Does light bend in a scalar gravitational field?

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Abstract: If a gravitational theory derived from a metric has metric induced by a scalar field, it is called Nordström's gravitational theory. Einstein claimed that light does not bend in Nordström's theory. The article shows that light does bend in the scalar gravitational theory if light travels along geodesics of the space-time with a scalar metric. If the scalar theory is understood as describing a field's geometry, not space-time geometry, then light does not travel along geodesics of the gravitational geometry. Light does bend e.g. when passing close to the Sun, but this is caused by matter in the space around the Sun. The article concludes that there are no good reasons to think that light should travel on geodesics of the gravitational field. The article also refutes the geodesic metric for a small test mass and therefore also Einstein's correction to the precession speed of Mercury's perihelion.

Keywords: Nordström's gravitational theory, light bending, General relativity Theory, geodesic metric.

1. Introduction

Gunnar Nordström wrote three papers on a scalar gravitational field that is placed on four-dimensional space-time in 1912-13. Essentially the Laplace operator is replaced by D'Lambertian, an operator that is Lorentz invariant. The theory basically contains two equations: a field equation and a dynamic equation for the movement of a test mass in the field. The theory is a small modification of Newton's gravitation theory and for a static field the solution of the field equation is the same as in Newton's gravitation theory. In the original version of the theory the dynamic equation is also very much the same as in Newton's theory. Because of Einstein's comments Nordström changed it. For Nordström's theory, see the original papers [1] and my take on the theory [2].

Einstein claimed that in Nordström's theory light does not bend. This claim has been repeated up to today as a reason why a scalar gravitational field is not possible. Section 1 shows that if light travels along geodesics of the gravitational field, then light bends in the metric induced by a scalar gravitational field. The equation describing the geodesics is very simple and can be solved analytically without any problems. Instead, as Section 2 shows, the corresponding equation calculated for the Schwarzschild metric is much more difficult and cannot be solved analytically.

Section 3 explains why the Lagrangean for a test mass cannot be used for light and it also shows a fatal problem in the dynamic equation for a test mass derived from the geodesic metric: a freely falling mass does not accelerate in the dynamic equation.

Section 4 discusses whether light should follow geodesics of the gravitational field. The conclusion in Section 4 is that there are no good reasons why light would travel along geodesics of a gravitational field.

2. Light bends in a scalar gravitational field if light follows geodesics

In Einstein's theory light follows the geodesics of the gravitational field. It is shown in this section that if the field is scalar, i.e., satisfies the field equation of Nordström's gravitational theory, then light does bend in the gravitational field. Furthermore, the equation that is obtained can be solved exactly but it does not predict how much light bends because the amount depends on an integration constant.

For light-like world paths the geodesic metric means minimizing the space distance that light travels. For simplicity, let us assume that light travels in the (x, y) plane i.e, $dz = 0$. In Cartesian coordinates the Lagrangean equation for light is

$$L(y, y', x)dx = \sqrt{g_{11}dx^2 + g_{22}dy^2 + g_{33}dz^2} = \sqrt{g_{11} + g_{22}y'^2}dx. \tag{1}$$

Notice that the geodesic Lagrangean for light is not the geodesic Lagrangean (37) for a test mass, discussed in Section 3. In (37) small variations in the direction of coordinates x^c are compensated by small variations in the direction of ds. This means that the set of paths over which (37) minimizes the action integral are paths where ds can vary. The paths in (37) exclude all paths where ds remains at the zero value. The paths for light are exactly the paths where $ds = 0$ in the whole set of paths over which the action integral is minimized.

Light travels on light-like world paths and they have $ds = 0$. Light cannot use any other world paths than those where the speed of light is constant c. A correctly formed metric must reduce to the Minkowski metric in an infinitely small environment of each point. (Notice that the Schwarzschild metric does not do so, it is not a correctly formed metric, see [3].) In a Minkowski space $ds = 0$ for all world paths where the speed of light is c. Therefore the set of paths that can be varied in the small variations of calculus of variations, i.e., in the Euler-Lagrange equations, must all have $ds = 0$.

The terms in the Euler-Lagrange equations are

$$\frac{\partial L}{\partial y} = \frac{y}{r}(g'_{11} + g_{22}{y'}^2)\frac{1}{2L} \tag{2}$$

$$\frac{\partial L}{\partial y'} = g_{22}y'\frac{1}{L} \tag{3}$$

$$\frac{d}{dx}\frac{\partial L}{\partial y'} = \frac{1}{2L}\frac{y}{r}(g'_{11} + g_{22}{y'}^2)(g_{11} + g_{22}y'^2). \tag{4}$$

The Euler-Lagrange equation is

$$2g_{11}g_2 2y'' = \frac{y}{r}\left(g_{11}'g_{11} + 2g_{11}'g_{22}y'^2 - g_{11}g_{22}'y'^2\right) \tag{5}$$

$$+ \frac{xy'}{r}\left(-2g_{11}g_{22}' + g_{11}'g_{22} - g_{22}'g_{22}'y'^2\right). \tag{6}$$

Inserting a scalar metric $g_{11} = g_{22} = \Phi^2$ gives the Euler-Lagrange equation

$$\frac{1}{r}\frac{\Phi'}{\Phi}(y - xy') = y''(1 + y'^2)^{-1}. \tag{7}$$

The Newtonian gravitation potential is the stationary solution for the field equation of Nordström's gravitation theory for the situation of a point mass in an otherwise empty space:

$$\Phi = -\frac{GM}{r} \qquad \Phi' = \frac{d\Phi}{dx} = \frac{GM}{r^2} \qquad \frac{\Phi'}{\Phi} = -\frac{1}{r}. \tag{8}$$

Inserting to (8) shows that the equation mixes y and x in a way making solution difficult, we change to spherical coordinates.

In spherical coordinates, letting $d\phi = 0$, $r' = dr/d\theta$, $r'' = d^2r/d\theta^2$,

$$L(r, r', \theta)d\theta = \sqrt{g_{11}dr^2 + g_{22}r^2 d\theta^2} = \sqrt{g_{11}r'^2 + g_{22}r^2}d\theta. \tag{9}$$

The terms in the Euler-Lagrange equations are

$$\frac{\partial L}{\partial r} = \left(g_{11}'{r'}^2 + {g'}_{22}r^2 + g_{22}2r\right)\frac{1}{2L} \tag{10}$$

$$\frac{\partial L}{\partial r'} = g_{22}r'\frac{1}{L} \tag{11}$$

$$\frac{d}{d\theta}\frac{\partial L}{\partial r'} = \frac{1}{L^3}r''g_{22}^2 r^2 \tag{12}$$

$$+ \frac{1}{2L^3}\left({g'}_{22}g_{22}{r'}^2 r^2 + 2{g'}_{22}g_{11}{r'}^4 - g_{22}{g'}_{11}{r'}^4 - 2g_{22}^2 r{r'}^2\right). \tag{13}$$

The Euler-Lagrange equation is

$$2r^2 g_{22}^2 r'' = {r'}^4(g_{11}'g_{11} + g_{22}{g'}_{11} - 2{g'}_{22}g_{11}) \tag{14}$$

$$+ {r'}^2 r^2({g'}_{11}g_{22} + g_{22}'g_{11} + {g'}_{22}g_{22}) \tag{15}$$

$$+ {r'}^2 r(2g_{22}g_{11} + 2g_{22}^2) + r^3 2g_{22}^2 \tag{16}$$

$$+ r^4({g'}_{11}g_{11} + {g'}_{11}). \tag{17}$$

Inserting a scalar metric $g_{11} = g_{22} = \Phi^2$ gives the Euler-Lagrange equation

$$r'' = (r')^2 \left(\frac{\Phi'}{\Phi} + 2 \right) + \frac{\Phi'}{\Phi} + r. \tag{18}$$

Let us first calculate (18) for the Newtonian gravitation potential $\Phi = -\frac{GM}{r}$. Then

$$\Phi' = \frac{d\Phi}{d\theta} = 0 \qquad \frac{\Phi'}{\Phi} = 0 \tag{19}$$

The equation is

$$r'' - 2(r')^2 - r = 0. \tag{20}$$

This equation has the exact solution

$$\theta - \theta_0 = \pm \int \frac{dr}{\sqrt{C_1 e^{4r} - \frac{r}{2} - \frac{1}{8}}} \tag{21}$$

where θ_0 is an integration constant.

This equation gives light bending in a situation that corresponds to Eddington's experiment. The smallest value of r that the light beam can get is the radius R of the Sun. It is so large that the other terms but the exponential term in the exact solution are negligible. The value C_1 must be positive and for positive θ the solution is very closely

$$\theta = \theta_0 - \frac{1}{2\sqrt{C_1}} e^{-2r} \qquad \theta_0 = \frac{1}{2\sqrt{C_1}} e^{-2R}. \tag{22}$$

For negative θ is it very closely

$$\theta = -\theta_0 + \frac{1}{2\sqrt{C_1}} e^{-2r}. \tag{23}$$

The angle θ_0 is an integration constant. We can set it by deciding that a light beam comes from the angle $-\theta_0$ by turning the coordinate system appropriately. Where does the light beam go? If it goes to the angle θ_0 we get no prediction to Eddington's experiment as θ_0 is not determined, we only turned the coordinate system by an unknown angle θ_0. But there are other problems. The solution derivative is not continuous. The discontinuity of the derivative at $\theta = 0$ is caused by $\pm$ in the square root. The path of the light beam is not what it should be neither in the positive nor in the negative branch though the solution is exact. We conclude that the geodesic metric does not predict correctly.

Equation (18) can be solved for any $\Phi = \Phi(r(\theta))$ by writing it as

$$r' \left(\frac{r''}{r'} - \frac{r'\Phi'}{\Phi} - 2r' \right) = \frac{\Phi'}{\Phi} + r. \tag{24}$$

$$r' \frac{d}{d\theta} \left(\ln \left(r'\Phi^{-1} \right) - 2r \right) = \frac{\Phi'}{\Phi} + r. \tag{25}$$

Defining

$$u = \ln(r'\Phi^{-1}) - 2r. \tag{26}$$

Solving

$$r'\Phi^{-1} = C_1 e^{u+2r} \quad r' = \Phi C_1 e^{u+2r}. \tag{27}$$

Using

$$u' = \frac{du}{dx} = \frac{dr}{d\theta}\frac{du}{dr} = r'\frac{du}{dr} \tag{28}$$

the equation turns into

$$(r')^2 \frac{du}{dr} = \frac{\Phi'}{\Phi} - r. \tag{29}$$

Inserting r'

$$e^{2u} du = \Phi^{-2} e^{-4r}\left(\frac{\Phi}{\Phi} + r\right) dr. \tag{30}$$

Integrating and taking the square root

$$e^u = \pm\sqrt{2}\left(\int \Phi^{-1} e^{-4r}\left(\frac{\Phi}{\Phi} + r\right) dr\right)^{\frac{1}{2}}. \tag{31}$$

Inserting to the equation of r'

$$r' = \pm\Phi C_1 \sqrt{2}\left(\int \Phi^{-1} e^{-4r}\left(\frac{\Phi}{\Phi} + r\right) dr\right)^{\frac{1}{2}} e^{2r}. \tag{32}$$

As $r' = dr/d\theta$ and terms with r can be moved to the right, we can integrate

$$\theta - \theta_0 = \int d\theta = \pm\int (\Phi C_1\sqrt{2})^{-1}\left(\int \Phi^{-1} e^{-4r}\left(\frac{\Phi}{\Phi} + r\right) dr\right)^{-\frac{1}{2}} e^{-2r} dr. \tag{33}$$

2. How are the equations with the Schwarzschild metric

The Scwarzschild metric is not a valid metric, as is shown in [3], but it is the only solution from which Einstein can have calculated a prediction for Eddington's measurement of light bending

The Schwarzschild metric does not have a Cartesian coordinate representation as it is not a valid metric [3]. Inserting to the spherical coordinate representation the value $g_{22} = 1$ as in the Schwarzschild metric gives

$$r'' = \frac{1}{2}\frac{r'^4}{r^2} g'_{11}(g_{11} + 1) + \frac{1}{2} g'_{11} r'^2 + \frac{r'^2}{r}(g_{11} + \frac{1}{2}) + r. \tag{34}$$

Inserting $g_{11} = \left(1 - \frac{r_c}{r}\right)^{-1}$ yields

$$r'' = \frac{r_s r - (1/2) r_s^2}{r^2 (r - r_s)^3} r'^4 + \frac{(3/2) r^2 - 2 r r_s + (1/2) r_s^2 - (1/2) r_s}{r(r - r_s)^2} r'^2 + r. \tag{35}$$

Compared to (20), having the exact solution (21), this equation for the Schwarzschild metric is very complicated. Paper [4] also found complicated formulas for light-like geodesics for this metric. It is doubtful that Einstein could have calculated the solution for the path of light in Eddinton's experiment in the Schwarzschild metric, and even if he did, the result does not give any prediction of how much the light beam bends: the amount of bending depends on integration constants.

3. Dynamic equation of a test mass in the geodesic Lagrangean

Starting from a general metric

$$ds^2 = g_{ab}dx^a dx^b \tag{36}$$

Einstein divided the equation with ds^2 getting a Lagrangean that is identically one

$$L^2 = g_{ab}\frac{dx^a}{ds^2}\frac{dx^b}{ds^2} = 1. \tag{37}$$

The Lagrangean (37) gives minimization of the action integral over the set of paths where ds varies: a small variation in the direction of dx^a is compensated by a small variation of ds. This set of paths omits all paths where ds remains at zero. This means, by using (37) one cannot find geodesics for light. The Euler-Lagrange equations for (37) can only find minimum action paths for test masses that have nonzero mass and cannot have the speed of light, i.e., cannot have $ds = 0$.

It may initially seem that making the following calculation in full detail is not needed in this article as the calculation can be found in the literature, but this is not so. Including this calculation with all small details is essential in this artice as the result shows that the geodesic metric is seriously incorrect. That crucial result is not found in the literature. The literature omits equations (61)-(64) when explaining Einstein's correction to the precession of Mercury's perihelion.

Notice that since $L = 1$, we get the same Euler-Lagrange equations for L and for L^2. Writing the Euler-Lagrange equations for L^2 gives

$$\frac{\partial L^2}{\partial x^c} = (\partial_c g_{ab})\frac{dx^a}{ds^2}\frac{dx^b}{ds^2} \tag{38}$$

$$\frac{\partial L^2}{\partial (dx^c/ds)} = 2g_{ac}\frac{dx^a}{ds^2} \tag{39}$$

where we used $g_{ab} = g_{ba}$. The Euler-Lagrange equations are

$$(\partial_c g_{ab})\frac{dx^a}{ds^2}\frac{dx^b}{ds^2} = \frac{d}{ds}\left(2g_{ac}\frac{dx^a}{ds^2}\right). \tag{40}$$

This equation is particularly simple in spherical coordinates if $g = g(r)$, then

$$(\partial_c g_{ab}) = 0 \quad \text{if} \quad \text{c} \neq 1 \tag{41}$$

giving a solution to all other indices c than $c = 1$, i.e., the coordinate $x^1 = r$

$$\frac{d}{ds}\left(2g_{cc}\frac{dx^c}{ds^2}\right) = 0 \qquad \frac{dx^a}{ds^2} = C_c(2g_{cc})^{-1} \tag{42}$$

where C_c are constants. For $c = 1$ the equation is

$$\sum_{i=0}^{3} g'_{ii}\left(\frac{dx^i}{ds}\right)^2 = 2g'_{11}\left(\frac{dx^1}{ds}\right)^2 + 2g_{11}\frac{d^2x^1}{ds^2}. \tag{43}$$

Inserting (42)

$$\frac{d^2x^1}{ds^2} + \frac{1}{2}\frac{g'_{11}}{g_{11}}\left(\frac{dx^1}{ds}\right)^2 = \frac{1}{2}\sum_{i=0,2,3}\frac{g'_{ii}}{g_{11}}\left(\frac{C_i}{g_{ii}}\right)^2. \tag{44}$$

Inserting spherical coordinates

$$r'\left(\frac{r''}{r'} + \frac{1}{2}\frac{g'_{11}r'}{g_{11}}\right) = \frac{1}{2g_{11}}\sum_{i=0,2,3} C_i^2\frac{g'_{ii}}{g_{ii}^2} \tag{45}$$

$$r'\frac{d}{ds}\ln\left(r'g_{11}^{\frac{1}{2}}\right) = \frac{1}{2g_{11}}\sum_{i=0,2,3} C_i^2\frac{g'_{ii}}{g_{ii}^2}. \tag{46}$$

Writing

$$u = \ln\left(r'g_{11}^{\frac{1}{2}}\right) \qquad r' = C_1 g_{11}^{-\frac{1}{2}}e^u \qquad \frac{d}{ds} = \frac{dr}{ds}\frac{d}{ds} = r'\frac{d}{ds} \tag{47}$$

$$(r')^2\frac{du}{dr} = \frac{1}{2g_{11}}\frac{d}{dr}\sum_{i=0,2,3} C_i^2\frac{1}{-g_{ii}}. \tag{48}$$

Inserting r' and integrating

$$e^{2u}du = \frac{1}{2}C_1^{-2}\frac{d}{dr}\left(\sum_{i=0,2,3} C_i^2\frac{1}{-g_{ii}}\right)dr \tag{49}$$

$$\frac{1}{2}e^{2u} = \frac{1}{2}C_1^{-2}\sum_{i=0,2,3}\left(C_i^2\frac{1}{-g_{ii}}\right) + C_4 \tag{50}$$

where C_4 is an integration constant. Taking square root and inserting to the equation of r'

$$r' = \pm g_{11}^{-\frac{1}{2}}\left(\sum_{i=0,2,3}\left(C_i^2\frac{1}{-g_{ii}}\right) + 2C_4C_1^2\right)^{\frac{1}{2}}. \tag{51}$$

Writing

$$\frac{dr}{d\theta} = \frac{dr}{ds}\frac{ds}{d\theta} = \frac{r'}{\theta'} = r'\frac{g_{22}}{C_2} \tag{52}$$

and integrating

$$\theta - \theta_0 = \int d\theta = \int \frac{C_2}{g_{22} r'} dr = \pm C_2 \int \frac{g_{11}^{\frac{1}{2}}}{g_{22}} \left(\sum_{i=0,2,3} \frac{C_i^2}{-g_{ii}} + 2C_4 C_1^2 \right)^{-\frac{1}{2}} dr. \quad (53)$$

Inserting the Schwarzschild metric and $d\phi = 0$

$$\theta - \theta_0 = \pm C_2 \int \frac{(-B(r))^{\frac{1}{2}}}{-r^2} \left(-\frac{C_0^2}{A(r)} + \frac{C_2^2}{r^2} + 2C_4 C_1^2 \right)^{-\frac{1}{2}} dr. \quad (54)$$

For large r the functions $B(r)$ and $A(r)$ are very close to unity

$$\theta - \theta_0 = \pm C_2 \int i \frac{1}{-r^2} \left(\frac{C_2^2}{r^2} - C_0^2 + 2C_4 C_1^2 \right)^{-\frac{1}{2}} dr \quad (55)$$

$$\theta - \theta_0 = \pm C_2 \left(C_0^2 - 2C_4 C_1^2 \right)^{-\frac{1}{2}} \int \frac{1}{-r^2} dr = \pm C_5 \frac{1}{r}. \quad (56)$$

Assuming that this dynamc equation describes a small test mass that is approaching the Sun from a negative angle $-\theta_0$ and leaving to the direction of some positive angle θ_0 we can select the branches of the solution as

$$\theta = C_5 \frac{1}{R} - C_5 \frac{1}{r} \quad \text{if } \theta \geq 0 \quad (57)$$

$$\theta = -C_5 \frac{1}{R} + C_5 \frac{1}{r} \quad \text{if } \theta < 0 \quad (58)$$

where R is the radius of the Sun. θ varies between $\pm C_5 \frac{1}{R}$ and we can select C_5 so large that the test mass bends to the correct direnction, but there is no prediction at all from this equation: the trajectory of the test mass depends essentially on integration constants.

Inserting a scalar metric $g_{00} = \Phi(r)^2$, $g_{11} = -\Phi(r)^2$, $g_{22} = -r^2\Phi(r)^2$ with $d\phi = 0$ removing g_{33} equation (53) yields

$$\theta - \theta_0 = \pm C_2 \int \frac{(-\Phi^2)^{\frac{1}{2}}}{-r^2\Phi^2} \left(\frac{C_0^2}{-\Phi^2} + \frac{C_2^2}{-r^2\Phi^2} + 2C_4 C_1^2 \right)^{-\frac{1}{2}} dr. \quad (59)$$

For large r

$$\theta - \theta_0 = \pm C_2 \int \frac{1}{-r^2\Phi} \frac{\Phi}{C_0} dr = \pm \frac{C_2}{C_0} \frac{1}{r}. \quad (60)$$

The result is similar to the one from the Schwarzschild metric. The real problem with the geodesic metric is that the equation (40) does not correspond to an equation of a test mass in a gravitational field. Let us solve the dependency of r on time t under a scalar field $\Phi(r)$, again with $d\phi = 0$ for simplicity. Then

$$\frac{dr}{dt} = \frac{dr}{ds} \frac{ds}{dt} = \frac{r'}{t'} = r' \frac{g_{00}}{C_0} \quad (61)$$

and

$$t - t_0 = \int d\theta = \int \frac{C_0}{g_{00} r'} dr = \pm C_0 \int \frac{g_{11}^{\frac{1}{2}}}{g_{00}} \left(\sum_{i=0,2,3} \frac{C_i^2}{-g_{ii}} + 2C_4 C_1^2 \right)^{-\frac{1}{2}} dr. \quad (62)$$

which gives the equation

$$t - t_0 = \pm C_0 \int \frac{(-\Phi^2)^{\frac{1}{2}}}{\Phi^2} \left(\frac{C_0^2}{-\Phi^2} + \frac{C_2^2}{-r^2 \Phi^2} + 2C_4 C_1^2 \right)^{-\frac{1}{2}} dr. \quad (63)$$

Especially if the mass falls radially $d\theta = d\phi = 0$. For a valid solution we can select any integration constants that are acceptable, let us select $C_4 = 0$. Then the equation is

$$t - t_0 = \pm C_0 \int \frac{1}{\Phi} \frac{\Phi}{C_0} dr = \pm r = r \quad (64)$$

as r and t are both positive. A stone falling freely in the gravitational field of the Earth does not accelerate in the geodesic metric. The geodesic metric is absolutely not correct for a dynamic equation. This is the geodesic metric that Einstein used in order to explain the precession of the perihelion of Mercury.

4. Should light travel along geodesics of a gravitational field?

We saw that in metric induced by a scalar gravitational field light does bend in a gravitational field provided that it travels along geodesics of that field. However, why should light travel along geodesics of a gravitational field?

The space around the Sun is not vacuum. There is some matter in it and we can expect that the density of this matter grows when approaching the Sun. According to Maxwell's equations the speed of light in a matter is smaller than in vacuum. In denser matter the speed of light is smaller. Consequently a wave front of light should bend when it travels close to the Sun and the bending it to the direction that has been observed in Sun eclipses. This means that there is another mechanism that causes light bending and if geometry of the space-time also would cause light bending, we could not differentiate these two mechanisms by making observations of light bending in Sun eclipses. Einstein could not have known what amount of light bending is due to slower speed of light in matter and what part is due to geometry. It could be that none of light bending is due to geometry. We have to look at the arguments that the geometry of the space-time actually changes because of gravitation.

One argument is that gravitational time dilation shows that the space-time geometry is changed by gravitation. Gravitational time dilation is real and verified by the Pound-Rebka experiment. This experiment can be explained as time slowing down and the same correct formula is obtained both from Nordström's gravitation theory where the field is the Newtonian gravitation field, and from the General Relativity Theory where the metric is the Schwarzschild metric. The difference between these two explanations is that experiments verify that the gravitational field around the Earth is at least very close to the Newtonian gravitational field while the Schwarzschild metric gives clearly wrong predictions: in the Schwarzschild metric the speed of light in vacuum is not c to a any direction but the speed of light in vacuum has been measured on the Earth and it is c to all directions. Therefore the explanation by the General Relativity Theory is false.

The explanation by Nordström's gravitational theory seems more correct, but the scalar field in this theory can be interpreted either as geometry of the space-time or as geometry of the field in the normal Euclidean space, in a similar way as fields are interpreted in Maxwell's equations. In Maxwell's equations the force fields have curved 4-dimensional geometry, but it is not interpreted as space-time geometry. In order to choose if the field in a scalar gravitational theory is geometry or a field in Euclidean space, we have to look at what the gravitational time dilation really means.

All clocks do not slow down in higher gravitation. The period of a pendulum clock is $T = 2\pi\sqrt{L/g}$ where L is the length of the pendulum and g is the gravitational constant on the Earth. This constant is smaller on a mountain than in a deep well. The pendulum clock ticks faster in higher gravity. A sundial ticks the same both on a mountain and in low lands. Thus, it depends on a clock. An atomic clock, relying on transitions of electrons in an atom, slows down in higher gravity. The period of a pendulum is derived by solving the Euler-Lagrange equation for the energy of the mass at the end of the pendulum. How are the oscillations of electrons solved?

The first version of the equation modelling these oscillations was the Schrödinger equation. It is not derived from Euler-Lagrange equations. It makes fully heuristic substitutions of energy by a partial time derivative and momentum by partial space derivative. The improved version of the equation, the Dirac equation, makes the same fully heuristic substitutions and additionally uses as the kinetic energy the formula for relativistic kinetic energy. Paper [5] shows that the relativistic kinetic energy formula is wrong, it violates conservation of energy and disagrees with Bertozzi's measurements. Therefore the Dirac equation is incorrectly derived and is fully heuristic.

The time that has time dilation in a gravitational field is the time in the Dirac and Schrödinger equations. There is no reason to think that these equations are correct and that the time in them is correct. These equations are fully heuristic and they are not correct, they are useful, they work well in their applications. As the gravitational field makes atomic oscillations slower, a correct equation must contain the gravitational field strength, just like the formula for a pendulum contans the gravitational constant g. Gravitational time dilation does not need to be interpreted as being caused by space-time curvature due to the gravitational field. It can very well be caused by the effect of the gravitational force on oscillations of electrons in an atom. In order to argue that gravitational time dilation is caused by space-time curvature, at the minimum there should be an equation describing these oscillations which is derived correctly by minimizing energy with an Euler-Lagrange equation, not by heuristic substitutions.

In addition to gravitational time dilation there is also acceleration time dilation. As [6] shows, these two - without the false Special Relativity Theory time dilation due to velocity - can explain the time advance in a GPS satellite. Gravitational time dilation and acceleration time dilation are closely related, but [6] shows in the calculation of the GPS satellite time advance that Einstein's equivalence principle does not fully hold: acceleration and gravitation are not causing the same time dilation.

Another argument that the geometry of the space-time should have importance in bending of light around the Sun is the correction that Einstein derived to the precession of the perihelion of Mercury from the General Relativity Theory (GRT). Einstein calculated it from the Schwarzschild solution. The Schwarzschild solution cannot be used as a model of the gravitational field around the Sun for the reasons given in [3]. It was shown in Section 3 that in the geodesic metric that Einstein used for calculating the correction to the precession speed a stone falling freely in a gravitational field does not accelerate, i.e., there is something fundamentally wrong with the geodesic metric. The article [7] shows that there is no need for any new mechanism, like GRT, for explaining the error in the precession speed of Mercury's perihelion. The methods used to calculate the precession speed are necessarily approximations as the effect of planets is a multibody problem which is analytically unsolvable in Newtonian mechanics. Approximations have approximation errors and the precession speed that they gave was almost correct. More detailed approximate calculations are given in [7] and they show that the effect of Jupiter can explain the error in earlier precession speed approximations. GRT cannot explain it: the Schwarzschild solution is not a valid metric and therefore it cannot be used as a model of the gravitational field of the Sun, and the geodesic metric is certainly not a valid way to derive a dynamic equation for a small test mass.

Einstein claimed that Nordström's gravitation theory gives a wrong sign to the correction of the precession speed of Mercury. This claim has been repeated later as an argument that supposedly shows that a scalar gravitational theory is not in agreement with experiments. This is not the case. The wrong sign to the correction term comes only if the correction term is calculated in the same way from the incorrect geodesic metric. Though Nordström's theory does not say anything of light bending or precession of Mercury's perihelion, we can conclude that Nordström's theory predicts the correction as in [7]. Nordström's theory in a static field case gives Newtonian gravity.

We can conclude that the precession of the perihelion of Mercury does not need an explanation claiming that space-time curvature has anything to do with the precession speed.

Yet another argument for the effect of space-time geometry is the Shapiro delay test. It is briefly discussed in [8]. The problem in this test is that for GRT it is made with the Schwarzschild metric, which is invalid [3], but even allowing the test to be made with the Schwarzschild metric, the metric fails the test because the speed of light is not constant in that metric. Therefore GRT has not passed this test. [8] shows that Nordström's gravitational theory does pass the test.

There is still left one argument for the importance of space-time geometry: a black hole. A black hole can be explained with metrics similar to the Schwarzschild metric. All these metrics have a time horizon and none of the metrics have locally constant speed of light in vacuum. There is an alternative explanation to black holes. It is not that light cannot escape a black hole. It is that the matter in the black hole does not emit light because it is so dense that there are no electron transitions that could emit photons. The mechanism is the same as in gravitational time dilation: a strong gravitational field makes oscillations of electrons slower and finally impossible. In a black hole matter is not in atoms, it is more densily packed. Yet, the fermion number is conserved and after bosons have already turned into energy and escaped the forming black hole, there is no matter that can change to energy: fermions can change into energy only if they merge with antifermions as otherwise the fermion number changes. It could be that novas and supernovas are a part of the process where a forming black hole emits its mass that can be changed into energy, i.e., bosons.

We see that all experiments that seem to support the idea that space-time is curved and seem to offer reasons why space-time curvature causes light bending close to the Sun can be given alternative explanations. Let us continue to more philosophical reasons why light bending should be at least partially caused by space-time curvature.

One argument is that in a flat space light travels along a straight line. A curved space is an an image of the Euclidian space under some mapping. Straight lines map to curved lines and under some conditions these curved lines are geodesics of the curved geometry. Therefore light should follow geodesics of the curved space-time geometry. As the curved space-time geometry is the gravitational field in geometric gravitational theories, light should travel along geodesics of the gravitational field.

About this argument one can say that the force lines of an electromagnetic field are an image of a conformal mapping from $\mathbf{R}^3$, but light does not follow those force lines. Charges follow the force lines of an electric field and magnetic test objects follow force lines of a static magnetic field, but electromagnetic waves do not change their direction because of other electromagnetic fields in the space. It is well confirmed by engineering that radio waves, in fact electromagnetic waves of any frequency, are superimposed on each others. They simply can be added, they do not influence each other. Why should this be different if the field is a gravitational field?

Light has energy and momentum and interacts with matter. The shape of an electromagnetic field very much depends on matter in the area. The effect is always calculated from an Euler-Lagrange equation that minimizes energy, not distance as the geodesic metric minimizes. The Euler-Lagrange equations for energy give forces that effect test objects and fields. Therefore bending of light should depend on its energy and momentum and light beams of different frequencies should not follow the same path in an environment where there are forces.

It is not at all clear that curvature of space-time geometry is needed to explain the shape of en electromagnetic field or wave and the reasons why light should follow geodesics of a gravitational field seem very weak.

5. Conclusions

It has been claimed that Eddington could not measure light bending in his experiment. Equation (35) makes one suspect that Einstein could not have calculated what light bending should have been. Yet, later measurements have confirmed that Einstein's prediction for light bending it correct. One explanation that comes easily to mind is that Einstein had read reports from earlier sun eclipses and knew that light bends and knew how much. If so, measurement of light bending does not verify GRT.

The article shows in Section 1 that if light follows geodesics of the gravitational field, then light does bend in the geometric scalar gravitational field theory, but Section 4 explains that there are no good reasons to think that light follows geodesics of the gravitational field. Therefore the best guess is that light does not bend in a scalar gravitational theory like Nordström's theory and the field in the theory should not be interpreted as space-time geometry.

Statement of conflicting interests and funding

There are no conflicting interests and this work has not been funded.

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