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On the Law of Universal Gravitation and the Quantum Essence of Gravity: Phenomenology

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Abstract

On the phenomenological level, using the concepts of electromagnetic component of the physical vacuum (the EM vacuum) as the basic medium for the expanding Universe, being an open system, into which there is constantly pumped the energy-mass from the sources of Planck power, and also with the introduction of a modified Weinberg relation establishing certain connections between the world constants, there has been revealed a decisive role of the EM vacuum in all the processes of micro- and macro-world. It has been established that gravity is a consequence of the Casimir polarization of electromagnetic component of the physical vacuum, which is the formation of specific values of the energy density of the EM vacuum in the vicinity of each material object (elementary particle, macroscopic body). In this case, the expression for the potential energy of interaction between two arbitrary masses takes the form of "Newton's law of universal gravitation", if, instead of the reduced mass of two interacting material objects, we introduce a mass which is universal for any pair of particles or material bodies, defining this mass as the "Mach mass". The resulted expression for the gravitational constant G in Newton's law can be regarded as a phenomenological representation of Mach's idea on the interrelation between each of the interacting masses with all masses in the Universe; all the more so as the Mach mass coincides with the known Planck mass. The possibility of experimental verification of the developed concepts based on the known experiments by L. Rancourt's group on the detection of "attraction of mass by the light flux" is discussed.

Keywords: Law of universal gravitation; the world's fundamental constants; Casimir polarization of the electromagnetic component of the physical vacuum; the Mach mass; the Planck numbers

1. Introduction

In 1964, in the lectures at Cornell University on the nature of fundamental interactions, R. Feynman emphasized that "… up to today, from the time of Newton, no one has invented another theoretical description of the mathematical machinery behind this law which does not either say the same thing over again, or make the mathematics harder, or predict some wrong phenomena. So there is no model of the theory of gravitation today, other than the mathematical form" [1]. And it was said despite the fact that Einstein's theory of gravity, the general relativity (GR) theory, has already demonstrated its ability to understand the Universe. The first predicted and experimentally verified corollaries of the general relativity theory were three effects: an additional shift of the perihelion of Mercury's orbit compared with the predictions of Newtonian mechanics; the deviation of the light beam in the gravitational field of the Sun; the gravitational redshift, or the slowing of time in the gravitational field [2]. According to general relativity, the bodies are attracted not because they are affected by gravity as a certain force, but because the masses that are in the space form a curved space-time, and the particles move along geodesic lines, the world lines of physical bodies, providing the shortest, the "fastest paths". However, the internal mechanism of the gravitational interaction, the root causes of the formation of these geometrically curved paths, and especially the reasons for the smallness of the gravitational forces, which are almost 40 orders of magnitude weaker than electromagnetic interactions, remain unknown. It should be noted here that during the creation of GTR (1921), Einstein, recognizing the limitations of the available information to resolve this type of problem, wrote: "We have seen, indeed, that in a more complete analysis the energy tensor can be regarded only as a provisional means of representing matter. In reality, matter consists of electrically charged particles, and is to be regarded itself as a part, in fact, the principal part, of the electromagnetic field. It is only the circumstance that we have not sufficient knowledge of the electromagnetic field of concentrated charges that compels us, provisionally, to leave undetermined in presenting the theory, the true form of this tensor" [2].

The question concerning the intrinsic nature of the gravitational interaction, the establishment of its quantum nature and, thus, incorporating it into an integral system of fundamental interactions together with the nuclear strong, electromagnetic and weak nuclear interactions still remains open. As is known, the heuristic guideline for the realization of such a hope seems to be the set of the so-called Planck numbers, which were introduced by Max Planck in 1899 purely numerologically on the basis of the arguments of dimension. These are the parameters of length a_{Pl}, time t_{Pl} and mass m_{Pl}, which combine the basic world's constants $\hbar$, c and G: the Planck constant, light velocity in vacuum and gravitation constant, respectively [3]:

$$a_{Pl} = 2^{3/4}\sqrt{\frac{G\hbar}{c^3}} = 2^{1/2}\frac{\hbar}{m_{Pl}c} \approx 2.64\cdot 10^{-33} cm; \qquad t_{Pl} = \frac{a_{Pl}}{c} = 2^{3/4}\sqrt{\frac{G\hbar}{c^5}} \approx 0.88\cdot 10^{-43}\ s$$

$$m_{Pl} = 2^{-1/4}\sqrt{\frac{\hbar c}{G}} \approx 1.78\cdot 10^{-5}\ g \qquad (1)$$

(The choice of numerical factors in (1) is explained in [4, 5]). We should immediately indicate here that the values of the parameters of length a_{Pl} and time t_{Pl} are absolutely unattainable in any physical experiment both now and always. Neither is attainable on the accelerators the energy $E_{Pl} = m_{Pl}c^2$, defined by the Planck mass, although there is nothing mysterious in the value of the mass m_{Pl} itself. To give to the entire set of the Planck numbers an outward unity of "unattainability" in experiments, it is natural to consider the Planck power w_{Pl} instead of the parameter m_{Pl}, which is represented, taking into account the numerical coefficient, in the form [4]:

$$w_{Pl} = \frac{m_{Pl}c^2}{t_{Pl}} = \frac{c^5}{2G} \approx 1.8\cdot 10^{59}\ erg/\mathrm{s}. \qquad (2)$$

The first attempts of implementing the $\hbar Gc$-plan, which presupposes achieving the gnoseological unity of the quantum theory (with the constant $\hbar$), special relativity theory (with its constant c) and the theory of gravitation (with its constant G) were realized by M. Bronstein [6, 7] in 1935. Bronstein constructed a quantum theory of the weak gravitational field, in which the gravitational interaction between the material bodies was realized by means of "gravitational waves-quanta". Although, in the non-quantum limit, there follow from the Bronstein results the result of Einstein for gravitational radiation, as well as Newton's law of universal gravitation, it was obvious that this was only a first step, since there arose and still arise the problems of correlation of the obtained results with the Planck parameters, with associating the results to some experiments.

And even now, decades later, the problems of creation of a general theory of quantum gravity as a science, connecting together quantum mechanics and general relativity (GR), as well as the problem of detection of the gravitational waves remain unsolved [7], although there are still hopes for the progress in these areas [8, 9].

In recent years, in connection with new discoveries in cosmology, with the discovery of new factors − the dark energy and dark matter [10-13] and their decisive role in the dynamics of the Universe – the issues of understanding the nature of the gravitational interaction and the law of universal gravitation should be rather associated with the establishing the essence of these Universe-forming factors. The overall dynamics of the Universe is usually presented in the form of isotropic models which consider the rate of change $\dot{a}$ with time t of the scale factor $a(t)$: the distances between two objects in the expanding Universe, depending on the values, averaged over all the galaxies and clusters, of the density of the energy and mass components of the Universe. In this case, the analyzed dynamics of the isotropic Universe can be determined simply from the law of conservation of energy E [14] (See also [4]). Note that in the representations of general relativity the total energy of the Universe $E = 0$.

In the standard model of the Universe [15-18], the basic factor that is responsible for the very possibility of existence of the Universe is the dark energy, which determines the cosmological term Λ in the equations of general relativity and plays the role of "antigravity":

$$\Lambda = \frac{8\pi G}{c^4}\varepsilon_V , \qquad (3)$$

Where ε_V is the dark energy density (the meaning of the subscript is connected with the attempts to link the nature of dark energy with the physical vacuum [15-18]). According to the present-day data [19], $\varepsilon_V \approx 0.66\cdot10^{-8}$ erg/cm^3. It is believed that the dark energy, which accounts for 73% of the total energy of the Universe, is uniformly "diffused" throughout the space. In addition, to the vacuum of the standard model there is ascribed the equation of state which is difficult to comprehend physically: $p_V/\varepsilon_V = -1$ with the negative pressure p_V. It is exactly due to the action of negative pressure in the expansion of the Universe that energy is not consumed but emitted, moreover, in the amount necessary for the "swelling" of the space. There is realized a kind of "free lunch" [20]: during each day the volume of the Universe increases by 10^{18} cubic light years.

The author believes that the theoretical models for describing the dynamics of the formation and subsequent expansion of the Universe should take into account the inevitable manifestation of irreversibility and dissipation in the dynamics of the Universe. If we assume, in accordance with the standard model of the dynamics of the Universe [15-18], that all energy-matter in the Universe was born almost instantaneously during the hot Big Bang, which was preceded by the stage of cold Inflation [21, 22], then to what extent the mysterious dark energy can reproduce itself to "fill" by itself the newly created volumes of the Universe to ensure constancy of the density ε_V, as well as to provide compensation for the dissipation losses? Such losses will inevitably occur not only due to friction in the mechanical movement of various objects, but also in any nuclear or chemical processes, including the processes, initiated by the EM vacuum (spontaneous emission of photons, the Lamb shift, contribution to radiative decay, etc.) [4, 5, 23]. At the same time, on each of the constantly occurring processes in the Universe there must be spent considerable energy, especially if we take into account their total number. It is also important to emphasize that the dissipated energy changes the quality of the total energy content of the Universe, leads to the shift of the energy distributions towards lower energies, and this process has been lasting for more than 13 billion years already. And how permanently can the hypothetical dark energy, generated during the expansion of the Universe, compensate this factor of the energy quality?

From the physics standpoint, it is also difficult to imagine another substance introduced in the standard model: the dark matter, the energy content of which is 23% and which is introduced into the equations of the Universe dynamics to eliminate the contradictions between the value of the observed mass of the gravitationally bound objects and their systems with their observed parameters, including the stability of the structure of galaxies and clusters of galaxies as the Universe expands. In this case, the share of the only understandable in its essence baryonic component (conventionally, it includes the energy contributions of electromagnetic radiation of all possible frequencies, as well as all types of neutrinos and antineutrinos) is just 4%. The acuteness of the problems of the standard model, besides the introduction of these physically obscure entities − dark energy and dark matter – has been intensified by the failed attempts to link the quantity ε_V, determined on the basis of (3) from the experimentally determined value of Λ, with the parameters of the physical vacuum, introduced in the physics of elementary particles (the differences can be [15-18] over a hundred orders of magnitude!). All this gives reason to assert that the modern cosmological science is in crisis. Moreover, one cannot but agree with the opinion that such a catastrophic discrepancy, such a gap of the orders of magnitude can be seen as "a stern test for the entire fundamental theory" [16].

Since the theoretical science is not yet able to answer the questions related to the establishing the essence of almost 96% of the energy content of the Universe, it becomes clear that the understanding of the whole complex of the indicated open problems, as well as the nature of gravity, should be searched for not on the road of creation of new theories, but on the level of phenomenology. Indeed, phenomenology (phenomenon – the manifesting; logos – the concept, doctrine) can become a starting point for "the elucidation of the reality exactly as it shows itself *before* the science turns to it with its questions" [24]. Phenomenology can be regarded as a general realistic methodology of cognizing the essence of this or that phenomenon, if we follow the basic maxim of Husserl: "Back to the things themselves!" without any attempt of premature systematization, to "the study "the things themselves", avoiding ... violence over the givenness" [25]. Moreover, the analysis of the experimentally obtained information should be based on a purely philosophical tradition with a priori use of transcendental images, such as a "thing in itself" (*das Ding an sich*) and "now", which are outside the direct experimental tests, but which reflect the basic essence of the studied phenomenon. As shown by the experience of developing the methodology of extracting information from complex signals [26], such a view of phenomenology and adherence to the indicated philosophical tradition allow not only focusing on achieving purely pragmatic goals in solving technical problems and believing that in the framework of phenomenology "the cognition of the laws of nature, to a great extent, is even redundant" [27], but also setting the goals of penetration into the physical essence of the phenomenon under investigation, establishing the basic postulates for the subsequent deduction during the formation of the corresponding theoretical models. It is this task − to establish the essence of gravity with the involvement of new knowledge provided by phenomenology – that is the goal of the present paper (see also [28]).

2. Electromagnetic Component of Physical Vacuum – The Em Vacuum as the Basic Environment for Gravity

Despite the limitations of theoretical science in connecting the dark energy with the physical vacuum, the electromagnetic component of the physical vacuum, the EM vacuum, is generally regarded as the basic medium for the formation of the gravitational interaction, the manifestation of the metric elasticity of space, according to the ideas of general relativity, because the matter is imbued with the fields of concentrated charges [29, 30]. Indeed, it is in the EM vacuum as a medium, which is polarizable under smaller external impacts than other parts of the physical vacuum, that the impacts from the gravitating masses can be first manifested.

It is known [31] that the EM vacuum manifests itself by the fluctuating mean squares of the electric and magnetic fields. This means that the system of concentrated charges and local currents of any material body is influenced by the EM vacuum by an electrodynamic noise component, the spectral composition of which, as it must be assumed, corresponds to the "white noise". As is known (see, e.g., [32]), such stochastic impacts initiate smearing out of the point electrons, which results in appearance of the natural width of the excited states of atoms, determines the Lamb shift and a number of other phenomena. It is also known [33-35] that white noise can induce transitions in nonlinear dynamical systems. In particular, in the interesting for us cases of the influence of the EM white noise on the electronic and nuclear subsystems of material objects, there can increase the probability of activation transitions between stable and metastable states in such sub-systems, provided these transitions are initiated simultaneously not only by chaotic but also by weak periodic impacts. The highest amplification of the periodic signal under the influence of white noise is achieved under a certain noise power: a "stochastic resonance" is realized [35, 36]. We will discuss below to what extent, under such mechanisms of the EM vacuum's influence on the systems of "concentrated charges", there are manifested the dependences of the experimentally observed effects on the masses of interacting objects.

Due to linearity of the equations of electromagnetic field, any their solution can be represented as a superposition of monochromatic waves, which can be considered as separate degrees of freedom of the electromagnetic field, characterized by the angular frequencies ω. The total energy of such distributed system can be represented as the sum of energies of the field oscillators, and for the average energy per the frequency range from ω to $\omega + d\omega$, there holds [36]:

$$u(\omega,\Theta)=\left(\frac{\hbar\omega}{2}+\frac{\hbar\omega}{\exp\Theta-1}\right)dN,\quad \Theta\equiv\frac{\hbar\omega}{k_BT}. \qquad (4)$$

Here $dN = \frac{\omega^2 V_\omega}{2\pi^2 c^3} d\omega$ is the number of field oscillators having frequencies within the indicated range; V_ω is the volume of the configuration in which the field corresponding to the oscillator with frequency ω is enclosed; k_B is Boltzmann's constant, T is the ambient temperature. The right-hand side of expression (4) includes two qualitatively different terms. Let us first consider the second term, which is associated with Planck's formula for the spectral distribution of the equilibrium blackbody radiation, and which has a specific binding to the local environmental conditions, to the particular temperature of various extended regions of the Universe.

We can assume that such regions are randomly scattered over the Universe and have different spatial extent. Therefore, when calculating the energy density of radiation associated with the second term in equation (4), the result obtained after integration over the entire possible frequency range will be assigned to one of these regions. The configurational volume of this region is represented as a constant value, $V_\omega = V = \text{const}$, assuming that in this volume there is localized the field produced by the oscillators with all possible frequencies. Obviously, in this case, the integration can be formally carried out over the infinite frequency interval. As a result, we obtain for the corresponding Planck density ε_P of the radiation energy, given the fact that to each wave vector there correspond two states of polarization [36]:

$$\varepsilon_P = \frac{\pi^2}{15} \cdot \frac{(k_B T)^4}{\hbar^3 c^3} \equiv \sigma T^4, \qquad \sigma = \frac{\pi^2 k_B^4}{15\hbar^3 c^2} \qquad (5)$$

Before defining the component ε_V^e of the density of the EM vacuum energy, the zero point energy, which is obtained by integrating the first term in the expression (4) over the possible frequency range and relating the obtained energy to the unit volume, it is necessary to give preliminary clarifications. First of all, we note that it is in the calculation of this term that there originated the above-indicated problem of the catastrophic "gap of the magnitude orders", if the zero-point energy is connected with the dark energy of the Universe. At the same time, according to [4], it is with the zero-point energy that one can consistently associate the dark energy, uniformly diffused over the entire space of the Universe. It is this connection that is indicated by the superscript in the designation of the density ε_V^e of the EM vacuum energy. It will be demonstrated below which additional factors are to be taken into consideration in order that the integration of the first term in the right-hand side of expression (4) over the entire interval of possible frequencies, indeed, make it possible to obtain for the density of the EM vacuum energy the value close to the one obtained from observational data.

But first, explaining the general state of the problem of establishing the relationship between gravity and polarization of the EM vacuum, let us note that polarization of the EM vacuum is usually regarded as the emergence of induced dipoles in the excitation of virtual electron-positron pairs [30, 37]. Moreover, it is postulated that the initial electric permeability ε_0 and magnetic permeability μ_0 of the EM vacuum, and hence the velocity of light in the vicinity of material body change in the gravitational field [37]:

$$\varepsilon_0 \to K\varepsilon_0, \quad \mu_0 \to K\mu_0, \quad c \to c/K, \qquad (6)$$

Where $K(\vec{r})$ is the dielectric function of vacuum, induced by the gravitational influence, which depends on the local value of the gravitational field? The choice for this function proposed in [30] was directed at the conformity of the obtained dependences with the results of general relativity for sufficiently weak gravitational fields. Although the obtained in [37] results on the influence of the vacuum polarization on bending of the light trajectory near a massive body, in fact, turned out to be close to the well-known results of general relativity, this work has made more specific a possible mechanism for the appearance of gravity. Nevertheless, the lack of quantitative estimates and explanations of the nature of exceptional smallness of gravitational interactions leaves open the majority of the questions related to the essence of gravity.

We also mention the paper [38], where a hypothesis has been proposed about the origination of the inertia forces due to the influence of the EM vacuum on the totality of elementary charges of the body during its accelerated motion in an inertial reference frame.

It was also assumed that, during the uniform and rectilinear motion of a body in an inertial reference frame, no forces act on it by the EM vacuum. Here, in fact, two issues are raised, which are important for the understanding of gravitational interactions: on the mechanism of influence of the EM vacuum on massive bodies and the need for an adequate choice of inertial reference system.

The issue about the choice of the reference frame in which there will be considered the indicated influences of the EM vacuum on material bodies is extremely important for the understanding of the essence of gravity. Usually, some problems arise connected with the choice of inertial reference frame, because it is extremely difficult to exclude the interactions of the considered object with the surrounding masses and therefore to define "whether there is a relativity with respect to the state of motion of the space of reference; in other words, whether there are spaces of reference in motion relatively to each other which are physically equivalent" [2], If we focus on the ideas of general relativity, according to which the masses in the space form a curved space-time, the introduction of inertial systems is impossible: transition to any frame of reference does not allow eliminating the tidal forces of gravity. This conclusion became the basis for the rejection of "the preference for inertial systems over all other co-ordinate systems, a preference that seems so securely established by experiment based upon the principle of inertia" [2], Therefore, as a rule, no global or even finite inertial reference systems is introduced in general relativity; that is, all reference systems are non-inertial. However, in some cases, local inertial frames of reference, in particular, the ones bound to a freely falling system (elevator), are introduced in general relativity.

In the paper [38] the studied objects are referenced to inertial and non-inertial reference systems: it should be noted that this practice has proved its practical expediency even from the time of G. Berkeley [20], who proposed to connect the choice of inertial reference systems with the orientation of the coordinate axes to the "fixed stars". The present practice shows that it is possible to introduce virtually absolute inertial reference system, in which the relative acceleration of sufficiently distant from each other bodies does not exceed 10^{-10} m/s². In particular, such a system is the International Celestial Reference System, whose origin is taken to be the position of the barycenter, the center of mass of the solar system, and whose axes are fixed in space with respect to quasars, the most distant objects of the observable Universe [39]. Thus, the dynamics of sufficiently large volumes of the Universe can be seen in the long-distance reference systems, which with good reason can be considered the inertial. Now, a question arises: to what extent the geometric ideas of the curved space-time of general relativity objectively reflect the local distortions of the three-dimensional space of the Universe, which, in contemporary understanding, is Euclidean on the cosmological scales [15-18]. All the more so as there remain open the questions about the physical parameters (characteristics) of the space, the change of which in the neighborhood of massive objects determines the observable effects of gravitational influence on light fluxes. As will be shown below (see also [28]), the manifestations of gravitational interactions can be naturally associated with local changes in the EM vacuum in the neighborhood of masses. So there is a certain analogy with the electric and magnetic phenomena and the presence in the space of the corresponding fields. However, the question about the geometry of space and the changes in the geometry does not arise in these cases. Therefore, as it seems to the author, there are no grounds for the refusal to introduce the inertial frames of reference into the analysis of dynamics of material objects in the conditions of various influences on them, including the gravitational and electromagnetic ones.

When considering gravity as a cosmological phenomenon, manifesting itself over the entire Universe, it is natural to use, following Burlankov [14], a frame of reference "tied" to the expanding Universe with a choice of global time t, uniform for all points of the Universe and counted from the moment $t = 0$, corresponding to the Big Bang. The space-time metric for such frame of reference was found, for the first time, in the paper [40] on the basis of general relativity. It is to this physically distinguished system that the equations of the dynamics of the Universe are "bound" (Friedman equations [4, 41]), in which the entire mass and energy, as well as the associated with this system EM vacuum are assumed to be uniformly distributed throughout the entire volume of the Universe. Let us define this frame of reference as the "Mach system", because it was him who first factually introduced a basic inertial system connected to the center of all masses of the Universe. Really, "… according to Mach, a material particle does not move in un accelerated motion relatively to space, but relatively to the centre of all the other masses in the Universe" [2].

3. Mass, Gravity and Inertia

3.1. Mass

We will assume that in addition to the EM vacuum polarization in the neighborhood of material objects (elementary particle, macroscopic mass) determined by the excitation of virtual electron-positron pairs, there is another type of polarization of the EM vacuum as a physical cause of gravitational interactions. The polarization of this type, which can be defined as the "Casimir polarization", is realized in the vicinity of any material object in the Universe due to conjugation of the components of the electric field of the EM vacuum on both sides (the "outer" and "inner") of the boundary between the material object and vacuum.

It is exactly because of this conjugation that there occurs a difference in the frequency spectra of virtual quanta of electromagnetic field (the "EM quanta"), as well as in the degree of concentration of the virtual EM quanta (the energy density $\varepsilon_{V\omega}$ of such quanta with different frequencies ω) in the regions of the EM vacuum inside and outside the material body. It is natural to assume that the potential energy of such polarization of the EM vacuum by a material object (to be specific, by an elementary particle with the mass m_0) has the Casimir form [4, 5, 42-44]:

$$U(\vec{r}) = -\gamma_0 \frac{\hbar c}{r}. \qquad (7)$$

Here $\vec{r}$ is the radius-vector (we associate the coordinate system with the EM vacuum and assume that the particle at rest is localized at the origin); γ_0 is a dimensionless parameter characterizing the intensity of this interaction.

Such character of polarization of the EM vacuum in the vicinity of the material particle actually means that the particle, together with the EM vacuum, form an integrated open system, a "vacuum polaron" [5, 45]. The introduction of such quasiparticle allows, first of all, to understand at the qualitative level the genesis of a priori limitation of the motion velocity of material objects with nonzero rest mass by the velocity of light c in the physical vacuum, where $c = 3 \cdot 10^{10}$ cm/s. This conclusion is due to the boundedness of the rate of restructuring of the EM vacuum adjacent to the moving object. Obviously, the pace of this restructuring of the regions of the physical vacuum adjacent to the boundary of the solid body is limited by the speed of light c, which makes it impossible for material bodies to move with such velocities in the physical vacuum, which acts as a kind of "aether".

The solution of the Schrödinger equation in a centrally symmetric field with the potential energy in the indicated form is well known [46]. The energy levels $\overline{E}(n_r)$ of the discrete spectrum, reflecting the degree of relationship of the particle of the mass m_0 with the EM vacuum due to its polarization, are represented in the form:

$$\overline{E}(n_r) = -\gamma_0^2 \frac{m_0 c^2}{2n_r^2}, \qquad (8)$$

Where n_r is the principal quantum number. The corresponding expression a_B for the "Bohr radius", which determines the region of localization of the particle, in this case has the form $a_B = \dfrac{2\hbar}{\gamma_0 m_0 c}$. For $\gamma_0 = \sqrt{2}$ the position of the lower energy level ($n_r = 1$), characterizing the binding energy of the considered particle with the EM vacuum, corresponds in the absolute value to the "rest energy of the considered particle" $\overline{E}_0 = m_0 c^2$ in the form proposed by Einstein, while $U(\vec{r})\big|_{r=a_B} = -m_0 c^2$. Therefore, the resulting quantity $\overline{E}_0$, should be more properly called "the binding energy of the particle with the EM vacuum" rather than "the rest energy of the particle", so that the mass defect in the nuclear processes simply characterizes the energy released due to the difference of the binding energies with the EM vacuum of the initial and final products. Therefore, as the author believes, the statements concerning the equivalence of mass and energy, the fact that "mass and energy are therefore essentially alike; they are only different expressions for the same thing" [2] should be considered incorrect.

We should take note of the same character of the dependence of the Casimir potential energy (7), which characterizes the polarization of the EM vacuum by the particles with different masses m_i, on the value of the radius-vector r. At the same time, the "depths" of the lowest energy levels in these potential wells, characterizing the binding energy of different masses m_i, are different. Moreover, in each potential well, there can be localized a finite, dependent on m_i number of "excited" levels ($n_r > 1$), if we mean their number from the ground state to the level of external "noise" (for example, the heat noise equal to $k_B T$). In accordance with the meaning of the problem, to each excited level $\overline{E}(n_r)$ here correspond virtual EM quanta. Furthermore, at each level there may "condense" arbitrary number of virtual EM quanta. Obviously, the larger the mass m_i, the more virtual EM quanta can be localized in the region of the EM vacuum polarization in the vicinity of this mass. Thus, in the EM vacuum, which on average is uniformly diffused throughout the Universe, in the neighborhood of each mass m_i, there are formed the regions of local heterogeneity.

It should be pointed out that the movement of a particle with mass m in the EM vacuum with a velocity u actually means the displacement of the EM vacuum local heterogeneity with momentum $p = mu$ and energy $E = \sqrt{p^2 c^2 + m_0^2 c^4} = mc^2 = \hbar\omega$, where m_0 is the particle mass in the case $u = 0$ and ω is the cyclic frequency of the moving perturbation. The phase velocity u_{ph} of such EM vacuum perturbation with wave number $k = p/\hbar = 2\pi/\lambda_{dB}$, which we associate with the de Broglie wave (λ_{dB} is the corresponding wavelength) is $u_{ph} = \omega/k = E/p = c^2/u$, and the group velocity is equal to $u_g = dE/dp = u$.

Since the phase velocity u_{ph} is frequency dependent, i.e. the movement of the perturbation region is characterized by temporal dispersion, the motion of a particle can not be represented in the form of a wave packet formed from the de Broglie waves.
However, each moving particle wave properties are inherent. It is these properties are due to the formation of well-known phenomena of diffraction patterns at extremely low fluxes of particles incident on diffraction gratings, when the interaction between the particles is excluded.

3.2. Gravity

Because of the infinite range of action of potential energy (7), the presence in the medium of various material objects with masses m_i inevitably lead to the overlap of potential fields and formation of the fields of the particle gravitation.

We show this on the example of the Casimir potential energy $U(\vec{r}_1,\vec{r}_2)$ of two particles with the masses m_1 and m_2, localized at the points with the radius-vectors $\vec{r}_1$ and $\vec{r}_2$, respectively. As before, we associate the coordinate system with the EM vacuum. Then

$$U(\vec{r}_1,\vec{r}_2)=-\frac{\sqrt{2}\hbar c}{|\vec{r}_1|}-\frac{\sqrt{2}\hbar c}{|\vec{r}_2|}. \qquad (7a)$$

We introduce the radius vector $\vec{R}$ of the center of mass of the particles m_1 and m_2, as well as the vector $\vec{\rho}$ of the difference of the radius-vectors $\vec{r}_1$ and $\vec{r}_2$:

$$\vec{R}=\frac{m_1\vec{r}_1+m_2\vec{r}_2}{m_1+m_2}, \qquad \vec{\rho}=\vec{r}_1-\vec{r}_2.$$

Then

$$U(\vec{r}_1,\vec{r}_2)=-\sqrt{2}\hbar c\left[\left|\vec{R}+\frac{m_{12}}{m_1}\vec{\rho}\right|^{-1}+\left|\vec{R}-\frac{m_{12}}{m_2}\vec{\rho}\right|^{-1}\right], \qquad m_{12}=\frac{m_1m_2}{m_1+m_2}. \qquad (7b)$$

We are interested only in the potential energy of interaction of the particles under consideration. Therefore, we choose the origin at the center of mass, $\vec{R}$ = 0. In this case:

$$U(\vec{r}_1,\vec{r}_2)\big|_{\vec{R}=0}=-\frac{\sqrt{2}m_1m_2}{m_{12}^2}\cdot\frac{\hbar c}{\rho}. \qquad (7c)$$

It must be understood that the Casimir form of the potential energy (7) of the EM vacuum polarization by the particle of the mass m_i is valid only in the immediate vicinity of the particle. On the macroscopic distances from the particle, when $r >> a_B$, the in evitable impact of the long-range fields of the EM vacuum polarization in the vicinity of other, not only relatively close particles but also distant masses may neutralize in the expression (7c) the normalization of each of the interacting masses m_1 and m_2 by the reduced mass m_{12}. Moreover, as the normalization of these masses, regardless of their absolute values, there should serve a universal mass, which we denote by m_M, because only in this case the expression (7c) can be reduced to Newton's law:

$$V_g(\vec{\rho})=-\frac{Gm_1m_2}{\rho}, \qquad (9)$$

Where,

$$G=\frac{\sqrt{2}\hbar c}{m_M^2}. \qquad (10)$$

Expression (10) together with (9) explains the essence of the gravitational constant G. In fact, the conclusion which we made about a single normalization mass m_M in the expression for the potential energy of attraction of any two masses m_1 and m_2, may be regarded as an expression of Mach's idea [47], about the influence of all the physical bodies of the Universe on each individual mass. However, in this case, we do not mean a manifestation of the inertia properties in the unaccelerated motion of a material point relative to the centre of all the other masses in the Universe, as it appeared to Mach, but the formation of the law of interaction of gravitating masses. Moreover, from the comparison of expression (10) and relation (1) for the Planck mass m_{Pl} we obtain:

$$m_M=\sqrt{2}m_{Pl}. \qquad (10a)$$

As far as the manifestation of inertia by a gravitating mass is concerned, in the genesis of this phenomenon there is revealed, first of all, the role of the EM vacuum (3.3). It should be emphasized that, within the framework of understanding being developed and bearing in mind that the polarization region in the vicinity of this mass is populated by the virtual EM quanta of different energies,

the polarization state of the EM vacuum in the vicinity of each particle depends on the spatial configuration of the polarization field of all particles of the considered system due to long-range action of gravitation. Each of the elementary displacements of an individual particle in the evolution of the entire system of attracting particles must be accompanied, in accordance with the principle of least action (PLA) [48], by redistribution of the system of virtual EM quanta in the vicinity of each mass with the "condensation" of the moved quanta at the corresponding excitation levels. Furthermore, the EM vacuum acts as a "regulator-distributor", because all the indicated redistribution processes are realized through it.

We will assume that, as a result of such redistribution, there takes place during the approach of two particles with different masses the diminishing of population of the virtual EM quanta (decrease of their total number) in the polarization region of the smaller mass and the corresponding increase in this population for the particle with the larger mass. As it can be assumed (see Section 6 below), the population by the virtual EM quanta of the polarization region in the vicinity of each mass result in some positive contribution to the value of the recorded mass of the corresponding particle.

It should also be noted that, in accordance with the "Trieste theorem" due to Weizsacker [49] (which states that any dynamic process comprises the realized discrete sequences of irreversible in time "steps-events" [26]), with each elementary shift in the system of gravitationally attracting particles there takes place a partial dissipation of the total energy of the system. In this case, the constant G acts as a dynamic parameter which integrally characterizes the set of irreversible processes associated with the change in the dynamic state of the polarization region of the EM vacuum in the vicinity of each of the attracting masses.

3.3. Inertia

Introduction of the ideas about the EM vacuum polarization in the vicinity of a material object, a particle, as a "vacuum polaron" allows to understand, as described above, the dynamic meaning of the limitation of the velocity of material object's motion by the velocity of light in the EM vacuum as a basic Mach inertial reference system. Consider this question in more detail. Let a particle move freely with the velocity u relative to the introduced basic inertial reference system, and let it have the mass m_0 for $u = 0$. Let us find out (see also [5]) with what changes in the polarization region of the EM vacuum in the vicinity of this material particle there can be linked the appearance of the factor η_u in the expression for the total energy E_u of the particle [50]:

$$E_u = \eta_u m_0 c^2, \quad \eta_u = \left(1 - \frac{u^2}{c^2}\right)^{-1/2}, \qquad (11)$$

For the first time this factor was introduced by Oliver Heaviside in 1889 [51], in the model calculations of the aether drag (a basic medium of the science of the XIX century) by the moving charged spherical particle of the radius a and the mass m_0. The effect of the aether drag increased proportionally to η_u with increasing of the particle velocity due to the geometric displacement of the "Faraday tubes" toward the equatorial plane passing through the center of the sphere and perpendicular to the direction of movement. In this case, the Faraday tubes were initially oriented normally to the surface of the particle. If we conditionally restrict the domain of such system by a sphere of radius R, equal to several radii a, then, under a small velocity of the particle, the initial spherical geometry of the system is transformed into a flattened ellipsoid of rotation around the minor axis of the ellipse oriented along the particle path, so that

$$R_s = R \cdot \eta_u^{-1} < R_l = R. \qquad (12)$$

Here R_s and R_l are the sizes of the small and major semi-axes of the oblate ellipsoid of rotation, respectively. Based on this result, J.J. Thomson calculated [51] the kinetic momentum in the space surrounding this particle and showed that the mass of the particle, with its velocity increasing, grows proportionally to the factor η_u due to increasing of the total amount of aether entrained by the Faraday tubes in the movement of the charged particle. The subsequent formation of the special theory of relativity (STR) and the experimental studies have fully confirmed the universal role of the factor η_u in the entire the spectrum of relativistic phenomena.

In accordance with the concepts being developed, the EM vacuum, being the basic medium and a physically distinguished system for all the objects in our Universe, is a modern analogue of the aether of the science of the XIX century. Thus, it is natural to try to relate the effect of the energy increasing of a relativistic particle in the STR with the changes in the vacuum polarization region in the vicinity of such particle in the direction of its motion, following the general ideas of O. Heaviside and J.J. Thomson. It should be understood that the postulated vacuum polarization in the vicinity of any material object with the EM vacuum, in reality, implies openness in the dynamic sense of this object for vacuum. In other words, the properties of any elementary particle are formed in the interaction of its inner essence with the electromagnetic component of the physical vacuum [5].

We will assume that during non-relativistic movement of the particle, to be specific, an atomic nucleus, relative to the basic inertial reference system, there is realized "equilibrium" exchange of virtual photons, which are localized in the EM vacuum polarization region in the vicinity of the nucleus, and of the virtual photons of the EM vacuum as the basic medium.

Furthermore, the polarization region is characterized by a certain level of "salvation", the condensation of virtual photons on the system of excitation levels of the nucleus. The exchange of virtual photons, realized on the boundary "atomic nucleus – EM vacuum" is disturbed under external influences on the nucleus (see Section 6) or under its relativistic movements.

In accordance with the logic of Weizsacker [49], the very fact of any change in the state of a system, in this case, due to the transition of virtual photons, is inevitably associated with the dissipativity and irreversibility of such process. But to what extent in the influence of quantum fluctuations of the EM vacuum − the fluctuating mean square values of the intensity of electric and magnetic fields [31] − there can manifest the real energy to initiate irreversible dissipative processes? In the author's opinion, as a basis for the possibility of this type of processes one can consider the established role of quantum fluctuations of the EM vacuum in the formation of the radiation pressure (the macroscopic manifestations of these effects were observed in [52]), as well as the static Casimir effect [43] together with the dynamic Casimir effect [53, 54] with the direct conversion of the fluctuations of virtual photons into real photons in the region of the boundaries of the objects moving with relativistic velocities.

To characterize the considered exchange of virtual photons, we consider, in accordance with [55, 56], a boundary condition of the third kind with the introduction of a boundary ad-state or a state I, from which effectively, with the rate constant k_1, there take place transitions of the localized virtual photons into the state of the EM vacuum in the vicinity of the nucleus. We also introduce the boundary state II, from which effectively, with the rate constant k_2, there occur the inverse transitions of virtual photons: from the state of the EM vacuum into the localized states in the region of polarization of the EM vacuum by the nucleus. Let us also introduce a dynamic variable $\xi(u)$, which characterizes the level of population of the state I by the localized virtual photons, which determines the level of the notional "lubrication" needed for the movement of the particle through the vacuum with the velocity u.

We will assume that, with the increasing of u to the relativistic values, the localized virtual photons will be "blown out" from the frontal with respect to the movement of the particle in the polarization region of the EM vacuum, which can be naturally associated with the increase of the rate constant $k_1 = k_1(u)$ as $u \to c$. Furthermore, the value of the "lubrication" level $\xi(u)$ should decrease (the particle is partially "get stripped"), whereas for $\xi(u) \to 0$, when the virtual photons in the frontal polarization region are absent, the particle in the EM vacuum cannot move. In fact, the EM vacuum acts as "reins" on the particle, which tries to break out of the shell polarizing it, so that, as the velocity u grows, the potential energy of such system increases.

Taking into account what is said, the corresponding balance equation for the variable $\xi(u)$ in the stationary case of moving a particle in the EM vacuum with the velocity u can be represented as follows:

$$\frac{d\xi(u)}{dt} = -k_1\xi(u) + k_2(1-\xi) = 0, \qquad (13)$$

so that

$$\xi(u) = \frac{k_2}{k_1 + k_2}. \qquad (14)$$

We assume, in accordance with the idea of J.J. Thompson, that the frontal region of polarization of the EM vacuum in the vicinity of a particle moving with the velocity u is transformed for $u \to c$ from a spherical one to spheroid, the surface of an ellipsoid of rotation, whose minor semi-axis b is oriented in the direction of the particle velocity, whereas the major semi-axis of this ellipse remains equal to the radius a of the spherical region of polarization in the case of a particle at rest or moving with non-relativistic velocities. The deformation of the polarization region of the EM vacuum as $u \to c$ can be naturally characterized by the ratio b/a of the diminishing small semi-axis b to the large semi-axis a, which is equal to $b/a = \sqrt{1-e^2}$, where e is the eccentricity of the ellipse, defined as the ratio of the distance from its center to each focus to half of the major axis. It is the dependence $e = e(u)$ on the velocity u that can be regarded as an indicator of increasing of the level of "nakedness" of the particle and the disappearance of "lubrication" due to the loss of localized photons in the region of EM polarization for $u \to c$. Clearly, $e \to 1$, when $b \to 0$, and the "nakedness" of the particle increases to its maximum. Furthermore, the value

$$\eta = 1/(b/a) = (1-e^2)^{-1/2} \qquad (11a)$$

can be regarded as a factor which characterizes the rate constant of losing by the EM polarization region of localized photons which provide "lubrication" for moving of the particle in the EM vacuum.

With the introduction of the phenomenological relation $e(u) = u/c$ for the eccentricity of the ellipsoid of rotation, whose form is assumed by the polarization region of the EM vacuum in the vicinity of the particle moving with the relativistic velocity u relative to the basic inertial reference system, it follows from comparing (11) and (11a): $\eta = \eta_u$. If one is guided by the relations of the STR and the results of the relevant experimental studies, then one should take $k_1 = k_{10}\eta_u$, where $k_{10} \equiv k_1(0)$ and η_u is the Heaviside factor (11). In addition, the rate constant k_2 should not depend on u. Then expression (14) can be rewritten as:

$$\xi(u) = \frac{k_2 \eta_u^{-1}}{k_{10} + k_2 \eta_u^{-1}} = \frac{k_2 \sqrt{1 - u^2/c^2}}{k_{10} + k_2 \sqrt{1 - u^2/c^2}}, \qquad (14a)$$

so that

$$\xi(0) = \frac{k_2}{k_{10} + k_2}, \quad \xi(u) \xrightarrow[u \to c]{} \frac{k_2}{k_{10}} \sqrt{1 - u^2/c^2} \ .$$

It is with the decrease of the value η_u^{-1} with the increasing of the particle velocity and the increasing of the potential energy of the system under the disappearance of "lubrication" needed to move the body in the basic medium that is natural to connect the nature of the relativistic increase in the inertial mass and the inability to move the object in the medium with the speed of light, according to the understanding of the relation (11) by Feynman [57]. This conclusion is fully consistent with the idea of J.J. Thomson that the arising in the movement of the charged particle kinetic perturbations of the surrounding medium turn out to be equivalent to the potential (not kinetic!) energy of the moving particle, causing an increase of exactly this component of energy [51].

Naturally, within the framework of introduced ideas, the motion of a particle with a constant velocity u relative to the basic frame of reference associated with the EM vacuum should be considered not as free but stationary. However, according to the existing tradition which goes back to E. Mach [47], the indicated "help" on the part of the EM vacuum in the preservation by a particle with the mass m_0 of the uniformity and rectilinearity of motion relative to the basic frame of reference without other bodies or fields affecting the particle will be considered natural, whereas the stationary motion of this type will be defined as the motion by inertia. However, in this case, the introduced inertia of the particle is formed not by all masses in the Universe [47], but, in fact, by the influence of the electromagnetic component of the physical vacuum on each particle. At that, there is realized a stationary (not "free", not reversible under the time reversal) particle motion by inertia relative to the basic medium, the EM vacuum, tied to the expanding space of the Universe. In fact, we believe that the bonding of material objects to the EM vacuum in accordance with (8), which causes the effective "freezing" of material objects into the expanding space of the Universe [4], is the reason for inertia. Such introduction of inertia is more consistent with today's understanding of the dynamics of the Universe, according to which all existing masses in the Universe are responsible for no more than 4% of the total energy of the Universe. At the same time, of course, there remain open questions about the magnitude of the energy contribution of the EM vacuum in such movement by inertia, about a possible dependence of such contribution on the mass and velocity of the particle. Thus, the movement of the particle by inertia, as well as the motion in the gravitational field, is connected with the dynamic restructuring of the EM vacuum along the trajectory of the moving particle. In fact, in both cases − the gravitational attraction and the motion by inertia – there is manifested an integral image of the particle, its mass as a dynamic characteristic of the material body.

Introduction of the EM vacuum as the basic medium of the Universe on all spatial-temporal scales of its organization gives reason to hope for the existence of relationships between the existing global constants which determine the specificities of the dynamics of the Universe on the micro- and macro-levels. In order to move forward in such a search at the phenomenological level, we will use, together with Planck numbers (to the analysis of whose meaning we will return later), one more numerological relation (see also [4, 5]).

4. Phenomenological Relations for Basic World's Constants and the Constants of Interactions

S. Weinberg [58] noticed an approximate equality:

$$\hbar \approx \frac{1}{2\pi} G^{1/2} m_\pi^{3/2} R_H^{1/2}, \qquad (15)$$

where R_H is the characteristic ("Hubble") radius of the Universe [40]; m_π is the mass of π-meson. Let us use the general character of this relation and represent the expression for $\hbar$ in the form of equality [4, 5]:

$$\hbar = \frac{1}{2\pi} G^{1/2} m_Q^{3/2} R_H^{1/2}, \qquad (16)$$

where we introduced a new energy parameter $E_Q = m_Q c^2 \approx$ 209.5 MeV, the value of which is defined in such a way that the well-known connection holds between the de Broglie wavelength and the momentum of the particle (note that $m_\pi c^2 \approx$ 140 MeV). Then the introduced parameter E_Q can be regarded as the specific energy of restructuring of the EM vacuum, corresponding to the elementary quantum of action. It should be noted that the obtained value of E_Q turns out to correspond to the energy scale E_{QCD}, considered in quantum chromodynamics [59]. It is the intra-nuclear temperatures corresponding to the characteristic energy $E_{QCD} \sim$ 200 MeV that are critical for the phase transition: the quarks inside the nucleus are no longer bound in nucleons and the quark-gluon plasma is formed.

It is also convenient to represent the expression (15) in the form:

$$G = \frac{(2\pi\hbar)^2 H}{m_Q^3 c} = \frac{8\pi^2 c H}{m_Q} a_Q^2 = \frac{8\pi^2 c^2 a_Q^2}{m_Q R_H}. \quad (16a)$$

Here $a_Q = 2^{1/2}\hbar / m_Q c \approx$ 1.3 10^{-13} cm = 1.3 fermi is the Bohr radius associated with the mass m_Q [5]. We assign to the obtained quantity $m_Q = E_Q/c^2 \approx$ 3.72 10^{-25} *g* the meaning of the standard or the "elementary *QCD* mass".

In this case, the potential energy of interaction between two masses m_1 and m_2 at the distance ρ apart ("the law of gravity") is conveniently represented in the form:

$$V_g(\rho) = -\frac{q_g^2}{\rho}\mu_1\mu_2, \quad \mu_i \equiv \frac{m_i}{m_Q}. \qquad (9a)$$

The quantity $q_g{}^2 \equiv Gm_Q{}^2$ will be considered as the square of the elementary gravitational charge. We also introduce a dimensionless constant α_g of gravitational interaction, determined by:

$$\alpha_g = \frac{Gm_Q^2}{\hbar c} = \frac{m_Q^2}{\sqrt{2}m_{Pl}^2} = (2\pi)^2\frac{\hbar H}{m_Q c^2} = 2^{3/2}\pi^2\frac{a_Q}{R_H} \approx 2.85\cdot 10^{-40}. \quad (17)$$

Expression (17), which reflects the quantum essence of gravitational interaction ($\alpha_g \sim \hbar$), allows us to understand the nature of the unique smallness of the gravitational interaction, the value of the dimensionless constants α_g, which is 38 orders of magnitude smaller than the fine structure constant α_e. It becomes clear from the expression (17) that the formal reason for this difference is in the smallness of the ratio of the characteristic size of the polarization region of the EM vacuum in the vicinity of the particle with an "elementary QCD mass", a kind of "seed" of the gravitational interaction, to the characteristic size of the Universe. Thus, at the conceptual level there is "justified" the name of "the law of universal gravitation" for the dependence, describing the gravitational interaction of two arbitrary masses.

For comparison, let us present the value of the square of "elementary charge of the weak interaction"

$$q_F^2 \equiv G_F / a_Z^2,$$

where $a_Z = 2^{1/2}\hbar / m_Z c \approx$ 3.3 10^{-16} cm is the Bohr radius associated with the mass of the intermediate Z^0 vector boson, m_Z = 91.2 GeV/c^2 = 1.62 10^{-22} *g*, and $G_F = 1.44\cdot 10^{-49}\,\mathrm{erg}\cdot\mathrm{cm}^3$ is the Fermi constant [59] of four-fermion interaction. Then we get the value of the corresponding dimensionless constant

$$\alpha_F = \frac{q_F^2}{\hbar c} = \frac{a_F^2}{a_Z^2} \approx 5.7\ 10^{-2}, \qquad (18)$$

where $a_F = (G_F/\hbar c)^{1/2} \approx 0.7\cdot 10^{-16}$ cm. Note, that $\alpha_F = \alpha_e = 1/137 \approx 0.73\cdot 10^{-2}$, if we choose $m^*_{eW} =$ 35.2 GeV/c^2 as the basic mass of the electroweak interaction.

It should be noted that the use of the introduced characteristic values a_Q and m_Q allows more compactly presenting not only the dimensionless constants of the gravitational and the weak nuclear interactions, but also the Planck number (1) and (2):

$$a_{Pl} = 2\pi a_Q\left(\frac{a_Q}{R_H}\right)^{1/2}, \quad t_{Pl} = 2\pi\tau_Q\left(\frac{a_Q}{R_H}\right)^{1/2}, m_{Pl} = \frac{1}{2\pi}m_Q\left(\frac{R_H}{a_Q}\right)^{1/2}, \ w_{Pl} = \frac{m_Q c^2}{4\pi^2\tau_Q}\cdot\frac{R_H}{a_Q}. \quad (1a)$$

Relations (1*a*) clarify the cosmological nature of the "smallness" of the Planck parameters l_{Pl} and t_{Pl}, as well as the cosmological scale of the quantities m_{Pl} and w_{Pl}, thereby demonstrating the heuristic validity of the representation (16) for the Planck constant. Moreover, according to (10*a*), the Planck mass, initially introduced as a purely numerological ratio, acquires quite a definite physical meaning, quantitatively characterizing the role of all masses in the Universe in the observable phenomena. Earlier in [4] the physical sense of another Planck's parameter w_{Pl}, defined by the relation (2), was revealed. It was shown that the energy generated by the source with such power for the lifetime of the Universe corresponds to the total energy of the Universe at the present moment.

Thus, besides the Planck mass, the physical meaning is acquired by the Planck time t_{Pl}, because $w_{Pl} = m_{Pl}c^2/t_{Pl}$, as well as by the Planck length a_{Pl}, obviously related to the Planck time. Therefore, despite the transcendent character of relations (1*a*) and (16) – the fundamental impossibility of obtaining direct experimental information about the nature of the formulated dependences on the ratio R_H/a_Q, these relations should be viewed not as "numerological" relations, but phenomenological relations, which in the future can become not only basic guidelines, but the basic postulates for the deductive construction of theoretical models of the dynamics of the Universe.

5. Zero-Point Energy of the EM Field Oscillators and the Quantum Nature of Gravity

To return to the calculation of the density ε_V^e of the zero-point energy of the EM field oscillators on the basis of expression (4), it is necessary to take into account another factor. The quantity ε_V^e turns out to be "tied" to the specificities of the dynamics of the Universe, as well as the gravitational constant *G* in the law of universal gravitation. Both of these characteristics are exactly as they are at this stage of evolution of the Universe. Here we follow the ideas about the dynamics of the Universe developed in [4, 5]. In contrast to the cosmological understanding of the standard model [15-18], in [4, 5] the Universe is considered as an open system. It is assumed that a permanent hypothetical source of energy with the Planck power (2), which originated after the completion of the cold inflation stage of the Big Bang, produces all the energy-mass of the observable Universe during its evolution. It is assumed that not only the entire mass and energy, as in the standard model, but also the energy of the Planck source is distributed uniformly and is generated constantly in each element of the emerged and emerging space; and every volume element of the Universe is expanding due to such energy release. In addition, the basic cosmological principle is being integrally maintained: the homogeneity and isotropy of the distribution of matter throughout the Universe on the scale of hundreds of Mpc [4].

As one of the possibilities of realization of such an evolution, there is considered in [4] the successive in time switching on the Planck sources, which chaotically change their location in the border region of the formed Universe (its volume $V_H = 4/3\pi R_H^3$) with the primary, inflationary vacuum, whose space after the Big Bang started to be absorbed by the expanding ("swelling") Universe. In other words, it is assumed in [4], in contrast to the current models of the Universe dynamics, that not the entire energy of inflationary vacuum, defined as a "false" metastable vacuum with the energy density exceeding the vacuum energy of the Universe, in a short time, in a fraction of second after the Big Bang was freed and realized into the observed energy of the emerging and growing Universe.

It is believed that the process of this assimilation of the energy of false vacuum with its transformation into the energy of the expanding Universe occurs permanently during the appearance of the sources of Planck power within the border regions of two vacuums: the EM vacuum and the false vacuum. Furthermore, within the understanding of [4], all the freed mass-energy of the Planck source must be emitted into the existing Universe, which is helped (see Section 3) by high affinity ("freezing-in") of the formed material particles to the EM vacuum, characterized by the energy of their connection with vacuum [42]. It should also be emphasized that the ideas developed in [4, 28], on the basis of which it was possible to understand the basic regularities of the Universe dynamics and to obtain an adequate estimate of the value of the energy density ε_V^e of the EM vacuum can also be considered as basic postulates for building models of the Universe dynamics.

While introducing into consideration the Planck power sources, it must be emphasized that the region of localization of such sources is extremely small (their Bohr radius [4] is $a_{Pl} = 2^{1/2}\hbar / m_{Pl}c \approx 2.6 \cdot 10^{-33}$ cm). There is nothing surprising in this: the Big Bang is also associated with a source of extremely small spatial extent. At the same time, starting from the uniform distribution of the dark energy across the entire space of the Universe, the length of which is characterized by the Hubble radius $R_H \sim 1.3 \cdot 10^{28}$cm [41], the averaging of the total zero-point energy must be carried out over the volume $V_H = 4/3\pi R_H^3$. It is obvious that the main contribution into the total energy of zero-point fluctuations of EM field is formed by the highest frequencies, starting from $\omega_Q = 2\pi c / a_Q \approx 1.45 \cdot 10^{24} s^{-1}$, at which quarks are no longer connected in the nucleons, and there is formed the quark-gluon plasma. As the extremely high cycle frequency of the zero-point oscillations of EM field, it is natural to consider the Planck value [4]:

$$\omega_{Pl} = \frac{c}{a_Q} \cdot \left(\frac{R_H}{a_Q} \right)^{1/2} \approx 0.73 \cdot 10^{44} s^{-1}, \qquad (19)$$

to which, as it was indicated earlier, there corresponds the spatial scale $a_{Pl} = 2\pi c / \omega_{Pl} \approx 2.6 \cdot 10^{-33}$ cm.

In accordance with the considered dynamics of the Universe as an open system, it is exactly the sources of such power, the energy of which is continuously introduced into the entire volume V_H of the Universe, that constantly arise in the region of the border of the two vacuums: the EM vacuum and the false vacuum. The powers of these point sources, which can be regarded as "micro Big Bangs" by several orders of magnitude exceed the powers of the most powerful of the known galactic objects, the gamma-ray bursts. It is exactly for this reason that in [4] it was suggested that the arising gamma-ray bursts are triggered precisely by the discussed primary explosions in the region

of the border of the two vacuums. There were also presented there some arguments in favor of this hypothesis.

Since $a_Q >> a_{Pl}$, as the configuration volume in the calculation of the average density of zero-point energy of EM field we choose $V_{\omega Q} = \frac{4}{3}\pi a_Q^3$. Then, in the integration of the first term in the right-hand side of expression (4) over the frequency interval $[\omega_Q, \omega_{Pl}]$ with referring of the obtained energy to the volume V_H and taking into account the fact that to each wave vector there correspond two polarization states, we obtain [28]:

$$\varepsilon_V^e = \frac{2^{1/2}}{16\pi^2} \cdot \frac{m_Q c^2}{a_Q^2 R_H} \approx 1.5 \cdot 10^{-8}\ \mathrm{erg/cm^3}. \quad (20)$$

The obtained quantity (taking into account certain conditionality of the selection of numerical coefficients in the introduction of the parameters used) is close the above value, obtained on the basis of observational data.

For the subsequent estimation it is convenient to introduce the dimensionless ratio φ of the energy density ε_V^e to the density ε_Q of intra-nuclear excitation $E_{\mathrm{QCD}} = m_{\mathrm{Q}}c^2$, localized in the volume $V_{\omega Q} = 4\pi a_Q^3/3$:

$$\varphi \equiv \frac{4\pi a_Q^3 \varepsilon_V^e}{3 m_Q c^2} = \frac{\varepsilon_V^e}{\varepsilon_Q}. \quad (21)$$

Then it follows from (10), (10*a*), (17) and (21) that

$$G = \frac{\hbar c}{\sqrt{2} m_{Pl}^2} = \frac{\hbar c}{m_Q^2}\alpha_g = \sqrt{2}\frac{\hbar c}{m_Q^2 \eta_g} = 2^{9/2}\pi^4 \frac{a_Q^4}{m_Q^2}\varepsilon_V^e = 24\pi^3 \frac{\hbar c}{m_Q^2}\varphi. \quad (22)$$

For the dimensionless constant of gravitational interaction α_g, taking into account the numerical values $\varepsilon_Q \approx 3.64 \cdot 10^{34}$ erg/cm^3 and $\varphi \approx 4.1 \cdot 10^{-43}$, we obtain:

$$\alpha_g = \frac{m_Q^2}{\sqrt{2} m_{Pl}^2} = 2^{3/2}\pi^2 \frac{a_Q}{R_H} = 24\pi^3 \varphi \approx 2.85 \cdot 10^{-40}. \quad (17a)$$

We note also that, with the introduction of the parameter φ, the representation (1*a*) of the Planck numbers is also simplified:

$$a_{Pl} = 2^{7/4} 3^{1/2} \pi^{3/2} a_Q \varphi^{1/2},\ t_{Pl} = 2^{7/4} 3^{1/2} \pi^{3/2} \tau_Q \varphi^{1/2},\ m_{Pl} = \frac{1}{2^{7/4} 3^{1/2} \pi^{3/2}} \frac{m_Q}{\varphi^{1/2}},\ w_{Pl} = \frac{1}{2^{7/2} 3\pi^3} \frac{m_Q c^2}{\tau_Q \varphi}, \quad (1b)$$

pointing, together with (17*a*), to the possible dependence of all the dimensional parameters, introduced in order to build the models for the structure and dynamics of the Universe, on the dimensionless parameter of the energy density of the EM vacuum.

Formulas (17*a*), (20)-(22) describe the physical essence of the gravitational constant *G* and of the energy tensor introduced in the general relativity theory. It follows from (22) that the gravitational interaction does not have its own specifics. It is a consequence of polarization of the EM vacuum in the vicinity of any mass, whereas the unique smallness of gravitational interaction is determined by the smallness of the energy density of the EM vacuum, diffused over the entire space of the Universe, compared to the local energy density of characteristic QCD energy.

Here, we also point out that the relations (3) (20)-(22) yield the following representation of the cosmological constant, which is convenient for understanding its physical essence [28]:

$$\Lambda = \frac{2^{1/2}\pi}{R_H^2}. \quad (3a)$$

We emphasize that the dependence (3*a*), as well as the results of [4], related to the Universe dynamics, do not agree with the accepted today conclusion about total accelerated expansion of the Universe at the present epoch.

It should be noted also that the rate of propagation of gravitational interactions should be connected not to the speed of light *c* in the vacuum, as it is assumed in general relativity [2, 60], but with the speed of information transfer under the relaxation of the EM vacuum itself, which may be different from the value of *c*. Indeed, it is exactly in this manner that one can understand the results of experiments [62], dating back to the "EPR experiment" by Einstein-Podolsky-Rosen and the analysis of the Bell-Leger inequalities [61] – the results related to the verification of the basic principles of quantum mechanics. In these experiments, the fixation (measurement by a device) of one of the two forming free particles, which originally constituted *a single system* and were in an entangled (with respect to polarization, the spin projection) state, means an irreversible, according to Weizsacker [49], simultaneous restructuring in accordance with the least-action principle of the entire system. The system includes, besides both particles and the device for fixation of the first particle, the entire EM vacuum with the restructuring in the process of measurement boundary conditions, including in the vicinity of the second, yet free particle. Furthermore, as one could assume from the experimental data [62], the rebuilding of vacuum in the vicinity of both subsystems (the measured particle and the measuring device, the free particle) occurred with the velocity, at least by 4 orders of magnitude exceeding the speed of light *c* in the vacuum.

We also point to yet another fundamental difference between the results of the presented phenomenology with the results of general relativity theory, associated with the difference in the corresponding space-time metrics. In general relativity, the metric is used in the local time (for the considered problem). An example of such a metric is the Schwarzschild metric with the following representation of the interval ds^2 of space-time outside a spherically symmetric body of mass *M* [2],

$$ds^2 = \left(1 - \frac{2MG}{rc^2}\right)c^2dt^2 - \left[\frac{dr^2}{1 - \frac{2MG}{rc^2}} + r^2\left(d\theta^2 + \sin^2\theta\, d\varphi^2\right)\right], \qquad (23)$$

where r, θ, φ are the coordinates of the radius-vector $\vec{r}$.

However, we use an inertial Mach reference system, "tied" to the expanding Universe when choosing a global time *t*, the same for all points of the Universe [14, 40] (see equation (3) from [4]):

$$ds^2 = \left(1 - \frac{2MG}{rc^2}\right)c^2dt^2 + 2\sqrt{\frac{2MG}{r}}dtdr - \left[dr^2 + r^2\left(d\theta^2 + \sin^2\theta\, d\varphi^2\right)\right]. \qquad (24)$$

In both cases – of the metric with global time and the Schwarzschild metric – the time scale increases in the gravitational field: the speed of light decreases and thus there increases the duration of a certain number of periods with the predetermined wavelength. At that, the velocity field of the light beam turns out to be dependent on the coordinates in the vicinity of the mass, which leads to the experimentally recorded deviation of the trajectory of the beam from the rectilinear.

In the case of metrics with the local time, used in the general theory of relativity, in the gravitational field there is also reduced the spatial scale: in the selected system of spatial coordinates, associated with a spherical body of mass *M*, there is reduced the length of the measuring rod [2], The same should apply also to the parameters of the crystal lattice in a crystalline solid in the vicinity of this mass. Thus, we are talking about changing the interatomic interactions, which seems unlikely. In the metric with a global time, the gravitational field, as it follows from the expression for the space-time interval, does not affect the length of the rod, which can be determined through the number of wavelengths. There may be appropriate here an analogy with the so-called "Lorentz contraction" of the rod in a reference frame moving with a relativistic velocity relative to the laboratory system. In fact, this contraction turns out to be phantom. Indeed, in the own frame of reference for the rod, where it rests, even if this reference frame moves with a relativistic velocity relative to the laboratory system, its length is always fixed [50], and, in this case, we cannot talk about changing the parameters of the crystal lattice of the crystalline solid body.

6. Remaining Questions and Possible Experiments

In the framework of developed understanding, there arise new questions, the answers to which can be obtained only by arranging the relevant experiments. It still remains unclear: at what macroscopic distances from the point mass there begins to fully manifest the influence of all masses of the Universe, and there is formed the gravitational constant *G*. Or even closer to understanding of the essence of gravity: what physically measurable parameter can be introduced to evaluate the degree of polarization of the EM vacuum in the vicinity of material body,

and can this characteristic depend on the nature of the material from which the body is made? The last part of the question is connected with the fact that it is exactly on the boundary conditions at the boundary "material object – EM vacuum" that the physical properties of the object may depend, in particular, its stability, if we are talking about the atomic nucleus [42]. All these questions are formulated with one purpose: to discuss possible methods of research, which would allow us to get closer to a more adequate understanding of gravity.

In connection with the developed ideas about the nonspecific nature of the gravitational interaction, which is realized due to polarization of the EM vacuum in the vicinity of the massive object and the anomalously low value of the dimensionless constant of the gravitational interaction α_g in comparison with the constants of other interactions, a very effective way of getting the discussed information may become the experiments [63] of detecting the "attraction of mass by the light flux". In these experiments, the light flux generated by fluorescent lamps of various intensity, was directed above or below the mass, capable of virtually free displacements and, at the same time, connected with a sensitive device measuring the weight of this mass. In a series of experiments [63] this device unambiguously detected an increase the weight of the initial mass of 200 g, when the light flux was directed below the mass and a decrease of the weight of the mass, when the light flux was directed above the mass. The observed increase or decrease of the weight (up to thousandths of a Newton) occurred with the characteristic times of the order of tens of minutes. During the same characteristic times, there took place the relaxation changes of the weight after turning off the light fluxes. At that, the recorded maximum changes of weight increased with the increasing of the light flux intensity.

The question about the mechanism of this effect is left open in the paper [63]. As it seems to the author, this effect may be due to localization of light during the propagation of waves in a medium with a large number of spatial in homogeneities [64]. In this case, we refer to localization of photons in the multiple scattering and re-scattering of photons on weakly absorbing chaotic roughness of the surface of the submicron scale [65, 66]. The localization of photons occurs due to the interference of light fluxes, propagating in the re-scatterings along different "paths of bypassing" of the roughness fragments of different spatial scales. The phenomenon of photons localization consists in converting the real photons into the virtual photons, for which the wave vector $\vec{k}$ and the frequency ω are independent variables, not related by the dispersion relation $\omega = kc = 2\pi c/\lambda$, valid for the real photon. For the given wavelength of the virtual photon, its frequency $\omega_{eff} = 2\pi u_{eff}/\lambda$ is determined by the effective speed of light u_{eff} in the massif of roughness, and for complete localization $u_{eff} \to 0$, so $\omega_{eff} \to 0$. Since virtual photons are not available for direct observation, the conclusion about the transition of a part of real photons into the virtual ones (this is a kind of effect, inverse to the dynamical Casimir effect [53, 54]) is usually associated with a decrease in the traditional scattering cross-section [65].

In connection with the series of experiments from [63], it can be assumed that in the directing of the light flux of varying intensity above or below a solid sample, capable of virtually free displacements in the region of surface roughness, there is realized the effect of localization of a part of photons of the light flux, flowing around the surface, with the transformation of such photons into virtual photons, localized in the regions of Casimir polarization of the surface atoms. The unambiguous recording of the increased weight of the initial sample, when the light flux was directed below it, and the sample weight reduction when the light flux was directed above it, could mean, within the assumed mechanism, that the localization of virtual photons in the near-surface regions of the sample increases the mass of these regions. In such cases, the center of mass of the entire sample somewhat moves in the direction of the light flux in both considered cases, which, in the conditions of the experiment [63] with setting a special balance as a sensitive instrument that measures the weight of this mass, is perceived as the attraction of the mass to the light flux. Hypothetically, the additional weight Δm_ω associated with one virtual photon with the wave number $k = 2\pi/\lambda$ and the frequency ω_{eff}, can be represented as $\Delta m_\lambda = \hbar\left(2\pi c\lambda^{-1} - \omega_{eff}\right)/c^2$. In this case, under complete localization of virtual photons in the system of surface roughness of the irradiated mass during irradiation of the sample surface by the light with the wavelength λ, we will obtain the following estimate for the total number N_λ of the appeared localized photons:

$$N_\lambda = \frac{\lambda c}{2\pi\hbar g}\Delta P_\lambda . \qquad (25)$$

Here ΔP_λ is the weight change of the sample under the impact on the surface by the light flux with the wavelength λ, g is the acceleration of gravity. For the values ΔP_λ = 10^{-4}-10^{-3} N, recorded in the experiment [63] for the case λ = 580 nm (yellow line of sodium), the estimate yields $N_\lambda \approx 10^{30}$-$10^{31}$.

Within the framework of the ideas about localization of a part of photons of the light flux as they pass through the medium created by the chaotically fragmented on the nano- and micrometer scales texture of the surface of a solid sample, one can also qualitatively understood other experimental regularities observed in [63].

Thus, an increase in the light flux intensity leads to increasing the observed effect of the weight change of the sample, because in this case there increases the portion of the light quanta in the laser flow turning into the virtual EM quanta localized in the vicinity of the surface atoms. Furthermore, sufficiently long (of the order of several dozens of minutes) times of establishing the value of the sample weight change under the turning on of the laser source as well as the time of the relaxation establishing of the initial sample weight after turning off the laser source, is naturally associated with the overall duration of the processes of formation of localized photons, as well as the processes of relaxation destruction of the localized photons after cessation of irradiation.

Clearly, the validity of realization of this mechanism of "attraction" can be checked by running a series of experiments by the method of [63], with variation of the parameters of roughness of both surfaces of the test sample, along which the laser beam is launched, and by changing the nature of the material from which the sample is prepared. The identification of the role of the latter factor in the formation of polarization region of the EM vacuum around the mass formed of different materials, as well as the establishment of the kinetics of the visible changes of the sample weight, is essential for the understanding of gravity as a phenomenon. In addition, we can talk about identification of quantitative relations between the changes of the "weight" of the sample and the set of 3D parameters of both surfaces [67-70] of the test sample, identified in the analysis of images obtained by atomic force microscopy (AFM). At that, the most interesting may be the so-called the spikiness parameter, characterizing the presence of the surface fragments with the most sharply varying on the submicron scale texture, since on these fragments the scattering and re-scattering of photons are most effectively realized, and, hence, the localized photons are formed. Of great interest might be the additional studies of the scattering of the laser light flux on the surface roughness, resulting in a decrease in the scattering intensity, which could help to establish the optimal conditions for the transition of real light quanta photons into the localized ones.

7. Closing Remarks

One of the objectives of this study was to demonstrate the possibilities of the phenomenological method as an initial stage of cognition of complex multifactorial phenomena, characterizing the Universe dynamics, prior to the construction of the corresponding physical theories. The need for such a consideration is explained by the fact that the existing tradition of linking all the specificities of the Universe dynamics to the basic concepts of general relativity still leaves more questions than answers: after all, the essence of more than 95% of the energy content of the Universe remains unknown. In developing the proposed phenomenological approach there were introduced, following the concept of Husserl's realist phenomenology, the transcendental entities, whose direct experimental detection is certainly impossible. Among these entities, "things in themselves", there are the understanding of the EM vacuum as the basic medium for the expanding Universe, being an open system, into which there is constantly pumped mass-energy from the Planck power sources; the Casimir polarization of the EM vacuum in the vicinity of material objects, playing the role of a "seed" for the gravitational interactions; the Mach-Planck mass, characterizing the influence of all masses in the Universe on each individual mass; a modified Weinberg relation. The latter one reflects the unity of our World at all spatial and temporal scales, which manifests itself in the interrelation of the basic fundamental characteristics of the Universe − the Hubble radius R_H, the elementary *QCD* mass and the gravitational constant G − with the basic fundamental constants: the Planck constant $\hbar$ and the speed of light c in vacuum.

Using the understanding of the dynamics of the Universe as an open system, the modified Weinberg relation, as well as the entire set of the Planck numbers allowed revealing a decisive role of the EM vacuum in all processes of micro- and macro-world and establishing, in particular, the lack of specificity of the gravitational interaction, which is a manifestation of the Casimir polarization of the EM vacuum in the vicinity of any material object. The conclusion made about the non-specificity of gravitational interactions can point to futility of the attempts to construct a theory of quantum gravity in the framework of the $\hbar Gc$-plan with the understanding of gravity as one of the four fundamental interactions, and also can point to the absence in Universe of gravitational waves, whose existence was predicted about 100 years ago, and the attempts of detecting them using the most modern instruments have been lasting for decades. (Remark added in proof. In the framework developed in this article ideas about the nature of gravity, it can be assumed that it is the wave propagation of the EM vacuum perturbation was recorded in the Laser Interferometer Gravitational-Wave Observatory (B.P. Abbott et al. Observation of Gravitational Waves from a Binary Black Hole Merger. Phys. Rev. Lett. 2016. V.116. 061102), and this disturbance could arise in the collision of two black holes or by some other large-scale events [4], such as gamma-ray bursts).

8. Dedication:

I would like to dedicate this article memory of Ernst Mach, who died 100 years ago.

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