Gravitation as a Secondary Effect of Electromagnetic Interaction

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It has been invested so much vain effort into the unification of gravity and quantum physics, that meanwhile it does not seem to be fallacious any more to estimate the so far pursued way as a dead end. Therefore, I resume an old approach and start from the precondition, that gravitation can be understood as a secondary effect of electromagnetic interaction. The unification of the forces, thus, is a prerequisite. Based on that, the four classical tests of General Relativity Theory including the shift of Mercury's perihelion can be reproduced. Mach's principle harmonically fits into the presented model. The covariance principle is renounced.

Contents

1 Light in the Gravitational Potential

Einstein himself tried to extend his Special Relativity Theory with the assumption of a variable speed of light in a paper of 1911 [1] to describe the effects of gravitation in this way. His starting point is the principle of equivalence. It says that a uniformly accelerated reference system is equal to a system that rests within a field of gravitation of equal gravitational acceleration. This shall be valid for all physical properties without exception. From that, Einstein deduces the deviation of clocks and the red-shift in the gravitational field. He had not done the transition to the geometric interpretation of gravitation in the form of the curved space-time at that time, yet. And so he stays for now at the flat Minkowski-space of Special Relativity and he assumes a reduced velocity of light in the gravitational field. His calculation for the deviation of a light beam grazing the surface of the sun by 0.83 arc seconds delivers a value that will be proved to be wrong by a factor of 2. The reason for that is, that he silently assumes the spherical potential of the sun to be spatially homogeneous and so he does not take into account the curvature of space or rather the contraction of the wavelength of light. Because of that, the preconditions for the correct calculation are not given. However, from the wrong result it does not follow, that the access via a variable speed of light is fundamentally wrong. Einstein's knowledge of gravitation simply was not mature enough at that time. We take this approach again and try to get a consistent description of gravitation using light walking this very same path.

We consider a laboratory in space that is freely falling directly towards the sun. An experimenter in the laboratory is directing a laser beam backwards from the sun to an opposite receiver. The transmitter laser and the receiver shall be positioned fixed in the space laboratory. No gravitational effects (in first order) arise for the observer, because there is zero gravity in the laboratory. He measures the same frequency, that is specified on the type label of the laser at the sender side as well as at the receiver side. He compares the frequency with his atomic clock and does not observe any deviation. He also verifies the wavelength of the laser beam with his high precision scale of length and gets the same result.

A second observer shall be in the laboratory, who wants to find out how the gravitation of the sun affects light. He knows about the acceleration of the lab associated with the gravitational force. Because the receiver is accelerated during the run-time of the light beam in direction of the transmitter, he estimates a blue-shift and accordingly, a reduction of the wavelength for a measurement located at the receiver due to the Doppler-shift acting on frequency and wavelength. The observer concludes, that the gravitational field must have exactly the opposite effect to cancel out both, because the experimenter is not able to measure such a Doppler-shift.

We assume without loss of generality that the laboratory and, thus, the transmitter is at rest at $t = 0$. The receiver, though, is accelerated during the run-time of the light beam through the lab across the distance h for the time $t = h/c$ to the velocity $v = gh/c$. It should occur a blue-shift of the frequency ν_R, measured at the receiver with respect to ν_T, measured at the transmitter. The potential ϕ within the space-lab can be assumed to be homogeneous, because the extension of the laboratory compared to the variation of the attracting force in the potential of the sun is small.

$$\frac{\nu_R}{\nu_T} = 1 + \frac{v}{c} = 1 + \frac{gh}{c^2} = 1 + \frac{\phi}{c^2} \quad \text{with} \quad \phi = gh \ll c^2 \tag{1}$$

Because of that, the observer concludes that the frequency of the laser beam is red-shifted for the same amount, when leaving the gravitational field. He also observes, that clocks are running slower by this factor in a gravitational field (at the transmitter).

The same consideration he makes for the wavelengths λ. Because the receiver is accelerated towards the sender, he expects a contracted wavelength at the receiver. The observer concludes, that the wavelength of the laser beam – in each case measured locally – is stretched by the same amount when leaving the gravitational field.

$$\frac{\lambda_R}{\lambda_T} = 1 + \frac{v}{c} = 1 + \frac{gh}{c^2} = 1 + \frac{\phi}{c^2} \tag{2}$$

Hence, wavelengths are shorter in a gravitational field.

If now the laboratory is held in levitation by a rocket drive or stands on a planet surface, then the compensating Doppler-shift of the acceleration is not there any more. Now, a local measurement at the transmitter still delivers the type plate values of the laser frequency and wavelength. But the frequency is reduced at the receiver, if locally measured, and the wavelength is elongated. Therefore, the locally measured velocity of light is unchanged. However, the conclusion of the speed of light being a global constant is not yet mandatory.

A laser itself is an excellent time and length scale. For that reason the official definition of time- and length-scales is based on the frequency of an atomic transition of cesium and the distance that light covers in a certain time interval. If we take a laser as reference scale for the measurement of the local speed of light, we must keep in mind that its frequency and wavelength is underlying the same gravitational changes as the laser beam through the lab. Therefore, a local measurement of the velocity of light always shows the constant value c, even if the speed of light should vary spatially or temporally. The supposed prove of the universal constancy of the speed of light by means of a local measurement represents a circular argument.

Within these considerations we assume, that space-time is flat and time- and length-scales change *indeed*. And we assume that the velocity of light is variable. Contrary to it, General Relativity Theory assumes, that clocks, length-scales and the speed of light are unchanged, but the curved space-time makes sure, that times and lengths seem to be modified. But this is more a question of view than of being. Because both definitions describe the same observations, they can be considered as equivalent, at least in weak gravitational field. We prefer a physical view as represented by the variable speed of light, because it offers a better access for energetic considerations. The geometrical representation of the curved space-time is more a mathematical description of an underlying physics. About this physics strictly speaking, however, nothing is declared.

Now we take the location of the receiver as fixed point of view. He measures a reduced frequency in our thought experiment. Because the potential is temporally constant, he concludes that the light beam was emitted already with the lower frequency. He knows that clocks run slower at the transmitter than his own clocks and also, that the wavelength at the transmitter is contracted. From his point of view energy conservation is valid for the light beam and with $E = h\nu$ the frequency stays constant along the beam, whereas, the wavelength is stretched two times, thus, by the factor $(1 + \frac{\phi}{c^2})^2$ to arrive at the receiver with greater wavelength. Thus, he concludes on a change of the velocity of light of

$$\frac{c_R}{c_T} = \frac{\nu_R \lambda_R}{\nu_T \lambda_T} = \frac{\lambda_R}{\lambda_T} = \left(1 + \frac{\phi}{c^2}\right)^2 . \tag{3}$$

A complementary situation arises, if a light beam moves through a spatially constant potential, but this potential shall change over time, e. g. it is continuously decreasing. The observer measures a frequency ν_R and a wave-length λ_R. He knows, that ν_T and λ_T were greater at the emission than the standard values, because the potential ϕ was higher than at the receiver-side measurement. Because of the temporally variation of the potential the energy is not preserved in this system, but the momentum is. Due to the flat potential $\nabla\phi = F = 0$ there is no change of the momentum $F = \frac{dp}{dt} = 0$. And with the photon momentum $p = \frac{h}{\lambda}$ it follows, that the wavelength does not change along the path of light. This was already recognized by R. Dicke [2]. If we describe a temporal change of the gravitational potential with a variable speed of light, then it is:

$$\frac{c_R}{c_T} = \frac{\nu_R \lambda_R}{\nu_T \lambda_T} = \frac{\nu_R}{\nu_T} = \left(1 + \frac{\phi}{c^2}\right)^2 \tag{4}$$

The change of the speed of light is expressed here by the modification of the frequency ν. When emitted, the frequency is higher than the standard value and it is lower at the receiver. A red-shift is expected. The reference point is at the receiver, as mentioned. Here is the zero point of the potential and we obtain the standard value for the speed of light c_0.

According to these considerations, we can regard the expression

$$n = \frac{1}{\left(1 + \frac{\phi}{c^2}\right)^2} \approx 1 - \frac{2\phi}{c^2} + ... \tag{5}$$

as the relative polarizability of vacuum, which describes the propagation of light and at the same time, the effect of gravitation on light. Thus we will regard c as variable velocity of light and c_0 as the standard value of a local measurement. In General Theory of Relativity the variable speed of light c is called "coordinate velocity".

$$c = \frac{c_0}{n} \tag{6}$$

2 Former Works about Gravitation as a Light Phenomenon

In 1921 Harold Wilson showed, that a variable polarizability of vacuum effects a force onto a charged particle, which can be interpreted as gravitational force [3]. His model included the correct twice as large deflection of light at the sun. Based on this work, Robert Dicke extended in 1957 this insight by explaining three classical tests of General Theory of Relativity by means of a variable refractive index of vacuum [2] [4] (not the scalar-tensor theory). Almost at the same time also H. Dehnen, H. Hönl and K. Westpfahl [5] and later Jan Broekaert [6] demonstrated, that the four classical tests including the perihelion shift of Mercury can be described with the model of a polarizable vacuum. All four classical tests are based on effects of a weak gravitational field. Because General Theory of Relativity as well as the theory of polarizable vacuum have the same solution in weak fields, there is no possibility to decide in favor or against any of the theories. In strong fields, however, both models differ essentially.

James Evans, Kamal Nandi and Anwarul Islam presented a method that enables the exact calculation of the propagation of light and also the movement of matter through a medium of variable index of refraction n [7]. Their method is a manifestation, that gravitation and light are of the same nature and can, therefore, be described by a uniform formalism.

As summarized by Harold Puthoff [8] in a more easy readable way, many values also become dependent on n within a theory of variable speed of light. Alexander Unzicker gives a good overview of the state of the theory in [9].

Still missing, is a stringent system of rules how to deal with quantities in a polarizable medium. This work is the attempt to combine some of these more or less loosely connected threads to a sustainable network.

Many of the authors mentioned regard the formulation with variable speed of light only as a more intuitive and mathematically easier access to General Relativity, whose correctness they do not have doubt about. But it shall be reminded here, that it is not about correctness or falseness of a theory. According this narrow-minded view also Newton's theory is "wrong". Not only because it is inaccurate, but first of all, because it is based on conceptions, which are not valid from a today's point of view any more. Nevertheless, Newton's theory reliably delivers answers on questions to nature within the boundaries of its validity. Nothing more than that can be expected from a theory. And the question, whether the principles of a theory are "correct", can only be judged from the perspective of another theory based on the assumption of fundamental principles on its part as well. The truth itself is not available.

Naturally, there are better and worse models of reality. The criteria, though, are such as the area of validity, the number of necessary parameters, or simplicity. General Relativity Theory, in particular, is not really strong when it comes down to mathematical economy. And the proofs for the correct answers in the strong-field are, unfortunately, rather poor even after a hundred years of research. I would like the theory of variable speed of light to be regarded as another possible and powerful model in this sense without associating a claim of "truth" with it.

3 Unit Considerations

The following considerations extend the already found relations to further quantities. It is important to make oneself aware of the index of refraction n being a purely relative quantity. This means, it is a comparison between an observer, whose potential is taken as a reference with refractive index $n = 1$ by definition, and locations with different refractive index. n describes always the relative difference but not an absolute value.

There are essentially two situations, which have to be distinguished:

1. A measurement is related to the location itself, at which it is conducted (local measurement). Then, the index of refraction n is equal one by definition and there, the standard value of each quantity is valid, explicitly indicated by index "0".

2. An observer is located at the reference potential and evaluates measurements at a location with different gravitational potential. The scales, clocks and reference masses arranged at reference potential look different to him at the location of the experiment. The local experimenter takes the modified scales as a reference for his tests. Then, the following relations are valid.

Starting point is the definition of the refractive index n on the basis of the speed of light:

$$c = \frac{c_0}{n} = \frac{c_0}{k^2}, \quad \text{with} \quad k := \sqrt{n}$$

Many expressions can be written more simply with the red-shift factor k here introduced. We will use k practically synonymously to the refractive index n.

As shown above, clocks run slower in a gravitational field, periods are longer, frequencies smaller:

$$\nu = \frac{\nu_0}{k} \tag{7}$$

The wave-length of light is smaller, lengths are shortened:

$$\lambda = \frac{c}{\nu} = \frac{\frac{c_0}{k^2}}{\frac{\nu_0}{k}} = \frac{\lambda_0}{k} \tag{8}$$

The Planck quantum of action h being unaffected by the gravitational field is an assumption. Dehnen, Hönl and Westpfahl present a plausible rationale in [5]. Dicke's argument is, that the angular momentum h for a circular polarized photon would not be preserved [2]. From the constancy of Planck's constant we conclude the energy dependency, which therefore, varies like a frequency:

$$E = \frac{h\nu_0}{k} = \frac{E_0}{k} \tag{9}$$

This relation is valid not only for photons, but also for matter. If a piece of matter is being moved slowly downwards in the field of gravity, its rest energy is being decreased by detracting gravitational binding energy. This happens in concordance with Special Relativity Theory, whose validity is assumed without restriction.

According to $E = mc^2$, the inertia of matter is increased threefold by this factor:

$$m = \frac{E}{c^2} = \frac{\frac{E_0}{k}}{\frac{c_0^2}{k^4}} = m_0 k^3 \tag{10}$$

Planck's constant has the unit J s. If the modification of all times, lengths and masses according to above relations is assumed, all variabilities cancel each other. The prior accepted assumption of the constancy of h, thus, turns out to be consistent.

$$[h] = \mathrm{J\,s} = \frac{\mathrm{kg\,m^2}}{\mathrm{s}} \tag{11}$$

These relations are valid in strong gravitational fields as well by definition. Additional relations can be stated by consideration of the units. The fine structure constant α is constant in any case, because all units and, hence, all values changing in the gravitational field cancel each other.

$$\alpha = \frac{e^2}{4\pi\varepsilon\hbar c} = \mathrm{const} \tag{12}$$

Einstein's gravitational constant is independent of a variable polarizability, too, because the variabilities cancel each other.

$$\kappa = \frac{8\pi G}{c^4} = \mathrm{const} \quad \text{due to} \quad [\kappa] = \frac{\mathrm{s^2}}{\mathrm{m\,kg}} \tag{13}$$

Newton's gravitational constant, however, is decreased in the gravitational potential:

$$G = \frac{G_0}{k^8} \quad \text{due to} \quad [G] = \frac{\mathrm{m^3}}{\mathrm{kg\,s^2}} \tag{14}$$

An acceleration g is decreased, because it is composed of lengths and times, whose modification we already know. Gravitational forces F_g stay constant, because the decrease of acceleration is nullified by the increase of inertia:

$$g = \frac{g_0}{k^3} \quad \text{due to} \quad [g] = \frac{\mathrm{m}}{\mathrm{s}^2} \tag{15}$$

$$F_g = mg = m_0 g_0 = \text{const} \tag{16}$$

Looking at the electric and magnetic field quantities, the unit Ampere comes into the game:

$$[\varepsilon] = \frac{\mathrm{A\,s}}{\mathrm{V\,m}} = \frac{\mathrm{A^2\,s^4}}{\mathrm{kg\,m^3}} \quad \text{and} \quad [\mu] = \frac{\mathrm{N}}{\mathrm{A^2}} = \frac{\mathrm{kg\,m}}{\mathrm{A^2\,s^2}} \tag{17}$$

Assuming, that the elementary electric charge is a preserved value in the gravitational field, currents transform inverted to times:

$$I = \frac{I_0}{k}, \quad \text{then} \quad e = \text{const} \quad \text{due to} \quad [e] = \mathrm{A\,s} \tag{18}$$

Then and only then the field quantities of vacuum vary in equal fashion:

$$\varepsilon = k^2 \varepsilon_0 = n\varepsilon_0 \quad \text{and} \quad \mu = k^2 \mu_0 = n\mu_0 \tag{19}$$

Ampere is canceled anyway in the relation of the velocity of light, though. The constancy of electrical charge in the gravitational field is no unavoidable choice, therefore, and leaves the door open to the possibility of alternative descriptions.

$$c = \frac{1}{\sqrt{\varepsilon\mu}} = \frac{c_0}{n} \tag{20}$$

The electrical force F_e between two elementary charges separated by a distance d does not show any variability as well, although the physical mechanism is different:

$$F_e = \frac{e^2}{4\pi\varepsilon d^2} = \frac{e^2}{4\pi\varepsilon_0 k^2 \frac{{d_0}^2}{k^2}} = \text{const} \tag{21}$$

A number of elementary physical lengths are compounded out of universal constants and scale according to these rules just as lengths with $\frac{1}{k}$.

$$\text{The Bohr Radius} \quad a_0 = \frac{4\pi\varepsilon_0 \hbar^2}{m_e e^2} \tag{22}$$

$$\text{The Compton wave-length} \quad \lambda_C = \frac{h}{mc} \tag{23}$$

$$\text{The classical electron radius} \quad r_e = \frac{e^2}{4\pi\varepsilon_0 m_e c^2} \tag{24}$$

Moreover, e. g. in a Lennard-Jones potential, the energy minimum is shifted following the same relation. Thus, there are good reasons to assume, that all atom- and molecule distances and, therefore, any material length scale is modified in equal manner just as a length scale in form of a laser.

As mentioned above, these relations present themselves in this way to an observer at the reference location, if the refractive index does not change for the investigated object. If movements in a gravitational field are analyzed or if there are temporal changes, then additional considerations have to be made.

4 Equivalence Principle

How does the situation look like to a local experimenter? This is a measurement related to the local place as its point of reference. Such a measurement is a comparison of a measurement value to a local scale, which, however, underlies the variabilities of the gravitational field as well. At all times $n_{\text{local}} = k_{\text{local}} = 1$ for a local observer.

An experiment to determine Newton's gravitational constant G would end up for instance, as follows: at first, an experimenter measures the mutual attractive force of two test masses M and m separated by the distance d at reference potential with $n = 1$ by means of a Cavendish balance.

$$G_0 = \frac{F_{g\,0}\, {d_0}^2}{m_0\, M_0} \tag{25}$$

He obtains the standard value for G. Now he transfers the experiment to a place with deeper gravitational potential nearer to the sun.

An observer, who remained at the reference point evaluates the execution of the second experiment. He gets the result, that the experimenter measures the same force, but the inertia of the test masses has increased. In exchange, though, the distance of the test masses is less than that at the reference experiment. From his point of view, G changes to:

$$G = \frac{F_{g\,0} \frac{{d_0}^2}{k^2}}{m_0 k^3 M_0 k^3} = \frac{G_0}{k^8} \tag{26}$$

From the view of the local experimenter, however, the measurement value did not change. The Cavendish-balance stayed the same. The test masses are unchanged from his point of view and all dimensions of the balance are the same in relation to the local measurement equipment as they were at the reference experiment, although they have shortened in the prospect of the reference observer. The force also did not change its value. For the local experimenter, the value of G also stayed unchanged.

$$G_{\text{local}} = G_0 \tag{27}$$

These considerations, though, only prevail, because all included values here underlie the same variation of the refractive index n. If the sun is taken as test mass M and we investigate the effects of a spatial variation of n within the solar system onto a test mass m, the mass of the sun M stays at its location, the index of refraction n, however, changes for m in case of its displacement, but not for M. Later more to that issue.

Another interesting question is the ratio of electrical force to gravitational force in a changed gravitational potential.

If we look at the electrical force $F_e = \frac{e^2}{4\pi\varepsilon d^2}$ and the gravitational force $F_g = \frac{Gm_pm_e}{d^2}$ between a proton and an electron, then their ratio is independent of the distance and also of the refractive index. Therefore, it does not change its value.

$$\frac{F_e}{F_g} = \frac{e^2}{4\pi\varepsilon G m_p m_e} = \frac{e^2}{4\pi\varepsilon_0 n G k^{-8} m_{p0} k^3 m_{e0} k^3} = \frac{e^2}{4\pi\varepsilon_0 G_0 m_{p0} m_{e0}} = 2.3 \times 10^{39} \qquad (28)$$

Because of that, it is not possible to draw any conclusion towards the gravitational potential out of a precision measurement of this ratio.

In general, it has to be stated that there are no absolute values in the theory of variable speed of light. Distances, velocities and frequencies can only be defined in relation to a reference and have validity only as comparison values. The index of refraction n is only of relative relevance, too. It only expresses the difference of the velocity of light for different locations. The space looks locally identical for each observer. That is nothing else than the Equivalence Principle of General Relativity Theory.

When we considered the units, we have transferred the found relations for mass, frequency and length to other quantities compounded of these units like acceleration and force. In order to get a well-defined framework, it must be assumed, however, that the Heavy Mass is transformed in the same manner as the Inertial Mass. Otherwise, the gravitational force would be distinguishable from the inertial force. Hence, the Equivalence principle is an implicit request of the theory.

In particular, the value of the constants of nature does not change for the local observer, if the gravitational potential varies. Some theories like the "Large Number Hypothesis" of Paul Dirac [10] demand such a temporal variation of Newton's gravitational constant. Examinations up to now, however, rather do not indicate a measurable change – for the local observer.

The Equivalence Principle is a basic assumption of General Relativity Theory, too, but its assumption does not determine the form of the field equations unambiguously. Einstein decided, that beyond this, the Covariance Principle shall be valid [11]. While the equivalence principle is a strong argument supported by evidence, the covariance principle merely is an argument of mathematical beauty and does not arise from a physical necessity. In the author's opinion, this degree of freedom can be used in a better way, namely the unification of gravity and quantum physics. In the approach outlined here, therefore, the basic assumption, that gravitation is an electromagnetic phenomenon, takes the place of the covariance principle.

A fundamental question is the shape of the law of gravitation. We silently assumed, that Newton's law with a $1/r^2$-dependency is valid in first approximation. The presented dependencies of physical quantities, however, do not deliver a foundation for this. In the contrary, in the definition of the units of Newton's gravitational constant G, the assumption of the validity of the law is already implicated.

There exists, however, a more general justification of Newton's law, which is based on universal properties of fields. For that, we only assume the vacuum – outside of matter as source of gravitation – being divergence free and curl-free. Without knowing anything about the physical mechanism, how electromagnetic fields act on vacuum, so that the index of refraction n changes appropriately to reproduce Newton's law, only from zero divergence and zero curl follows in a euclidean space, that the gravitational force decreases inversely to the square of the distance r to a point-like mass. In general, the field intensity is $\propto 1/r^{dim-1}$. dim is the number of space dimensions. Furthermore, energy conservation, which we rely on throughout, corresponds to a divergence free and curl-free field.

Newton's law of gravitation loses its exact validity, because different observers do not agree upon the measurement of distance and time.

5 Homogeneous Gravitational Potential

We have examined a continuously accelerated laboratory in free space for weak fields. This situation is equivalent to a homogeneous gravitational potential with constant spatial gravity acceleration g, that can be described with $\phi = gh$. Here, h is the height difference in the homogeneous potential. We do not restrict ourselves on weak fields any more, however, and we follow Dehnen, Hönl and Westpfahl how to extend the results on strong fields [5]. We start with equation (1).

$$\frac{\nu}{\nu_0} = 1 - \frac{gh}{c^2} = 1 - \frac{\phi}{c^2} \tag{29}$$

That means an observer at the location $h = 0$ observes a light beam propagating from him to position h. The frequency there is red-shifted for the receiver, if h is positive. As long as $gh \ll c^2$, ν_0 can be regarded as constant. If we look at the situation more closely, we must incorporate, though, that the change of the frequency actually is related to the local frequency ν, which will vary with the propagation of the light beam noticeably against the starting frequency ν_0 at some point. Then, the frequency change does not simply add up linearly, but obeys an exponential law.

$$\frac{\mathrm{d}\nu}{\nu} = -\frac{g\mathrm{d}h}{c^2} = -\frac{\mathrm{d}\phi}{c^2} = -\frac{\mathrm{d}k}{k} \tag{30}$$

$$\int_{\nu_0}^{\nu} \frac{d\nu}{\nu} = -\int_{0}^{h} \frac{g}{c^2} \mathrm{d}h = -\int_{1}^{k} \frac{\mathrm{d}k}{k} \tag{31}$$

$$\ln \nu - \ln \nu_0 = -\frac{gh}{c^2} = -\ln k \tag{32}$$

$$\frac{\nu}{\nu_0} = e^{-\frac{gh}{c^2}} = e^{-\frac{\Phi}{c^2}} = \frac{1}{k} \tag{33}$$

$$k = e^{\frac{gh}{c^2}} = e^{\frac{\Phi}{c^2}} \tag{34}$$

So far Dehnen, Hönl and Westpfahl. The red-shift factor k and, thus, the index of refraction n are equal to one at $\nu = \nu_0$ by definition.

At this point now we must be very careful. We have seen, that almost all values that we were so sure about, all of a sudden seem to be uncertain. They depend on the index of refraction k and we cannot simply use the reference values any more. At the starting point, we can use the reference values g_0, dh_0, c_0^2 for g, dh and c^2. Here is $k = 1$ by definition. But when ν and with it also the index of refraction k has noticeably changed, the observer at the reference point must use indeed the values of the location of the measurement related to the reference point $\frac{g_0}{k^3}$, $\frac{dh_0}{k}$, $\frac{c_0^2}{k^4}$. The acceleration etc. at the location of the measurement indeed is not g_0 any more from the view of the reference observer. The local observer, in contrast, still measures g_0.

$$\frac{g}{c^2}\,\mathrm{d}h = \frac{g_0\,k^{-3}}{c_0{}^2\,k^{-4}}\,\mathrm{d}h_0\,k^{-1} = \frac{g_0}{c_0{}^2}\,\mathrm{d}h_0 \tag{35}$$

As we can see, the variations by the variable index of refraction k cancel each other and the starting values preserve their validity. Hence, a measurement related to the location itself is allowed to calculate with the same values, too. This is, though, not at all self-evident and as we will see, the exact assignment of the reference values is of significant importance. Here it is successful, because all measurement values are related to the same location. And because the exponent does represent a unit-less quantity, all units cancel each other, their correction factors k included.

Additionally, a conceptual difficulty becomes evident here, namely the definition of distance. As already mentioned a flat space is assumed. The reference observer places a coordinate system across the three-dimensional space without regarding the spatial variation of the index of refraction. His location and distance indication is always related to this coordinate system related to the reference. The boundary of integration of equation (31) is still h, because it represents the location coordinate of the reference observer. The distance to location h can be defined in a different way by local scales stringed together as well. This distance does not agree, though, to the coordinate distance in the reference system.

This form of the index of refraction has been discussed in the literature several times already. Robert Dicke obtains this form from different reasons in his second paper to that subject [4], Huseyin Yilmaz [12] and Kris Krogh [13] as well. Even Einstein indicated this form of red-shift in a work of 1907 [14] (on page 457 of the original publication), with the hint, that otherwise the zero point of the potential would be exceptional.

6 Central Potential

Now we investigate the field of a point-like mass M instead of a homogeneous potential.

$$\phi = -\frac{GM}{r} \tag{36}$$

Thus, we get for the redshift at $r = r_0$:

$$\frac{d\nu}{\nu} = \frac{d\phi}{c^2} = \frac{GM}{r_0^2 c^2} dr = -\frac{dk}{k}, \tag{37}$$

with the gravity acceleration $g = \frac{GM}{r^2}$ at $r = r_0$. Now we let vary r_0 with r in an analogous manner:

$$\int_{\nu_0}^{\nu} \frac{d\nu}{\nu} = \int_{r_0}^{r} \frac{GM}{r^2 c^2} dr = -\int_{1}^{k} \frac{1}{k} dk \tag{38}$$

$$\ln \nu - \ln \nu_0 = -\frac{GM}{c^2}\left(\frac{1}{r} - \frac{1}{r_0}\right) = -\ln k \tag{39}$$

$$\frac{\nu}{\nu_0} = e^{-\frac{GM}{c^2}\left(\frac{1}{r} - \frac{1}{r_0}\right)} = \frac{1}{k} \tag{40}$$

And with that, the index of refraction is

$$k = e^{\frac{GM}{c^2}\left(\frac{1}{r} - \frac{1}{r_0}\right)} \tag{41}$$

This form of the index of refraction agrees now also in second order, and, therefore, the perihelion shift of mercury is described correctly, see [5] or [8].

Newton's law of gravitation now arises as approximation, if the force is developed as energy gradient:

$$F = \frac{dE}{dr} = \frac{d}{dr}\frac{E_0}{k} = E_0 \frac{d}{dr} e^{-\frac{GM}{c^2}\left(\frac{1}{r} - \frac{1}{r_0}\right)} \tag{42}$$

We develop the e-function up to the first order in $\frac{1}{r}$ and and replace E_0 by mc^2. Then, for the energy gradient the result is Newton's gravitational force on a mass m:

$$F = mc^2 \frac{d}{dr}\left[1 - \frac{GM}{c^2}\left(\frac{1}{r} - \frac{1}{r_0}\right) + ...\right] \approx m\frac{GM}{r^2} \tag{43}$$

However, there is a complication at the central potential. As in the case of the homogeneous potential, also here we must take care of the fact, that the involved values themselves vary in the gravitational potential. This problem is not treated in literature, yet.

We have to correct the values at the location $\vec{r}$ by the local refractive index k, because we examine the problem from the view of the reference observer. If we execute this as we have done at the homogeneous potential and replace the values by their modified ones, $G = G_0 k^{-8}$, $M = M_0 k^3$, $c = c_0 k^{-2}$ and $r = r_0 k^{-1}$, then all correction terms by k would again cancel themselves. But: For the central mass M this procedure is not correct and, therefore, the attainment of the solution of equation (41) in this form is definitely wrong!

The key point is, that the central mass M remains at a location with constant k, whereas the other involved quantities at the place $\vec{r}$ are subjected to a modification of k along the path of integration.

The solution can be found by looking at the energy. The actual cause of gravity, according the Special Relativity, is energy and not mass. In fact, energy in any form, which in the case of matter is its rest energy or kinetic energy. Mass is no quantum property but an energetic state. Even thermal energy contributes to gravity. Applying $E = mc^2$, mass can be converted into energy 1:1, but in the view of variable speed of light, the conversion factor c^2 is not constant any longer. So we will compare the rest energy of the central mass $E_M = Mc^2$ with the rest energy of the test mass $E_m = mc^2$ and not the inertia M or m, respectively. For that, the test mass m is moved slowly within the gravitational field, that means, without consideration of kinetic energy. Slowly shall mean, that the released or to be expended potential energy is absorbed or spent by an elevator transporting the test mass m. The test mass is quasi at rest all the time. Its rest energy is reduced by this quantity, if it is moved in the gravitational potential nearer to the central mass M.

The reference observer on his fixed potential notices a variation of the rest energy of the test mass $E_m = \frac{E_{m0}}{k}$ as shown in equation (9), whereas, E_M stays constant. **Because the energy is the essential factor for the gravitational effect, the gravity effect of the central mass *M* consequently seems to increase by a factor *k* in relation to the test mass *m*, independent from the location of the observer.**

Expressed in an equivalent way, we must take the speed of light c at the location of the test mass m when converting M_0 into M: $M = \frac{E_M}{c_0{}^2/k^4} = M_0 k^4$. Then $M = M_0 k^4$ is changing in relation to $m = m_0 k^3$ by the factor k.

Therefore, the obtained solution of k in the form of equation (41) is lost for the moment.

7 Mach's Principle

For further examination, we first must relieve ourselves from a geocentric trap, which confines the view unnecessarily and obstructs the sight onto the big picture.

In the general literature it is assumed throughout at this place, that the zero point of the potential is at $r = \infty$. In accordance to that, in General Relativity Theory, a flat space is postulated as solution at $r = \infty$. This determination is seemingly plausible, because one looks for a solution, which transitions into the weak field solution for weak gravitational fields. That solution is believed to be found with $\phi = 0$ for $r = \infty$.

The model, which the Schwarzschild equation is based on, treats the universe as point mass M in an otherwise matter-free space. But this does not agree with reality. If one only looks at the potential of our sun, its influence vanishes in greater distance indeed. However, we are also located in the potential of our galaxy. If we go even further into the intergalactic space, there still acts the much deeper potential of the average matter density of the universe.

The gravitational potential outside the solar system obviously is not zero at all like it is included in the model of the Schwarzschild equation. Moreover, it is assumed silently, that the rest of the matter in space has no relevant influence on the relationship between masses. This is a perspective that has to be questioned in terms of Ernst Mach.

In any case, it becomes obvious, that the interstellar or the gravitational potential on earth, respectively, is not extraordinary at all. It is only an arbitrary, geocentric point of reference, that wrongly is attributed a special physical meaning to by assigning curvature zero at large distance from the sun.

If we take our basic intention seriously, namely that the refractive index of vacuum is able to describe the effect of gravitation correctly, then the cause of gravitation lies in the mutual electromagnetic interaction of matter. There is no direct electrical attraction or repulsion of stars or galaxies, because ordinary matter consists of charged particles throughout, in fact protons, neutrons – which is included here due to its inner structure – and electrons, but mostly it has balanced charge. Nonetheless, all charged particles are in steady exchange with other charged particles in the universe as far as light reaches. This sea of virtual photons can be regarded as the reason of the polarizability of vacuum and, hence, also as the cause of the finiteness of the speed of light. Thus, the perception seems to be likely, that in a universe that does not contain any matter at all, vacuum would not be polarizable and, therefore, the velocity of light would be infinite.

How, then, would the speed of light behave at a place, where the gravitational potential vanishes? That would be a location separated by infinite distance from any matter. We imagine the real universe in a simple model as a sphere equally filled with matter. It has a radius R_u and total mass M_u and, we are located at its center. For any distant observer, the universe looks the same, too, only the center point of the universe is shifted from his perspective. The gravitational potential is equally deep at any location within this homogeneous universe. To be able to reach a place with vanishing potential, we conceptually contract the entire mass of the universe M_u in one single point. So we stay at the world model of a central mass and an otherwise matter-free space. The Newtonian potential is $\phi = -\frac{GM_u}{r}$. If we depart from the center, the absolute value of the potential becomes smaller and vanishes at infinite distance. At first, we search for the distance r_u from the central mass, which exhibits equal gravitational potential as the center point of the homogeneous sphere.

The infinitesimal mass element of a sphere $\mathrm{d}m = \varrho\,\mathrm{d}V_u$ with constant density ϱ and volume element $\mathrm{d}V_u$ from the center of a sphere generates the potential

$$\mathrm{d}\phi = -\frac{G\,\mathrm{d}m}{r} = -\frac{G\varrho\,\mathrm{d}V_u}{r}. \tag{44}$$

The potential in the center of a sphere is the superposition of all potentials, thus, we integrate across the volume of the sphere V_u:

$$\phi_u = \int\limits_{V_u} -\frac{G\varrho}{r}\mathrm{d}V_u = -G\varrho \int\limits_{\phi=0}^{2\pi}\int\limits_{\theta=0}^{\pi}\int\limits_{r=0}^{R_u} \frac{1}{r}\, r^2\mathrm{d}r\ \sin\theta\,\mathrm{d}\theta\,\mathrm{d}\phi = -2\pi G\varrho {R_u}^2 \tag{45}$$

The density ϱ also can be expressed with the total mass M_u.

$$\varrho = \frac{M_u}{V_u} = \frac{M_u}{\frac{4}{3}\pi {R_u}^3} \tag{46}$$

The potential ϕ_u in the mid point of a homogeneous sphere of mass M_u with radius R_u has the same absolute value as the potential in the distance r_u from a point mass M_u with $r_u = \frac{2}{3}R_u$.

$$\phi_u = \frac{GM_u}{\frac{2}{3}R_u} = \frac{GM_u}{r_u} \tag{47}$$

At the distance r_u, we position our reference point, the index of refraction becomes 1 here. Our boundary condition now requests, that the speed of light goes to infinity in infinite distance of the mass center, such as the potential vanishes and no interaction of matter takes place. That represents the highest possible gravitational potential and, thus, an absolute point of zero.

Our previous solution for the index of refraction in form of equation (41), applied to this model of the universe

$$k = e^{\frac{GM_u}{c^2}\left(\frac{1}{r}-\frac{1}{r_u}\right)} \tag{48}$$

obviously does not cope with this postulate. If we set $r = \infty$, then k stays finite in any case.

But the solution of the weak field of equation (5) can also be interpreted in another way: **The index of refraction k describes the action of a mass M onto the vacuum in relation to the action of the entire mass of the universe onto the vacuum.** This is done in the same manner as we treated the red-shift as relative change against the frequency ν itself. R. Dicke has indicated this on page 3 of his paper from 1957 ([2]), but he did not develop this further.

Let us look again at equation (30):

$$\frac{\mathrm{d}\nu}{\nu} = \frac{\mathrm{d}\phi}{c^2} \tag{49}$$

Now we apply the new interpretation and replace the (fixed) value ${c_0}^2$ with the total potential of all masses in the universe:

$$\frac{\mathrm{d}\nu}{\nu} = \frac{\mathrm{d}\phi}{-\phi_{\mathrm{abs}}} \tag{50}$$

The negative sign in front of ϕ_{abs} comes from setting the zero point of the potential at the reference point. Actually, it should be located at the absolute zero point of the potential, but we stay with the convention that the zero point of the potential of a point-like mass is at $r = \infty$.

The notion c^2 and the potential of the universe being essentially the same is not new. What is new here is that we introduced additionally to implement the obtained insight, how quantities have to be treated at modified refractive index.

This is at the same time the simplest possibility to relate the index of refraction to the potential. It straightforwardly equates the relative variations of red-shift, wavelength, potential and refractive index. This constitutes astonishingly the key to the solution of a number of other problems. The in principle free choice of the zero point of the potential turns out to be an approximation in this respect, at which the variation of the potential is small against its absolute potential.

What we have applied to the frequency ν in case of the homogeneous potential, we extend here to the potential of a point-like mass. In equation (30) we have put the change of the frequency $\mathrm{d}\nu$ in relation to the frequency ν, and we modified ν during the integration and we did not relate it only to the starting frequency ν_0. Now, we do the same for the potential: First, we interpret the denominator of the fraction $\mathrm{d}\phi/{c_0}^2$ as the potential of the universe $-\phi_u$. Second, when integrating, we relate the potential change ϕ not only to the starting point ${c_0}^2 = \phi_u$ any more, but to the whole potential of the particular place $\phi_{\mathrm{abs}} = \phi_u + \phi$, thus, the constant background potential of the universe plus the potential change ϕ generated by the mass M.

Now again we start with the red-shift for the point-like universe.

$$\frac{\mathrm{d}\nu}{\nu} = \frac{\mathrm{d}\phi}{-\phi} = -\frac{\mathrm{d}k}{k} \tag{51}$$

Because M_u is the only mass in the thought universe, the potential variation in relation to the total potential of the universe looks like this:

$$\frac{\mathrm{d}\phi}{-\phi} = -\frac{\frac{GM_u}{r^2}\mathrm{d}r}{\frac{GM_u}{r}} = \frac{\mathrm{d}r}{r} \tag{52}$$

Only the ratio of radius change to radius does remain and it turns out to be a very simple solution for the point-like universe.

$$\int_{\nu_0}^{\nu} \frac{\mathrm{d}\nu}{\nu} = \int_{\phi_u}^{\phi} \frac{\mathrm{d}\phi}{-\phi} = \int_{r_u}^{r} \frac{\mathrm{d}r}{r} = -\int_{1}^{k} \frac{1}{k}\mathrm{d}k \tag{53}$$

$$\frac{\nu}{\nu_0} = \frac{\phi_u}{\phi} = \frac{r}{r_u} = \frac{1}{k} \tag{54}$$

The correction of the quantities with the refractive index k drops out. If we let the radius go to infinity, the potential vanishes and with it the index of refraction k as well. This means that the speed of light diverges. Hence, all frequencies and length scales become infinite as well. At infinite distance, thus, space and time is not definable at all.

The approach pursued here perfectly meets the conception of Ernst Mach. It can be regarded as a consistent numerical representation of Mach's principle. Mach criticized the idea of an absolute space as Newton had it in mind. It was unthinkable for Mach, that a space would be definable at all in a matter-free universe. Only through the presence of reference objects this would be possible. And the interaction between matter would be influenced by the presence of all other masses [15].

In General Relativity Theory, however, the (small) dependency of inertia of the gravitational field sometimes is mentioned as implementation of Mach's principle, but it does not deserve to be denoted as realization of it, because it misses Mach's central statement.

Two important consequences result from our assumptions. The first concerns the numerical value of the speed of light and the gravitational constant, respectively. We identify c^2 (here strictly speaking ${c_0}^2$) with the absolute potential of the universe ϕ_u. In 1925, Erwin Schrödinger was the first to mention the numerical agreement of $c^2 \approx \frac{GM_u}{R_u}$ [16] and he suspected a deeper connection. Before that time, one was by far not conscious of the true dimensions of the universe anyway.

Because all quantities in equation (47) are determined independently, the gravitational constant G can be constituted dependently and can be understood as conditional equation of G.

$$G \approx \frac{R_u c^2}{M_u} \tag{55}$$

Nevertheless, we cannot expect an exact relation, because the model of a sphere is rather a support for a conception than a realistic model of the universe.

If we identify c^2 with the potential of the universe, we are able to contextualize Einstein's most famous equation $E = mc^2$, which virtually has a monolithic character:

$$E = -m\phi_u = mc^2 \tag{56}$$

The rest energy of a body is equivalent to its potential energy in the absolute potential of the universe. And so, Newton's gravitational potential energy is connected with the velocity of light.

8 Central Potential II

The second consequence will restore us the correct dependency of the refractive index, which we lost above. Again, we start with the red-shift. This time we relate the potential variation $\Delta\phi$ not only to the potential of the starting point ϕ_u or ${c_0}^2$, respectively, but to the total absolute potential $\phi_{\text{abs}} = \phi_u + \Delta\phi$ at the location we are looking at. ϕ_u represents the constant background potential of the universe. If the potential increases, then also the frequency increases.

$$\frac{\mathrm{d}\nu}{\nu} = \frac{\mathrm{d}\phi}{-\phi} = -\frac{\mathrm{d}k}{k} \tag{57}$$

In this model, mass is split into two parts: The constant background potential of the universe ϕ_u and the central mass M, whose potential $\Delta\phi$ is added to the back ground potential ϕ_u. We start at the reference point $r = \infty$, thus, $\phi = \phi_u$,

$$\int\limits_{\phi_u}^{\phi_u+\Delta\phi} \frac{\mathrm{d}\phi}{\phi} = \int\limits_{1}^{k} \frac{\mathrm{d}k}{k} \tag{58}$$

$$\ln\frac{\phi_u + \Delta\phi}{\phi_u} = \ln k \tag{59}$$

$$\phi_{\text{abs}} = \phi_u + \Delta\phi = \phi_u k \tag{60}$$

Therefore, we can represent a variation of the absolute potential by a multiplication with the refractive index k.

Now we start again with equation (37), but we equate c^2 with the variable absolute potential $\phi_u k$, represent M as energy $\frac{E_M}{c^2}$ and perform the usual corrections of all quantities with the refractive index:

$$\frac{\mathrm{d}\nu}{\nu} = \frac{\mathrm{d}\phi}{-\phi_{\text{abs}}} = \frac{GM}{r^2\phi_u k}\mathrm{d}r = \frac{G\frac{E_M}{c^2}}{r^2c^2k}\mathrm{d}r = \frac{G_0k^{-8}\frac{E_M}{{c_0}^2}k^4}{{r_0}^2k^{-2}{c_0}^2k^{-4}k}\frac{\mathrm{d}r}{k} = \frac{G_0M_0}{{r_0}^2{c_0}^2}\mathrm{d}r_0 \tag{61}$$

Now, the correction of mass M and that of the potential of the universe ϕ_u cancel each other. We integrate from r_0 to r again and receive the original result of equation (41), where we can now take the reference values at all places:

$$k = e^{\frac{G_0 M_0}{c_0{}^2}\left(\frac{1}{r}-\frac{1}{r_0}\right)} \tag{62}$$

The result is valid for the potential of a point-like mass M in free space with the constant background potential ϕ_u.

In a notation equivalent to the isotropic Schwarzschild metric the line element can be expressed as:

$$\mathrm{d}s^2 = \frac{1}{n}c^2\mathrm{d}t^2 - n\,\mathrm{d}\vec{r}^2 = e^{-\frac{2GM}{c^2}\left(\frac{1}{r}-\frac{1}{r_0}\right)}c^2\mathrm{d}t^2 - e^{\frac{2GM}{c^2}\left(\frac{1}{r}-\frac{1}{r_0}\right)}\mathrm{d}\vec{r}^2, \tag{63}$$

which agrees in first approximation with the Schwarzschild solution for $r_0 = \infty$, see [8]. But, whereas the Schwarzschild solution exhibits a divergence at a finite distance from the mass center, which leads to the so called event horizon, there is a point of infinity in the refractive index within the solution of the variable speed of light only at $r = 0$, which is physically no problem, though. Therefore, no "black hole" occurs. An infinite index of refraction n corresponds to a vanishing speed of light. Translated into the Schwarzschild solution this would mean, that the speed of light would be zero at the event horizon and farther inside even "negative". A negative speed of light does not make sense in the picture of a variable speed of light.

9 Conclusion

A consistent model of gravitation was developed solely based on the assumption, that gravitation can be described as an electromagnetic phenomenon, under abandonment of the covariance principle. Mach's principle is not an artificial ingredient, but a natural consequence of the very general assumptions. The refractive index of vacuum as a scalar quantity has the central function to describe relative length and time differences within the framework of a flat space-time. Hereby, as a consequence, the velocity of light is not to be regarded as constant any more. The exponential law of the refractive index, which was introduced in the literature several times already, can be deduced by giving careful attention to the view points of different observers. The speed of light is interpreted as the potential of the universe, which all potential differences are related to. The theory of variable speed of light abandons the assumption of General Theory of Relativity being irrevocably correct and offers an alternative description of gravitation. Clear differences between both theories emerge in strong gravitational fields. The models of the physical structure of the universe differ as a consequence significantly, as well. This will be the topic of future work.

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