deflection" of starlight without invoking a four-dimensional space-time continuum that is warped by the presence of matter.

The Dynamical Properties of Photons

Photons are dynamic entities that carry linear momentum. The magnitude of the linear momentum depends on the wavelength or frequency of the photon and is given by $\frac{h}{\lambda}$ or $\frac{h\nu}{c}$. In addition, photons carry angular momentum, which was originally called the moment of momentum—emphasizing the importance of a radial extension. The spin angular momentum for each and every photon is equal to $\frac{h}{2\pi}$—often denoted as spin-1. The value of the spin angular momentum is a property shared by all photons, independent of their frequency and wavelength.

Nicholson [4] introduced the importance of angular momentum in understanding the spectrum of atoms. He interpreted Planck's constant to be a "*natural unit of angular momentum,*" indicating that "*the angular momentum of an atom can only rise or fall by discrete amounts when electrons leave or return.*" Sommerfeld [5] also insisted on the importance of angular momentum when he wrote, "*…in the process of emission…, we demanded…the conservation of energy. The energy that is made available by the atom should be entirely accounted for in the energy of radiation v, which is, according to the quantum theory of the oscillator, equal to hv. With the same right, we now demand the conservation of momentum and of moment of momentum: if in a change of configuration of the atom, its momentum or moment of momentum alters, then these quantities are to be reproduced entirely and unweakened in the momentum and moment of momentum of the radiation.*"

The spin angular momentum of photons is basic for understanding the selection rules that describe atomic spectra. Angular momentum is one of the fundamental concepts of physics, and if indeed, a photon has extension in the radial direction, as suggested by Lorentz [6] and Millikan [7], in order to explain interference phenomena; and Wayne [8,9], in order to explain the observed arrow of time and why charged particles cannot exceed the speed of light, then spin angular momentum will represent rotational motion of or within the photon—not just a number.

I propose that the existence of the spin angular momentum of a photon is an indication of the potential, for a general theory of optical phenomena, to consider the rotational motion of a photon in addition to its translational motion. This opportunity is analogous to the one seized by Clausius [10], who provided an explanation of the observed values of specific heats by treating molecules as having both translational and rotational motions. The inclusion of rotational motion brought the predictions of the mechanical theory of heat closer to the observed values. Maxwell [11] further utilized the concept of the equipartition of energy when he asserted that in ideal gases, the energy of rotation was equal to the energy of translation, and Boltzmann [12] generalized the equipartition theorem to say that the average energy of all systems was equally divided among all the independent components of motion, including the potential and kinetic energies of oscillators.

The total energy (hν) of a photon can be transferred to or from an atom when the photon is destroyed or created upon absorption or emission, respectively. In optical processes that do not depend on absorption, it is possible that only parts of the total energy may be relevant in describing and explaining the phenomenon. I consider the photon in free space to be an adiabatic thermodynamic system composed of a longitudinal oscillator, containing potential and kinetic energy and a rotational oscillator, containing potential and kinetic energy [13]. The two orthogonal oscillators are in thermal equilibrium and, by extension of the equipartition theory; the total energy of the photon is equally distributed among the four degrees of freedom (Figure 2).

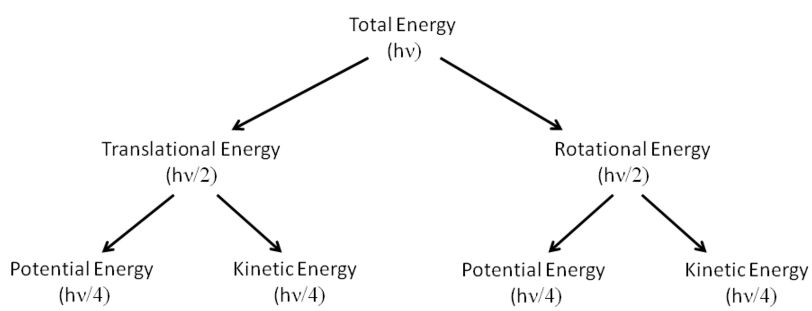

Figure 2. A model of the photon described in terms of the equipartition of energy. According to the model [13], a photon is composed of two complementary particles that form a harmonic oscillator that vibrates in the longitudinal direction, parallel to the propagation vector as it rotates orthogonally to the propagation vector. Absorption consists of the transfer of its total energy (hν) to the absorber, while emission consists of the transfer of energy (hν) from the emitter to the photon. The energy integral that describes the trajectory of a photon in a gravitational field makes use of the kinetic portion of the translational energy to describe the kinetic energy of the photon. By contrast, the gravitational energy of the photon used in the energy integral results from the interaction of the gravitational field of the sun with the total energy of the photon [15].

My approach to formulate an equation of motion for a photon moving through a gravitational field is analogous to the approach used to formulate an equation of motion that explains the trajectory of an artillery shell by taking the rotational as well as the translational motion of the projectile into consideration. The ratio of rotational motion to translational motion of projectiles is not constrained by the equipartition theory. Consequently, the goal of ballistic research is to find the rifling twist that is just sufficient to provide the rotational motion necessary to stabilize the projectile while minimizing the loss of translational kinetic energy. By contrast, I assume in developing the equation of motion that describes the trajectory of a photon through a gravitational field, that the equipartition theorem is applicable to photons and that the rotational kinetic energy of a photon is equal to its translational kinetic energy.

By using the equipartition theorem and taking the assumed rotational as well as the translational properties of the photon propagating through Euclidean space and Newtonian time into consideration when deriving the equation of motion, I will show that the observed magnitude of the gravitational deflection of starlight can be explained without invoking the General Theory of Relativity that posits that matter induces a curvature of a dynamical four-dimensional space-time continuum. The ability to explain the observed "double deflection" of starlight lends support to the validity of the complex, dynamical model of the photon, and its movement through Euclidean space and Newtonian time.

Using Dynamical Photons to Analyze the Deflection of Starlight

In Einstein's theory of light, the mechanical properties of the quantum of light, including energy and momentum, were described with elegant simplicity by point-like properties of hν and hν/c, respectively. However the lack of any predicted internal structure of the photon limits one's ability to visualize optical processes in mechanical terms and this may have had the unintended consequence of obscuring many of the unsolved mysteries inherent in the wave-particle duality. While, it has been productive at first to treat atoms and the elementary particles that comprise them as ideal, point-like particles propelled by forces through empty space much like the earth is propelled around the sun, I consider the possibility that the photon may not be an elementary particle [13]. A composite photon has been proposed by Bragg, de Broglie, Born, Jordan and others [see 13,14]. I extend their proposals by considering the photon to have internal motions and that its total energy is equipartitioned between each degree of freedom (Figure 2).

The total energy (E) of a photon, which includes both translational energy and rotational energy, is given by the following equation:

$$E = h\nu \tag{2}$$

where hν is equal to the amount of energy required to create or destroy a photon during the emission and absorption process, respectively. The linear momentum of a photon is given by $\frac{\mathrm{h}\nu}{c}$. The relationship between the total energy and total linear momentum (p) of a photon, as measured in processes in which the photon is absorbed, is:

$$p = \frac{E}{c} \tag{3}$$

When we define the momentum of a photon as a dynamical quantity given by the product of its apparent mass (m) and its velocity (c), we get:

$$p = mc \tag{4}$$

By equating equation 3 and equation 4, we get the well-known relationship between mass and energy:

$$E = mc^2 \tag{5}$$

Solving for the apparent mass (m) or a photon, we get:

$$m = \frac{p}{c} = \frac{\mathrm{h}\nu}{c^2} \tag{6}$$

When starlight, composed of photons, passes near a massive body, it will be subjected to the gravitational binding energy of that body. I assume that the gravitational energy acts on the total mass-energy of the photon (Figure 3). This assumption is supported by the agreement between theory and observation in my analysis of the gravitational red shift [15]. The gravitational energy will cause a solid particle to be deflected in the radial direction toward the massive body instead of continuing in the tangential direction. If the translational kinetic energy of the photon is greater than the gravitational energy, the photon will follow a hyperbolic path around the massive body. Consequently, the position of the star will appear to an observer to be displaced from its actual position (Figure 1). The displacement will depend in part on the relationship between the translational kinetic energy of the photon and the gravitational energy. The gravitational energy between a large gravitational mass (M) and a photon with apparent mass (m) separated by a center-to-center distance (r) is given by:

$$E_{gravitational} = -\frac{GMm}{r} \tag{7}$$

where G is the gravitational constant.

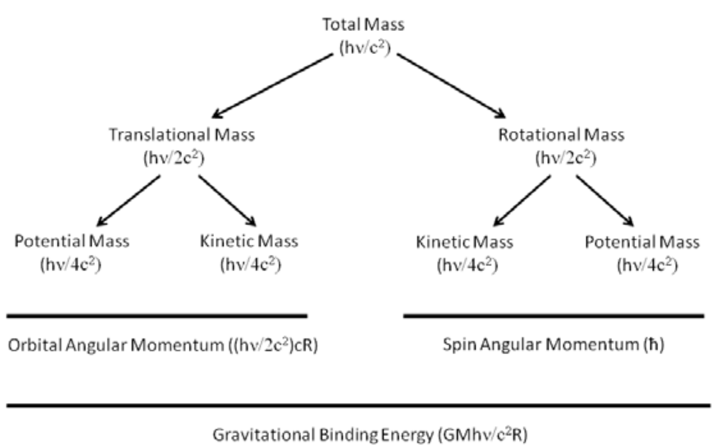

Figure 3. A model of the photon described in terms of equipartition of mass-energy using the mass-energy relation, $m = \frac{E}{c^2}$, and applying the equipartition theorem. According to the model, the orbital angular momentum results from the translational mass and the spin angular momentum results from the rotational mass.

Energy is conserved as the photon propagates through Euclidean space and Newtonian time in its trajectory past a massive body. The constant of motion ($E_{orbital}$) that takes into consideration the translational kinetic energy ($\frac{1}{4}mv^2$) of the photon and the gravitational binding energy ($-\frac{GMm}{r}$) between the massive body and the photon is given by:

$$E_{orbital} = \frac{1}{4}mv^2 - \frac{GMm}{r} \tag{8}$$

Using polar coordinates and decomposing the translational kinetic energy into the radial (r) and tangential (θ) components, we get:

$$E_{orbital} = \frac{1}{4}m\left(\frac{dr}{dt}\right)^2 + \frac{1}{4}mr^2\left(\frac{d\theta}{dt}\right)^2 - \frac{GMm}{r} \tag{9}$$

As the photon passes a massive body, orbital angular momentum is also conserved. The orbital angular momentum of a photon following a hyperbolic trajectory as it approaches the sun is given in terms of its apparent mass, its velocity and the impact parameter. The two constants of motion, which are based on conservation of energy and conservation of angular momentum, act as adjustable parameters, which along with the initial conditions, r_o and θ_o, yield a complete solution to the photon's trajectory in terms of the two degrees of freedom, r and θ. In the case for photons grazing the limb of the sun, the impact parameter, which is equivalent to the moment of inertia, is given by the radius of the sun, R.

I assume that only the translational mass, which is half of the total mass, contributes to the orbital angular momentum when a photon propagates in a trajectory around the sun (Figure 3). The rotational motion of the photon, although present and ubiquitous, is a spinning motion and does not contribute to its orbital angular momentum. Since $v = \left(\frac{d\theta}{dt}\right)r$, the constant of motion ($L_{orbital}$) based on the conservation of angular momentum, can be written like so:

$$L_{orbital} = \frac{1}{2}mvr = \frac{mr^2}{2}\left(\frac{d\theta}{dt}\right) \tag{10}$$

After rearranging equation 10, we get:

$$\frac{d\theta}{dt} = \frac{2L_{orbital}}{mr^2} \tag{11}$$

where $\frac{mr^2}{2}$ is the moment of inertia. After substituting equation 11 into equation 9, and cancelling like terms, equation 9 can be rewritten as:

$$E_{orbital} = \frac{1}{4}m\left(\frac{dr}{dt}\right)^2 + \left(\frac{L_{orbital}{}^2}{mr^2}\right) - \frac{GMm}{r} \tag{12}$$

Solving for $\frac{dr}{dt}$, we get:

$$\frac{dr}{dt} = \mp\sqrt{\frac{4E_{orbital}}{m} - \left(\frac{4L_{orbital}{}^2}{m^2r^2}\right) + \frac{4GM}{r}} \tag{13}$$

We can use the chain rule to combine equations 11 and 13. This yields an equation for the shape of the trajectory in terms of the change in the polar angle with respect to the change in the radial distance:

$$\frac{d\theta}{dr} = \frac{d\theta}{dt}\frac{dt}{dr} = \mp \frac{2L_{orbital}}{mr^2\sqrt{\frac{4E_{orbital}}{m} - \left(\frac{4L_{orbital}{}^2}{m^2r^2}\right) + \frac{4GM}{r}}} \tag{14}$$

In order to integrate equation 14, we separate the variables and simplify:

$$\int d\theta = \mp \int \frac{\left(\frac{L_{orbital}}{r}\right)^2\left(\frac{1}{L_{orbital}}\right)}{\sqrt{\left[mE_{orbital} - \left(\frac{L_{orbital}}{r}\right)^2 + \frac{GMm^2}{r}\right]}} dr \tag{15}$$

We can conveniently integrate equation 15 after substituting $u = \frac{L_{orbital}}{r}$, and simplifying:

$$\theta(r) - \theta_o = \pm \int \frac{du}{\sqrt{\left[-u^2 + \frac{GMm^2}{L_{orbital}}u + mE_{orbital}\right]}} \tag{16}$$

where θ_o is the constant of integration. This integral can be solved using a Table of Integrals:

$$\pm \int \frac{du}{\sqrt{[-au^2 + bu + c]}} = \pm \frac{1}{\sqrt{-a}} \sin^{-1}\left[\frac{2au+b}{\sqrt{b^2-4ac}}\right] \tag{17}$$

where a = -1, $b = \frac{GMm^2}{L_{orbital}}$ and $c = mE$, and we take the negative solution to yield the concave portion of the hyperbola relative to the origin and evaluated from 0 to π as shown in Figure 1. After substituting the values for a, b, and c into equation 17, we get:

$$\theta(r) = \theta_o - \sin^{-1}\left[\frac{-\frac{L_{orbital}}{r} + \frac{GMm^2}{L_{orbital}}}{\sqrt{\left(\frac{GMm^2}{L_{orbital}}\right)^2 + 4mE_{orbital}}}\right] \tag{18}$$

After taking the sine of both sides, we get:

$$\sin(\theta) = \sin(\theta_o) - \frac{-\frac{L_{orbital}}{r} + \frac{GMm^2}{L_{orbital}}}{\sqrt{\left(\frac{GMm^2}{L_{orbital}}\right)^2 + 4mE_{orbital}}} \tag{19}$$

Because $\sin(0) = 0$, by setting $\theta_o = 0$, we get:

$$\sin\theta = \frac{\frac{L_{orbital}}{r} - \frac{GMm^2}{L_{orbital}}}{\sqrt{\left(\frac{GMm^2}{L_{orbital}}\right)^2 + 4mE_{orbital}}} \tag{20}$$

After rearranging, we get:

$$\frac{L_{orbital}}{r} = \frac{GMm^2}{L_{orbital}} + \sqrt{\left(\frac{GMm^2}{L_{orbital}}\right)^2 + 4mE_{orbital}} \sin\theta \tag{21}$$

Next we rewrite equation 21 in order to get r as a function of θ:

$$r = \frac{\frac{L_{orbital}{}^2}{GMm^2}}{1 + \sqrt{1 + \frac{4mL_{orbital}{}^2 E_{orbital}}{G^2M^2m^4}} \sin\theta} \tag{22}$$

Equation 22 has the form of an equation for a conic section where one focus is at the origin. The utility of the equation for a conic section comes from its ability to transform the characterization of the deflection of starlight from the polar coordinate system where the sun is at the center to a coordinate system of the observer where the sun is at the focus. When the energy integral, $E_{orbital} > 0$, and the eccentricity, $\varepsilon > 1$, the equation describes a hyperbola in polar coordinates where:

$$r = \frac{\alpha}{1 + \varepsilon \sin\theta} \tag{23}$$

where α is the semi-latus rectum, which is equal to $\frac{L_{orbital}{}^2}{GMm^2}$. In the initial condition, when $\theta = \theta_o = 0$, $r = r_o = \infty$. By comparing equation 22 with equation 23, we see that eccentricity (ε) is given by:

$$\varepsilon = \sqrt{1 + \frac{4mL_{orbital}{}^2 E_{orbital}}{G^2M^2m^4}} \tag{24}$$

$E_{orbital}$ and $L_{orbital}$ are constants of integration. By letting $L_{orbital} = \frac{1}{2}mvr = \frac{mcR}{2}$, where $v = \text{c}$, the speed of light, and r = R, the radius of the sun, we get:

$$\varepsilon = \sqrt{1 + \frac{4mm^2c^2R^2E_{orbital}}{4G^2M^2m^4}} = \sqrt{1 + \frac{c^2R^2E_{orbital}}{G^2M^2m}} \tag{25}$$

By letting $E_{orbital} = \frac{1}{4}mv^2 - \frac{GMm}{r} = \frac{1}{4}mc^2 - \frac{GMm}{R}$, where $v = \text{c}$, and r = R, we get:

$$\varepsilon = \sqrt{1 + \frac{c^2R^2mc^2}{4G^2M^2m} - \frac{c^2R^2GMm}{G^2M^2mR}} = \sqrt{1 + \frac{c^4R^2}{4G^2M^2} - \frac{c^2R}{GM}} \tag{26}$$

where $\frac{c^4R^2}{4G^2M^2} = 5.5454936 \text{ x } 10^{10}$ and $\frac{c^2R}{GM} = 4.709774353 \text{ x } 10^5$. Since $\frac{c^4R^2}{4G^2M^2} \gg \frac{c^2R}{GM}$ and $\frac{c^4R^2}{4G^2M^2} \gg 1$,

$$\varepsilon \cong \sqrt{\frac{c^4R^2}{4G^2M^2}} \cong \frac{c^2R}{2GM} \tag{27}$$

After taking the reciprocal of ε, we get:

$$\frac{1}{\varepsilon} \cong \frac{2GM}{c^2R} \cong 4.246487942 \text{ x } 10^{-6} \tag{28}$$

The final formula is independent of the mass of the photon, indicating that the gravitational deflection of starlight should not be a source of chromatic aberration. From the properties of a conic section, we can obtain β:

$$\beta = \cos^{-1}\left(\frac{1}{\varepsilon}\right) \cong 89.99975669° \quad (29)$$

Given that one degree equals 3600 arcseconds, we can obtain the predicted angle of deflection (δ) from β given in equation 29 and from the relations shown in Figure 1:

$$\delta \cong 180° - 2\beta \cong 4.86612 \times 10^{-4}° \cong 1.75 \text{ arcseconds} \quad (30)$$

which is the same as the value of the "double deflection" predicted by Einstein's General Theory of Relativity and observed by astronomers. The generalized energy and angular momentum integrals, for a generalized photon propagating through the gravitational field of the sun, are given by the following equations::

$$E_{orbital} = \frac{1}{2N}mv^2 - \frac{GMm}{r} \quad (31)$$

$$L_{orbital} = \frac{1}{N}mvr = \frac{m}{N}\left(\frac{d\theta}{dt}\right)r^2 \quad (32)$$

where N characterizes the assumptions used to equipartition the mass-energy of the photon. N = 1 for a simple corpuscular photon with translational motion only, and N = 2 for a complex photon with translational and rotational motion. Using this derivation, the predicted deflection for a Newtonian corpuscle that lacks rotational motion is calculated to be equal to one-half the deflection calculated for a photon whose mass-energy is equipartitioned between its translational and rotational oscillating components [15]. While my analysis leaves us ignorant of the physical mechanism by which the gravitational force acts between the sun and the photon, any putative physical mechanism is no less mysterious than the physical mechanism that must be imagined to explain how matter can warp a dynamic four-dimensional space-time continuum.

Conclusion

The "double deflection" observed by the astronomers on the eclipse expeditions can be explained equally well by assuming that that photon is point-like and propagates through a dynamic four-dimensional space-time continuum that is warped by matter as posited by the General Theory of Relativity, or by assuming Newtonian gravitation, that space is Euclidean, time is Newtonian, and the photon has a complex dynamical structure with both translational and rotational motions. The latter explanation has the advantage of encompassing the dynamical properties of photons, including their characteristic angular momentum, which were neither known to Newton nor employed by Einstein. By taking the mechanics out of space-time and putting it back into the spin-1 photon, gravitational lensing, the Global Positioning System, the gravitational red shift, and black holes become understandable without invoking a warped, four-dimensional space-time continuum [15]. This treatment, which gives a deep and elegant understanding of the nature of reality, also makes the gravitational deflection of starlight understandable to the "*common folk*" and the "*man in the street,*" without feeling like one has been "*wandering with Alice in Wonderland and had tea with the Mad Hatter*" [16-26].

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