Physical interpretation of general relativity

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Abstract. Sjödin (1990) and Broekaert (2005) demonstrated that many redundancies of general relativity postulates may be eliminated by introducing a scalar potential instead of four-tensor to represent a gravitational field. The present paper provides further reduction of GR complexity. This is done by addressing physical nature of the phenomena for a static gravitational field. The physical interpretation is based on Einstein's later conception confirmed by a large amount of published and unpublished manuscripts (Kostro, 2000).

1. Introduction

Many physicists are convinced that Einstein objected to the idea of the universal medium. For example, Smolin (2006) wrote "Einstein killed this particular idea with his own proposal for unification", however this opinion is incorrect. In 1920 Einstein wrote in a deleted section of an article for "Nature": "… in 1905 I was of the opinion that it was no longer allowed to speak about the ether in physics. This opinion, however, was too radical as we will see later when we consider the general relativity theory. It is allowed much more than before to accept a medium penetrating the whole space and to regard the electromagnetic fields and the matter as states of it ...One can thus say that the ether is resurrected in the general theory of relativity".

This 'resurrection' of ether in Einstein's mind is confirmed by a large amount of published and unpublished manuscripts that have been collected in a book by Kostro (2000). It is clear from the quoted fragment that Einstein was compelled to hide his views. Quite probably that avoiding mentioning the medium has led to mathematical complication of the general theory of relativity (GR). It is the same as if one attempted to explain behavior of waves on a water surface without mentioning the water.

As the mentioned paragraph was finally deleted from Einstein's article, his optimism was premature. Probably today, when the number of conservatives in physics has decreased, and the vacuum is not considered emptiness any more, we may use the concept of universal medium to simplify GR. All the more Sjödin (1990), Broekaert (2005), Okun, Selivanov, Telegdi (2000) and others have already founded the base for such a revision.

It is only natural to consider that the universal medium state may influence the light speed which results in the delay of the radar echo when passing near the Sun (Shapiro, 1964, 1966). The same property explains the deviation of a light ray by the Sun. Thus, there is no necessity to introduce the concept of local time to explain the experimental results.

The reader will probably ask "What about the time delay detected in vicinity of massive bodies?" Indeed, some physicists consider acceleration of the standard cesium clocks when being lifted high as a proof of time acceleration. This happens because the theory of relativity presents no definition for the time notion (see Bakman and Pogorelsky, 2007), as a result any change of the standard clock rate is erroneously perceived as a change of the time rate. Actually, any standard can change and then it ceases to be the standard. For example, heating of the meter standard leads to its lengthening, but it does not mean that heating expands the space. Actually, any change of the standard clock rate (or the standard meter length) testifies only that the clock (or the meter) ceased to be the standard. By the way, a pendulum clock slows down its swings when placed on the top of a mountain.

The changeable light speed allows to get rid not only of the necessity of time dilation, but also of the space curvature. Sjödin (1990) and Broekaert (2005) showed that the geometry of space is a convention, so that for the description of the reality physicists may choose the Euclidean geometry. They reduced the number of GR assumptions by introducing a scalar potential instead of the metric tensor of GR (10 arbitrary functions) to represent a gravitational field. They also showed, that their theories predict results of all classical experiments of GR.

2. Basic assumptions

Our basic assumptions are as follows:

Assumption 1. A static gravitational field may be described by a scalar potential $0 < \Phi(r) \leq 1$, $\Phi(\infty) = 1$. For spherically symmetric gravitational field we also adopt Broekaert's (2005) form of $\Phi(r)$

$$\Phi(r) = \exp(-\kappa/r), \quad (1)$$

where $\kappa = MG/c^2$ (half the Schwarzschild radius).

If an atom is placed in a gravitational field with potential Φ, the energy levels of the atom will be influenced by the field. The radiation/absorption spectrum will change accordingly. The spectral lines of an atom placed on the tower roof are blueshifted compared to the same type of atom placed at the bottom. The relational change of energy levels for an atom elevated to the height H in a spherically symmetric gravitational field equals $\frac{\Delta\Phi}{\Phi} \approx \frac{\kappa}{r^2}\mathrm{H} = \frac{gH}{c^2}$ (the linear approximation for the potential increment $\Delta\Phi$ was used). Similarly the radiation of an atom at the bottom is redshifted compared to the identical atom on the roof.

This effect was confirmed recently by the Global Positioning System (GPS). Although it is neither designed nor operated as a test of fundamental physics, it must account for the gravitational redshift in its timing system based on the cesium atomic clock. The clock is tuned so that its microwave oven frequency provides resonant absorbtion of the oven radiation by cesium atoms. The oven pulses serves as the clock ticks, thus the frequency of ticks is fitted to the cesium atoms resonant absorbtion. The first satellite was launched without the clock adjustment built into subsequent satellites. It showed the predicted shift of 38 microseconds per day (Wikipedia).

When Pound, Rebka, and Snider (1960, 1964) carried out their redshift experiments, GPS had not existed yet. These experiments used photons as mediators between atoms of the same types, some of which (absorbers, receivers) being placed on the roof of a high tower while the others (emitters) at the tower bottom. The results could be interpreted doubly: either the photons became redshifted when moving upwards, or their frequency did not change but the atoms on the roof were blueshifted compared to those at the bottom. Okun, Selivanov, and Telegdi (2000) explained that though a stone looses its energy when overcoming the gravitational attraction, the analogy between a photon and a stone is wrong: the energy of a photon remains unchanged. Therefore when measuring the "gravitational redshift of photons" one actually measures the gravitational blueshift of atoms. Now after the GPS confirmation it is clear that the latter interpretation of the redshift experiments is correct.

Assumption 2. Following Broekaert (2005), the field potential Φ(r) influences the speed of light according to the formula

$$c(r)=c_0\,\Phi(r)^2, \qquad (2)$$

where c_0 is the speed of light at infinity. Sjödin (1990) and Broekaert (2005) assumed in addition the Lagrangian or Hamiltonian forms; we shall use physical reasons instead.

For spherically symmetric gravitational field Eqs.(1)-(2) yield $c(r)=c_0\exp(-2\kappa/r)$. Since for a weak field $\kappa/r \ll 1$, the corresponding linear approximation is $c(r)\approx c_0(1-2\kappa/r)$. This formula is known as the coordinate or world speed of light in the gravitational field of a massive body. It is confirmed by Shapiro's experiments (Shapiro, 1964, 1966) in which the radar echo dilation in Sun's gravitation field was registered.

Thus, two of the four classical GR experiments had previously got physical interpretations. The present work uses the earlier studies as a starting point. Now we pass to a physical explanation of experiments in which a light ray is deflected by the Sun.

3. Deflection of photon's velocity in a gravity field

Fock (1964, p.222) derived the light ray path near the Sun as a consequence of geometrical optics considering the refractive index of the gravitational field medium $\left(1-\frac{2\kappa}{r}\right)^{-1}$, therefore the following derivation seems superfluous at least for the case of a spherically symmetric gravitating body. However in what follows we consider not a light ray but rather a photon which will be further generalized <u>for any particle</u> in any static gravitational field.

Suppose a photon moves in a gravitational field. The photon turns around an instant center O due to the velocity difference between its top and bottom edges (see Fig.1). Let points A and B inside the photon lay on a straight line passing through the point O. We will show that any such segment inside the photon turns around O with an identical angular velocity. This means that the turn of the photon occurs as a whole without deformation of its structure.

Let us compute the angle dα by considering two similar triangles (Fig.1):

$$d\alpha = \frac{c(r)dt}{R} = \frac{[c(r) + D(\nabla c(r)\cdot \vec{n})]dt}{R+D} = \frac{D(\nabla c(r)\cdot\vec{n})dt}{D} = (\nabla c(r)\cdot\vec{n})dt \qquad (3)$$

where $\vec{n}$ is a unit vector perpendicular to the photon's velocity and directed away from the point O, *D* is the distance between A and B. It should be emphasized that *d*α does not depend on *D*.

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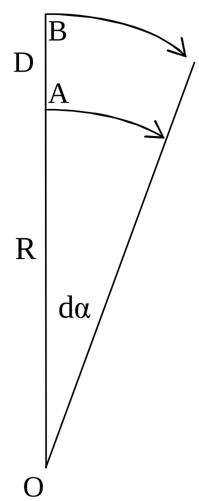

Fig.1. Photon's velocity rotation in a gravitational field

Correctness of Eq.(3) may be verified when applied to the light deflection experiment in which a light ray passes near the Sun (see Fig.2). Taking into account that for the spherically symmetric case of a massive body c(*r*)=c_0 exp(-2κ/*r*), we substitute the directional derivative $(\nabla c\cdot\vec{n})$ in (3) by

$$\partial c/\partial\rho = c_0\exp(-2\kappa/r)\ \frac{2\kappa}{r^2}\frac{\partial r}{\partial\rho}$$. Then

$$d\alpha = (\nabla c\cdot\vec{n})dt = c\frac{2\kappa}{r^2}\frac{\partial r}{\partial\rho}dt = c\frac{2\kappa}{r^2}\frac{\partial\sqrt{\rho^2+z^2}}{\partial\rho}\frac{dz}{c}$$

and after differentiation $d\alpha = \frac{2\kappa}{r^2}\frac{\rho}{r}dz = 2\kappa\rho\frac{dz}{(z^2+\rho^2)^{3/2}}$ (3a)

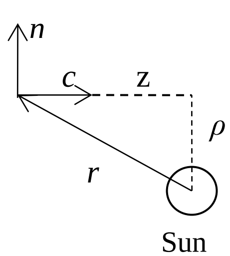

Fig.2. Light ray passing near the Sun

Since the total deflection of the light ray is very small, we approximate *ρ* as a constant. Then integrating (3a) for z from ∞ to 0 yields half the total deflection of the light ray $\alpha/2 = 2\kappa/\rho$, which corresponds to the classical expression obtained by Einstein in 1915.

Now let us return to the general case. Since $\nabla c = c_0\, 2\Phi\nabla\Phi = 2c\nabla\Phi/\Phi$, the angular velocity of the photon equals

$$\omega = \frac{d\alpha}{dt} = (\nabla c \cdot \vec{n}) = \frac{2c}{\Phi} \cdot (\nabla\Phi \cdot \vec{n}) . \qquad (4)$$

Multiplying ω by the photon's speed c yields the photon's centripetal acceleration $a_c = c\cdot\omega$ or

$$\vec{a}_c = -\vec{n}\,\frac{2c^2}{\Phi} \cdot (\nabla\Phi \cdot \vec{n}) . \qquad (5)$$

4. Generalization of the result for the case of any particle

Let us generalize the previous result (5), obtained for photons, for the case of any free particle in a gravity field. First of all a static charged particle cannot be stable, hence there must exist some stabilizing cyclic process – a wave – running around the particle along its perimeter and providing its stability. The speed of such a wave must be equal to the speed of light.

Compare the suggested model with the particle-wave duality. In our model the wave is tightly connected to the particle. In the duality model, one chooses either an infinite wave or a point particle for his/her convenience without any relation between the two contradictory representations.

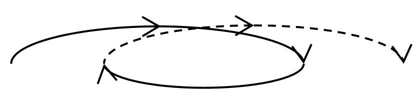

Fig.3. Motion of a cyclic wave.

It is most probable that the light speed dependence on the distance to the gravitating body deflects not only the photon's velocity but also velocities of other particles influencing upon their cyclic waves. Let the cyclic wave runs around a particle as shown in Fig.3. The particle moves rightward at a speed v, therefore the cyclic wave runs rightward more than a half of its period T, say γT (γ>0.5), and the rest of the period, i.e. (1-γ)T, it runs leftward. On the whole the speed of displacement is equal to $v = \frac{1}{T}[c\gamma T - c(1-\gamma)T] = c(2\gamma - 1)$.

Hence $\gamma = \frac{1}{2}\left(1 + \frac{v}{c}\right)$, and the leftward displacement lasts for $(1-\gamma)T = \frac{T}{2}\left(1 - \frac{v}{c}\right)$. According to (4), the top wave movement causes the particle's velocity rotation by angle

$d\alpha' = \omega \cdot (\gamma T) = \frac{2c}{\Phi}(\nabla\Phi \cdot \vec{n})\frac{T}{2}\left(1+\frac{v}{c}\right)$. Similarly, the bottom wave movement rotates the particle's velocity by angle $d\alpha'' = -\frac{2c}{\Phi}(\nabla\Phi \cdot \vec{n})\frac{T}{2}\left(1-\frac{v}{c}\right)$ in the reverse direction. The whole rotation during one period is equal to $d\alpha = \frac{2c}{\Phi}(\nabla\Phi \cdot \vec{n})T\frac{v}{c}$ which corresponds to the angular velocity of rotation

$$\omega = \frac{2v}{\Phi}(\nabla\Phi \cdot \vec{n}). \qquad (6)$$

Multiplying (5) by v yields the particle's centripetal acceleration $a_c = v \cdot \omega$ or

$$\vec{a}_c = -\vec{n}\frac{2v^2}{\Phi} \cdot (\nabla\Phi \cdot \vec{n}) \qquad (7)$$

We see that acceleration (5), true for photons, is a particular case of formula (7) when v=c. Thus, formula (7) is valid for all particles including photons.

5. Longitudinal acceleration of a particle

Photon's acceleration along the velocity vector equals

$$\vec{a}_v = \hat{c} \cdot dc/dt = (\nabla c \cdot \hat{c})d\vec{r}/dt = \vec{c}\frac{2c}{\Phi}(\nabla\Phi \cdot \hat{c}) = \frac{2\vec{c}}{\Phi}(\nabla\Phi \cdot \vec{c})$$

where $\hat{c}$ denotes a unit vector in the velocity direction. This acceleration is due only to the light speed change in a gravitational field.

Applying the same technique as in the previous section to generalize the result for any particle, we should multiply the above acceleration by v^2/c^2 which yields $\vec{a}_v = \frac{2\vec{v}}{\Phi}(\nabla\Phi \cdot \vec{v})$. (8)

6. Three consequences of gravitation

So far we considered two consequences of a gravitational field: the shift of atomic spectral lines, and slowing down the light speed. Sections 4-6 were devoted to the acceleration due to the latter effect. However there is another acceleration resulting from the potential gradient $\nabla\Phi$.

Everyone knows that g is the free fall acceleration due to the gravity force. Actually g is the acceleration of a body at rest. Indeed, since there is a velocity limit, one would not expect that a body can be accelerated infinitely. That is why we will use a_g instead of g to denote the acceleration due to the gravity force for any velocity v: $a_g = g$ only for a particle at rest. Bunchaft and Carneiro (1998) provided the following formula for the general case:

$$\vec{a}_g = \vec{g}(1 - v^2/c^2) \qquad (9)$$

Consequently for the photon a_g=0.

Since g is a measure of the gravity field intensity, it may be expressed by the potential gradient ∇Φ. Indeed, for the point mass field Φ=exp(-κ/r), therefore $\vec{g} = -c^2 \frac{\nabla\Phi}{\Phi}$. This expression may be generalized for any static gravitational field and substituted in Eq. (9). Then

$$\vec{a}_g = \vec{g}(1-v^2/c^2) = -\frac{\nabla\Phi}{\Phi}(c^2-v^2). \qquad (10)$$

7. The overall acceleration of any particle in a static gravitational field

To get the particle overall acceleration we will use the three formulas (7), (8) and (10)

$$a_c = -\vec{n}\frac{2v^2}{\Phi}\cdot(\nabla\Phi\cdot\vec{n}),\ a_v = \frac{2\vec{v}}{\Phi}(\nabla\Phi\cdot\vec{v}),\ \vec{a}_g = -\frac{\nabla\Phi}{\Phi}(c^2-v^2)$$

As a result we have three components of the total acceleration, expressed by three different vectors n, v и ∇Φ. We may represent ∇Φ as follows ∇Φ=(∇Φ $\hat{v}$) $\hat{v}$ +n(∇Φ n), where $\hat{v}$ denotes a unit vector in the velocity direction. Multiplying this equality by $-2v^2/\Phi$, yields

$$-\frac{2v^2}{\Phi}\nabla\Phi = \frac{2}{\Phi}(\nabla\Phi\cdot\vec{v})\vec{v} - \vec{n}\frac{2v^2}{\Phi}\cdot(\nabla\Phi\cdot\vec{n}) = \frac{2}{\Phi}(\nabla\Phi\cdot\vec{v})\vec{v} + \vec{a}_c$$

Thus we can express a_c by v и ∇Φ:

$$\vec{a}_c = -\frac{2v^2}{\Phi}\nabla\Phi + \frac{2v^2}{\Phi}(\nabla\Phi\cdot\hat{v})\hat{v} = -\frac{2v^2}{\Phi}\nabla\Phi + \frac{2}{\Phi}(\nabla\Phi\cdot\vec{v})\vec{v}.$$

Now we add the three accelerations to get the total acceleration a_t :

$$\vec{a}_c + \vec{a}_v + \vec{a}_g = -\frac{2v^2}{\Phi}\nabla\Phi + \frac{4}{\Phi}(\nabla\Phi\cdot\vec{v})\vec{v} - \frac{\nabla\Phi}{\Phi}(c^2-v^2) = \frac{4\vec{v}}{\Phi}(\nabla\Phi\cdot\vec{v}) - \frac{\nabla\Phi}{\Phi}(c^2+v^2)$$

which exactly coincides with Boekaert's (2005) Eq. (50). We may use Boekaert's consequent mathematical deduction which leads to the correct formula for anomalous shift of a planet's perihelion. Thus all four classical experiments confirming GR may be explained by simple physical reasons.

For the particular case when the particle velocity is directed along ∇Φ, the a_t projection on this direction equals $-\frac{4v^2}{\Phi}|\nabla\Phi| + \frac{|\nabla\Phi|}{\Phi}(c^2+v^2) = \frac{|\nabla\Phi|}{\Phi}(c^2-3v^2)$ and is negative for v>c/√3. This is the known critical velocity obtained earlier by many authors.

8. Summary

In this paper classical tests of GR obtained elementary explanation due to the use of Euclidean geometry and the usual concept of time. According to such interpretation the gravitational field manifests itself in decrease of atomic energy levels, in delay of the light speed, and in the free fall acceleration. The first effect gives a simple explanation of the redshift, the second - to the delay of the radar echo and the deviation a light ray near the Sun. The slowing of the light speed together with the free fall acceleration results in the anomalous shift of Mercury perihelion.

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