Matter Structuring and Fundamental Constants of Physics

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Abstract: It is generally believed that all fundamental constants are the same everywhere. The experience with the variable velocity of light suggests however that such a belief may not be justified. In spite of that the possibility that the Planck constant may be different at different scales and at different places of our Universe never was discussed. Since the constancy in space of the Planck constant cannot be checked in direct experiments the only way of proving its constancy or variability is to consider theories which allow to vary this fundamental constant. The comparising of the derived results with the corresponding results of standard quantum mechanics solves then the problem. In the talk we present an approach to quantum mechanics which allows to vary the Planck constant. Due to troubles with exact solutions our results have approximate character only. The possible consequences for practical nanotechnology, for theories of many-electron atoms and for large scale structures of the Universe are discussed.

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Introduction

Our world manifests different properties at each level and scale of investigation. This is reflected in the existence of many physical theories which are applied to different parts of our knowledge. It seems therefore that physics is divided into many particular domains which sometime has very little in common. But we believe in the unity of physics. It is therefore worth to ask the question whether physics indeed is a unified intellectual technology of investigating and understanding the surrounding world. Or is it a collection of different theories for each scale of our knowledge? To find the answer to this question we first should specify the starting point of our consideration. It should be as much universal as possible and therefore it cannot be restricted to any particular branch of physics. Since each branch of physics is characterized by specific sets of physical constants we must analyze the role of these constants in physical description of the world. Let us observe that the most universal physical theories like Newton's mechanics and Maxwell's electrodynamics in their basic equations do not contain constant at all. This is one of the reason of their universality and generality. All customary mechanical and electrodynamical physical constants appear only at the stage of applying these theories to particular phenomena. Technically it is done by using different constitutive relations for different physical situations. On the contrary, quantum mechanics and Einstein theory of gravity contain physical constants in their basic equations. We must therefore decide whether the basic and primary equations of physics should contain physical constants or not? Our answer to that question is: *physics on its very primary and most fundamental level should not be based on any physical constants irrelevant how fundamental they are thought!* So, we must look for physics without physical constants! [1] Universality and generality of any theory may be achieved only after adequate choice of its basic concepts. But how do choose the basic concepts? To answer such question we must find some guiding principle. All branches of physics have one common feature: they all describe the symmetries observed in physical systems. The numerical coincidence of theoretical results with experimentally observed data is a secondary requirement and depends on the required and achieved degree of accuracy. *The most general and powerful guiding principle therefore must be related to the symmetry principles of physics*.

Spacetime Symmetries

As it is well-known we have spacetime symmetries and higher symmetries. Among spacetime symmetries we have the Galilean low energy symmetry and the Lorentz high energy symmetry. So, it seems that the situation with respect to the choice of spacetime symmetry should be sufficiently clear. It is customary to choose only one from these two possibilities. But neither for very small sizes like nanosystems nor for very large sizes like cosmic scales we do not know what the spacetime symmetry is. Therefore, instead of making a definite choice we may proceed in a different way which join smoothly both Galilean and Lorentz symmetries. In fact, in Galilean physics it is known that the proper symmetry is described by the so-called one-parameter extension of the Galilei group [2]. It acts in the five dimensional extended spacetime with five coordinates x^μ where $\mu = 0, 1, 2, 3, 4$, with $x^0 = ct$, $x^1 = x$, $x^2 = y$, $x^3 = z$ and x^4 with different physical interpretations [3]. For example, we may look on x^4 either as on some control parameter or as on the action integral in Jacobi-Hamilton formalism. The change of the inertial reference system is described by the transformations

$$\begin{aligned} &\vec{x} \to \vec{x}\,' = R\vec{x} + \vec{\upsilon} t + \vec{a}\,, \\ &t \to t' = t + b\,, \\ &x^4 \to x^{4\,\prime} = x^4 + \vec{\upsilon}\cdot R\vec{x} + \frac{1}{2}\upsilon^2 t + \varphi\,, \end{aligned} \tag{1}$$

where R is the rotation orthogonal 3×3 matrix. These transformations leave invariant the extended spacetime interval

$$(\Delta s)^2 = 2\left(\Delta x^4\right)(\Delta t) - \left(\Delta\vec{x}\right)^2 + c^2\left(\Delta t\right)^2\,, \tag{2}$$

where c is an arbitrary constant with the dimension of velocity. If we ask for the most general linear transformations which leave the expression (2) invariant we shall get the result

$$\begin{aligned} &\vec{x} \to \vec{x}\,' = R\vec{x} + \gamma\vec{\upsilon} t + \frac{\lambda}{c^2}\vec{u}x^4 + \vec{a} \\ &t \to t' = \gamma t + \frac{\vec{u}\cdot R\vec{x} - \varepsilon\vec{\upsilon}\cdot R\vec{x}}{c^2\left(1-\varepsilon\alpha\right)} + \frac{\lambda}{c^2}\varepsilon x^4 + b\,, \\ &x^4 \to x^{4\,\prime} = c^2\alpha\gamma t + \frac{\left(1+\varepsilon\right)\vec{\upsilon}\cdot R\vec{x} - \left(1+\alpha\right)\vec{u}\cdot R\vec{x}}{1-\alpha\varepsilon} + \lambda x^4 + \varphi \end{aligned} \tag{3}$$

where

$$\gamma = \left(1 + 2\alpha - \frac{\vec{\upsilon}^{\,2}}{c^2}\right)^{-\frac{1}{2}}$$

$$\lambda = \gamma\left[\left(1+\alpha\right)\sqrt{1+\frac{\vec{u}^{\,2}}{c^2}} - \left(\alpha + \frac{\vec{\upsilon}\cdot\vec{u}}{c^2}\right)\right]^{-1}$$

$$\varepsilon = \sqrt{1+\frac{\vec{u}^{\,2}}{c^2}}$$

and R is a 3×3 matrix which satisfy the generalized orthogonality relation

$$R^T V R = I \ ,$$

where the matrix elements of V are given by

$$V_{ls} = \delta_{ls} + \frac{(1+2\alpha)u_l u_s - (1+\alpha\varepsilon+\varepsilon)(u_l \upsilon_s + \upsilon_l u_s) + \varepsilon(2+\varepsilon)\upsilon_l u_s}{c^2(1-\alpha\varepsilon)} \ , \qquad (4)$$

Here we have altogether 15 free parameters and from mathematics we can learn that our group of transformations is the de Sitter group SO (4, 1). The de Sitter group contains as subgroups the Galilean group - specified by the relations

$$\alpha = \frac{\vec{\upsilon}^2}{2c^2}, \quad \vec{u} = 0$$

the Lorentz group - specified by the relations

$$\alpha = 0, \quad \vec{u} = (1+\varepsilon)\vec{\upsilon}$$

and the four-dimensional Euclidean group - specified by

$$\alpha = 0, \quad \vec{\upsilon} = 0$$

So, having a theoretical description invariant under the de Sitter group we always may reduce it to either Galilean or Lorentz covariant descriptions. It is also possible to write down a general differential equations covariant under the de Sitter group [4] using the invariant differential operator

$$2\frac{\partial}{\partial t}\frac{\partial}{\partial x^4} - \Delta - c^2\frac{\partial^2}{\partial^2 x^4} \ , \qquad (5)$$

or a square root of it in the case of Dirac like theories [5]. Concluding this part we may say that there exists a common symmetry group unifying all possible spacetime symmetries. In each particular case we may pass to some subgroup of this unified group either by intentional choice of the subgroup or by some procedure of spontaneous breaking of the original symmetry on the level of the choice of non-covariant solutions of the covariant starting equations. In covariant description of phenomena each set of physical quantities carries some representation of the spacetime symmetry group. Having unified these symmetries into one de Sitter group we may start from the Galilean symmetry whose representations by a well-known mathematical procedure can induce the representation of the whole de Sitter group and after finding the induced representations of the whole de Sitter group any such representation may be restricted to another subgroups as, for example, the Lorentz group. In such a way we have the possibility of transferring the non-relativistic information into the relativistic world and vice versa.

Higher Symmetries

Each higher symmetry needs some physical carrier. Usually in fundamental physics the carriers of higher symmetries are physical fields defined on spacetime because the symmetries are local. More exactly, the fields are carriers of a given representation of the symmetry group. As long as the higher symmetries will not be unified into one universal group we cannot speak on one symmetry group as we did for spacetime symmetries. This is exactly the reason why we must consider so many different symmetry groups. But the principle is unique: we always have to choose a set of some basic fields which completely reflects the symmetries of the system. These fields in each particular case may have additional physical interpretation. But this is a secondary feature. Let us denote the basic fields by $\Psi_\alpha(x)$, where the index α stands for all indices needed in the theory. The basic fields propagate in spacetime and in order to describe their propagation we introduce a second collection of fields denoted by $\Phi_{\mu,\beta}(x)$. Here the index μ is a spacetime index while all other indices are denoted by. Having the Ψ and Φ fields we may relate them by the first set of basic equations in the form

$$K^{\alpha,\upsilon}_{\beta,\mu}\nabla_\nu\Psi_\alpha(x) = \Phi_{\mu,\beta}(x), \tag{6}$$

where $K^{\alpha,\nu}_{\beta,\mu}$ are some numerical factors and the summation over repeated indices is understood. The numerical factors vary for each particular case. However the general structure of all kinematical equation of physics is just contained in equations (6). They have exactly the same structure as the first Newton equation which relates the trajectory function with the velocity. To formulate the dynamical laws of physics we introduce a third collection of fields denoted by $\Omega_\gamma(x)$ which describe the influence of the external environment on the studied systems of matter or fields (here γ denotes a set of indices necessary to describe such influence). The fields $\Omega_\gamma(x)$ define the balance equations expressed in terms of a collection of fields $\Pi^\mu{}_\gamma(x)$. These balance equations have the familiar form

$$\nabla_\mu \Pi^\mu_\gamma (x) = \Omega_\gamma (x) , \tag{7}$$

Equations (6) and (7) are the basic primary equations of physics. They have to be completed by suitable set of constitutive relations. This is exactly the place where physical constants enter physics. We shall now show that eqs. (6) and (7) indeed contain all known equations of physics.

For all evolution equations of matter we have

$$K^{\alpha,\nu}_{\beta,\mu} = \delta^\alpha_\beta \delta^\nu_\mu , \tag{8}$$

and in flat spacetime the derivatives $\nabla\mu$ reduce to the ordinary partial derivatives $\partial\mu$. In the Newton equations of a single material points all fields depend only on the time variable. Choosing the basic fields ψ as the trajectory functions $x(t)$, $y(t)$, $z(t)$ and the Φ fields as the components of the velocity $\upsilon_x(\mathrm{t})$, $\upsilon_y(\mathrm{t})$, $\upsilon_z(\mathrm{t})$ we easily can check that our equations (6) exactly coincides with the Newton equations

$$\frac{d\vec{x}(t)}{dt} = \vec{\upsilon}(t) , \tag{9}$$

Similarly, choosing the fields Π as the three components of momentum and the Ω fields as the components of the acting force we shall get the Newton dynamical equation

$$\frac{d\vec{p}(t)}{dt} = \vec{F}(t) , \tag{10}$$

The theory will be complete provided the momentum (the Π fields) will be connected to the velocity (the Φ fields) by the standard relation

$$\vec{p}(t) = M\vec{\upsilon}(t) , \tag{11}$$

and the acting force (the Ω fields) will be given by some force law (expressed in terms of the Ψ or/and Φ fields). For Schroedinger equation of a scalar field $\Psi(x)$ we should assume the following constitutive relations

$$\Pi^0 (x) = i\hbar\Psi(x) , \tag{12}$$

$$\Pi^{j}\left(x\right)=-\frac{\hbar^{2}}{2M}\Phi_{j}\left(x\right), \tag{13}$$

$$\Omega\left(x\right)=-V\left(x\right)\Psi\left(x\right), \tag{14}$$

where $V(x)$ is the usual non-relativistic potential. It is easy to check that such constitutive relations indeed lead to the Schroedinger equation for the field $\Psi(x)$. Similarly, for the Klein-Gordon equation for a scalar field with self-interaction we must assume the following constitutive relations

$$\Pi^{\mu}\left(x\right)=g^{\mu\nu}\Phi_{\nu}\left(x\right), \tag{15}$$

where $g^{\mu\nu}$ is the Minkowski metric tensor and

$$\Omega\left(x\right)=-\frac{M^{2}c^{2}}{\hbar^{2}}\Psi\left(x\right)+F\left(\Psi\left(x\right)\right), \tag{16}$$

where F describes the self-interaction of the field $\Psi(x)$. The Dirac field equations are also obtained from our basic equations through the suitable constitutive relations [4]. The Maxwell field equations for electrodynamics and Einstein equations for gravity may be obtained as well.

In the first case we have to choose the following kinematical factors

$$K^{\lambda\varepsilon\nu}_{\omega\eta\mu}=\delta^{\lambda}_{\omega}\delta^{\varepsilon}_{\eta}\delta^{\nu}_{\mu}+\delta^{\lambda}_{\eta}\delta^{\varepsilon}_{\mu}\delta^{\nu}_{\omega}+\delta^{\lambda}_{\mu}\delta^{\varepsilon}_{\omega}\delta^{\nu}_{\eta}, \tag{17}$$

The basic fields of the type Ψ are here the components of the electromagnetic skew symmetric tensor $F_{\mu\nu}$, the fields of the type Π are the components of the skew symmetric tensor $H^{\mu\nu}$, the external influence on the system is the current fourvector j^{ν} (the fields of the type Ω) and the fields of the type Φ vanish. In the second case we have to choose

$$K^{\beta\eta\lambda\varepsilon\nu}_{\alpha\omega\kappa\xi\mu}=\delta^{\beta}_{\alpha}\delta^{\eta}_{\omega}\left(\delta^{\lambda}_{\kappa}\delta^{\varepsilon}_{\xi}\delta^{\nu}_{\mu}+\delta^{\lambda}_{\xi}\delta^{\varepsilon}_{\mu}\delta^{\nu}_{\kappa}+\delta^{\lambda}_{\mu}\delta^{\varepsilon}_{\kappa}\delta^{\nu}_{\xi}\right), \tag{18}$$

The basics fields (of the type Ψ) here are the components of the curvature tensor and the fields of the type Φ vanish. The famous Einstein equations cannot however be obtained from our basic primary equations. The only equation of general relativity which has the form of (7) is the conservation law for energy and momentum

$$\nabla_\nu T_\mu^\nu (x) = 0 \, , \tag{19}$$

The Einstein equations are non-differential relations between the Ricci tensor field $R_{\mu\nu}(x)$ (constructed from the basic curvature tensor) and the dynamical energy-momentum tensor field $T_\mu{}^\nu(x)$ and this relation contains the gravitational constants. According to our approach the basic equations should not contain physical constants. These are the non-differential constitutive relations which introduce all the necessary constants into consideration. Therefore, Einstein equations should be treated as constitutive relations and not as basic equations which describe Nature!

Advantages of the New Approach

The approach presented here has at least two big advantages over the standard approach. First, our approach shows that all quantum mechanical wave equations have a common root with classical mechanics. The connection of classical and quantum physics is on the level of basic evolution equations [7] and is independent from the canonical formalism widely used in the passage from classical to quantum physics. All these theories differs only by different choices of basic fields and constitutive relations and not by different laws of physics. Second, the basic equations (6) and (7) of any physical theory do not contain physical constants. All constants are introduced by constitutive relations. However, only for very simple physical systems these relations operate solely with physical constants while for more complicated and non-uniform systems the constants are always replaced by some functions of spacetime variables. In the case of classical mechanics in such a way we get the possibility to describe bodies with changing masses. In electrodynamics such a replacement allows to take into account the influence of impurities of the medium on the electromagnetic processes and we may consider media whose physical properties change (polarize and magnetize) under the influence of external electromagnetic interactions. Similarly, in the case of gravity we may consider gravitational systems whose properties change under the influence of external gravitational fields. The standard Einstein theory in analogy to electrodynamics must then be treated as the "vacuum" version of the theory of gravity. It is clear that all that considerably extends the range of applicability of known theories. We may generalize this by saying that physical phenomena at each scale are governed by the same physical laws but by different (sometimes very drastically different) constitutive relations. The constitutive relations reflects the structuring of matter at each scale. In particular, in the presented approach we may consider the consequences of the possible different values of the Planck constant $\hbar$ at each scale level. What we really know is that the Planck constant has its experimental value at the level of atomic phenomena. Has it the same value in nuclear physics, for subnano scales or at the cosmological scale? These are examples of questions which up to now were impossible to ask due to the lack of a suitable formalism. Now we can attack such problems. The problem is relatively simple when the Planck constant changes with jumps. In such a case it is sufficient to consider the quantum mechanical wave equations in each domain of constancy of $\hbar$ separately and at the end to match the solutions with suitable boundary conditions. The results then crucially depend on the boundary conditions. In quantum mechanics it is customary to consider only one type of boundary conditions for which the wave functions and/or their first derivatives are continuous. Such boundary conditions are not enough physically justified. The existing arguments are purely mathematical. Meanwhile already in classical physics, particularly in electrodynamics, we have to do with discontinuous wave quantities like the electrostatic potential. The continuity or discontinuity depends on the physical nature of the boundary. In classical physics we may have passive or active boundaries (in electrostatics it means charged slabs or consisting from dipoles) while in quantum physics all boundaries or barriers are always considered to be passive. The introduction of active quantum mechanical barriers means that the barriers may produce or annihilate quantum mechanical probability. In this way we may speak on amplifiers of probability [6] which were first introduced by Stanislaw Lem in his science fiction writings. It is strange that up to now nobody was trying to incorporate this notion into the rigorous science. The amplification or annihilation of probabilities at boundaries may also be connected with sudden change of the values of the Planck constant in very narrow domains of space. The discontinuity of wave functions can be discussed only for problems defined in restricted domains of space. For, for example, the hydrogen atom it is vague because the only boundary conditions are put at infinity. For problems with barriers, so widely considered in solid state physics and in nanotechnological problems, the discontinuous boundary conditions lead to shifts in the wave number spectrum and correspondingly to the rearrangements of the energy spectrum. The shift of the ground state energy means the appearance of some new kind of vacuum energy because the only way to explain the emerging of the ground state energy is to treat it as some kind of the quantum mechanical vacuum energy. The case with smoothly changing Planck constant is much more complicated. So, we restrict ourselves only to the simple example.

Simple Example

From the constitutive relation (12) - (14) with variable Planck constant instead of the Schroedinger equation we get the equation

$$-\frac{1}{2M}\partial^k\left[\hbar^2(x,t)\partial_k\Psi(x,t)\right]+V(x,t)\Psi(x,t)=i\frac{\partial}{\partial t}\left[\hbar(x,t)\Psi(x,t)\right], \qquad (20)$$

which may be rearranged into the form

$$-\frac{\hbar^2}{2M}\left[\partial_k-(\partial_k\ln\hbar)\right]\left[\partial_k-\partial_k(\ln\hbar)\right]\Psi+\mathbf{V}\Psi=i\hbar(\partial_t-\partial_t\ln\hbar)\Psi, \qquad (21)$$

where

$$\mathbf{V}=V+\frac{\hbar^2}{2M}\left[\Delta\ln\hbar-(\nabla\ln\hbar)^2\right], \qquad (22)$$

This form shows that the changing Planck constant introduces both new interaction (the expression in the square bracket) and a special gauge field with vanishing classical electromagnetic field. We have therefore to do with some kind of the Aharonov -Bohm effect induced by the variation of Planck constant. Unfortunately, at the moment we do not know what the variation of the Planck constant is. Therefore, we must go to some particular models which however will spoil the universality of our consideration. Another way of proceeding is to consider the Planck constant as a dynamical field with its own field equation. The Schroedinger theory is the only case for which we know how to introduce variable Planck constant. For relativistic equations arising from the constitutive relations (15) and (16) the primary location of the Planck constant is not clear. But due to our unification of all spacetime symmetries into one de Sitter symmetry we may start from the Schroedinger equation and end up with Lorentz covariant theory.

Conclusions

We have shown that basic equations of all fundamental physical theories can be derived from one universal and simple set of primary equations which do not contain any physical constants. All necessary constants appear through constitutive relations which define the concrete physical situation to which the primary equations have to be applied. Our scheme allows the unification of all particular theories into one more elegant and simple supertheory. In the framework of such theory we may vary the fundamental physical constants replacing them by functions of spacetime coordinates. This leads to a significant extension of possible physical systems which may be subjected to theoretical description.

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