Review Article

Science Set Journal of Physics

Information, Matter, Energy …

Yuriy Zayko*

Russian Presidential Academy of National Economy and Public Administration: Stolypin Volga Region Institute, Russia, 410031, Saratov, Sobornaya st, 23/25

***Corresponding author:** Yuriy Zayko, Russian Presidential Academy of National Economy and Public Administration: Stolypin Volga Region Institute, Russia, 410031, Saratov, Sobornaya st, 23/25.

Submitted: 31 May 2024 **Accepted:** 06 June 2024 **Published:** 13 June 2024

Citation: *Yuriy Zayko (2024 Information, Matter, Energy … Sci Set J of Physics 3(3), 01-05.*

Abstract

The article discusses issues of information transfer in various physical processes. Quantum tunneling, focusing of a spherical electromagnetic wave, and the physics of the early universe are considered. It is shown that in all these processes there is an instantaneous transfer of information, which distinguishes this phenomenon from material phenomena characterized by a finite speed of flow, not exceeding the speed of light. Exact solutions of the Maxwell-Einstein equations of wave and non-wave nature are found. It is shown that the crosslinking of these solutions at the boundary of their existence leads to the disappearance of the singularity at the focal point of a spherical electromagnetic wave. It is noted that these solutions help to construct a theory of the behavior of the early universe that does not have singularities, in contrast to the well- known Friedman-Robertson-Walker model.

Keywords: Information, Schrödinger Equation, Maxwell-einstein Equations, Friedman- Robertson-Walker Model, Singularity, Big Bang.

Introduction

N. Wiener owns the statement: "Information is information, not matter or energy...", which is usually cited in computer science textbooks as confirmation of the fundamental nature of the concept "information", and the impossibility of reducing it to other fundamental concepts, including in this case matter and energy. But this is not a complete quote. The full text looks like this:" Information is information, not matter or energy. No materialism which does not admit this can survive at the present day" [1]. The second half of the quote is rarely mentioned, but it is just as important, as shown below.

If no one will dispute the truth of the first half of the quote, then with the second the situation is somewhat more complicated. Let us explain this with a few examples to illustrate its importance.

For example, in the increase in entropy of a Kerr black hole when a certain particle falls onto it is calculated [2]. In this case, along with the particle under the horizon of the black hole, all the information carried by it is lost. To avoid an obvious contradiction with N. Wiener's concept, the loss of minimal information (1 bit) is considered, which consists in the very fact of its existence before being absorbed by a black hole. One can hope that the result will "survive" due to this limitation [2].

In contrast, in numerous works devoted to tunneling (see below), N. Wiener's concept was neglected, which will prevent their "survival".

If we follow the concept of N. Wiener, then some questions regarding in- formation, for example, the speed of its propagation, should be interpreted differently than in the cases of matter and energy in order to avoid the emergence of paradoxes regarding the speed of information transmission.

As shown below, the correct approach to information processes not only ex- plains (or rather, eliminates) the noted paradoxes, but also requires a radical re- structuring of ideas about the structure of space-time, especially in extreme conditions, characteristic, for example, of the early universe.

[1]The review provides a reference to Hartman's work and earlier works [5, 6]. At the same time, an interpretation of the phenomenon is given with an emphasis on superluminal speeds of the wave packet. Without going into priority disputes, let's focus on the essence. The superluminal (c > 299792,458 m/s) speed of a packet constructed from solutions of the Schrödinger equation does not mean anything, because in the Schrödinger equation, the speed of light is $c = \infty$, so there is no reason to talk about a paradox [4] (Hartman's paradox [6]).

Information Transfer in Tunneling

The problem of time spent on tunneling through a potential barrier was considered by E. Kane [3, 4]. As follows from quantum mechanical calculations, a wave packet falling on a potential barrier of finite width appears at its output be- fore falling on it1. Subsequently, this result was repeatedly reproduced in calculations, accompanied by speculation on the topic of superluminal propagation of signals and the like (see review [5]). The correct interpretation of the phenomenon is given in, where the tunneling of a wave packet in a one-dimensional problem in a system of two symmetric potential wells separated by a central potential barrier is considered [4]. This example is convenient in that it allows us to trace the difference between the passage of a wave packet entirely through a potential barrier, which characterizes a material process, and the transfer of information under the same conditions.

Let us consider the state described by the solution of the nonstationary one- dimensional Schrödinger equation, corresponding to one level with energy E0 in one of the rectangular wells of a two-well symmetrical structure separated by a central potential barrier [4]. Due to tunneling, this level has a finite width $\delta E << E_0$, and the state corresponding to the particle being in the left well at time t = 0 looks like

$$\Psi = 2exp(-iE_0 t/\hbar)[\Psi_L cos(\delta E t/\hbar) + i\Psi_R sin(\delta E t/\hbar)] \quad (1)$$

ΨL,R – describe states in the left (right) isolated wells. The complete transition of the particle to the right well will occur after time $t = \pi\hbar / 2\delta E >> T$, here $T \sim \hbar / E0$ - period of oscillation of a particle in an isolated well. Δt is the time characterizing the speed of energy (material) processes in the structure under consideration.

On the other hand, for small t, we receive from (1)

$$\Psi \sim 2(1 - iE_0 t)\Psi_L + 2i\delta E t \Psi_R \quad (2)$$

From (2) it follows that information about the presence of a particle in the left well enters the right well instantly, which is quite natural, because for this it is not necessary to present the particle itself.

The same can be obtained when taking into account several levels. Indeed, the wave function in the case of taking into account only two levels (denoted 0.1) looks like [7]

$$\Psi = \Psi^0 + \Psi^1 = exp\left(-\frac{iE_0 t}{\hbar}\right)\left[\left(\Psi_L^0 + \Psi_R^0\right)exp\left(\frac{i\delta E_0 t}{\hbar}\right) + \left(\Psi_L^0 - \Psi_R^0\right)exp\left(-\frac{i\delta E_0 t}{\hbar}\right)\right] + exp\left(-\frac{iE_1 t}{\hbar}\right)\left[\left(\Psi_L^1 + \Psi_R^1\right)exp\left(\frac{i\delta E_1 t}{\hbar}\right) + \left(\Psi_L^1 - \Psi_R^1\right)exp\left(-\frac{i\delta E_1 t}{\hbar}\right)\right] \quad (3)$$

$E_{0,1}$ – energies of the levels ($E_1 > E_0$) which are corresponded the states $\Psi_{L,R}^{0,1}$ in the left and right wells correspondingly, 2δE0,1- splits of the levels due to tunneling through the central barrier (δE0<< δE1). At the moment t = 0

$$\Psi(0) = 2\left[\Psi_L^0 + \Psi_L^1\right] \quad (4)$$

which corresponds to the state of the particle in one half of the left well. For arbitrarily small t, from (3) we obtain an expression for TR, which describes the state of the particle in the right well

$$\Psi_R = \frac{2it}{\hbar}\left[\delta E_0 \Psi_R^0 + \delta E_1 \Psi_R^1\right] \quad (5)$$

which allows one to judge by the state of the particle in the right well about its initial state in the left one. At the same time, it is an arbitrary little time to transmit information, in other words, information is transmitted instantly.

It makes no sense to talk about an infinite speed of information transfer, since the very concept of speed for tunnel processes loses its meaning. Indeed, the concept of speed is applicable to wave processes only in the case when particle- like solutions can be constructed from solutions of the wave equation, be it the Schrödinger equation (SE) or Maxwell's equations, which is only possible for real wave numbers, or, in the case of SE, motion in potential well, but not under the potential barrier, where the wave number is imaginary.

Focusing a Spherical Electromagnetic Wave

The problem of focusing a spherical electromagnetic wave is an example of a problem illustrating the phenomena discussed. For a long time, it did not enjoy the attention it deserved. This is apparently explained by two reasons. On the one hand, its solution within the framework of Maxwell electrodynamics seems obvious and does not require separate consideration. However, attempts to solve it using Maxwell's equations encountered unexpected difficulties and required non- trivial methods, for example, the idea of fictitious sources [8]. This indicates the artificial nature of the solution and makes it difficult to interpret.

On the other hand, the presence of a singularity in the solution of Maxwell's equations near the focus of a spherical wave indicates that it is not physical. This state of affairs can be eliminated by assuming that the problem cannot be solved within the framework of Maxwell electrodynamics. The solution can be found if we take into account that the field of the light wave, being an effective source of gravity, at least near the specified focus, must be described by the solution of the joint system Maxwell's equations and Einstein's equations of gravity. This problem was posed and partially solved in the author's works (see, for example, [9, 10]).

Let us briefly describe the problem statement and results. The task is to find solutions to the Maxwell-Einstein (ME) system of equations:

$$R_{ik} - \frac{1}{2}g_{ik}R = \frac{8\pi K}{c^4}T_{ik}; F_{,k}^{ik} + \Gamma_{kl}^{l}F^{ik} = 0 \quad (6)$$

Here R – is a trace of the Ricci's tensor R^i_k: R = R^i_i, g_{ik}–is a metric tensor; T_{ik} and F_{ik}– are the energy-momentum and the electromagnetic tensors; Γikl – Christoffel symbols; K – constant of gravity; indices i, k, l = {0, 1, 2, 3}; summation is per- formed over repeating indices; the comma denotes the usual one, i.e. non-covariant derivative [11]. We study solutions (6) in which a spherical convergent electro- magnetic wave is present at spatial infinity.

The tensor T^{ik} looks like [11]

$$T^{ik} = \frac{1}{4\pi}\left(-F^{il}F_l^k + \frac{1}{4}g^{ik}F_{lm}F^{lm}\right) \tag{7}$$

The metric corresponding to our task is given in the form

$$ds^2 = g_{00}c^2dt^2 + g_{11}dr^2 - r^2\left(d\theta^2 + \sin^2\theta \cdot d\phi^2\right)$$
$$g_{00} = e^{-\alpha} = -g_{11}^{-1} \tag{8}$$

For the possibility of such a choice of metric, see [10]. In (8), the quantity α(r) is introduced, through which it is convenient to express the solution. As shown in [9, 10], from equations (6) we can obtain an equation for the radial part of the compo- nent F01=Ψ(r,t)Pl(θ), here Pl(θ) – Legendre polynomial of order l :

$$\frac{\partial}{\partial r}\left[e^{-\alpha}\frac{\partial f}{\partial r}\right] - e^{\alpha}\frac{\partial^2 f}{c^2\partial t^2} - \frac{l(l+1)}{r^2}f = 0, f = r^2\Psi$$
$$e^{\alpha} = \pm\frac{\partial f}{\partial r}\left(\frac{\partial f}{c\partial t}\right)^{-1} \tag{9}$$

Below, in contrast to works, where approximate solutions to (9) were studied, the exact solution is given [9, 10]. It looks like

$$f(r,t) = f_0 \exp\left(\pm i\frac{r_c}{r}\right)\exp\left[e^{i\Omega(t-t_0)}\right]$$
$$r_c = \frac{cl(l+1)}{\Omega} \tag{10}$$

f0 ,Ω ,t0 - are constants. Let us explain the meaning of solution (10) for Ω($t - t_0$) << 1. In this case, (10) takes the form (up to a constant factor)

$$f(r,t) \sim \exp\left[i\Phi(r,t)\right]$$
$$\Phi(r,t) = \pm\frac{r_c}{r} + \Omega((t-t_0)) \tag{11}$$

here Φ - phase of a solution. From (11) it is easy to find the wave period T

$$T = \frac{2\pi}{\Omega} + \frac{r_c}{\Omega r} \tag{12}$$

The first term corresponds to the period of the wave with frequency Ω at infinity (r→ ∞), and the second describes the known gravitational redshift [11].

In addition to solutions of the form (10), the ME equations have solutions of a non-wave nature

$$f(r,t) = f_0 \exp\left(\pm\frac{r_c}{r}\right)\exp\left[e^{i\Omega(t-t_0)}\right] \tag{13}$$

which makes us assume the "tunnel" nature of the transformation of a convergent wave into a divergent one.

The expression for metric (8) corresponding to solutions (10) and (13) has the form (for Ωt << 1)

$$g_{00} = l(l+1)\left(\frac{r}{r_c}\right)^2, g_{11} = -g_{00}^{-1} \tag{14}$$

At first glance, it has a singularity at r = 0. In fact, it is a fictitious singularity, since the quantity $g = det(g_{ik})$ is finite at this point. On the other hand, the vanishing of goo at the origin of coordinates (at the focus of the electromagnetic wave) has a physical meaning: "turning off" time at the point where the red shift reaches an in- finite value. As a result, all processes, including the transformation of a convergent spherical wave into a divergent one, occur with "turned-off" time, i.e. instantly. The role of this instantaneous transformation is especially significant in extreme conditions, for example in the early stages of the development of the Universe.

Let's consider the properties of solution (10) in details. To do this, let's imagine it as

$$f(r,t) = f_0 e^{Cos(\Omega\tau)} e^{i\left[\pm\frac{r_c}{r} + Sin(\Omega\tau)\right]}$$
$$\tau = t - t_0 \tag{15}$$

The constant value of the solution's (15) phase is determined by the equation

$$r = \frac{\mp r_c}{Sin(\Omega\tau)} \tag{16}$$

The ± signs correspond to convergent and divergent waves. Equation (16) defines the propagation of the front, i.e., the surface of the constant (zero2) phase of the solution and allows us to get an idea of the behavior of a spherical EMW, taking into account the influence of its gravitational field. Wave solutions of the ME equations
(6) exist in the domain r > rc and present time-alternating packets of convergent and divergent waves. In the domain r < rc solutions of the form (11) exist that make it possible to stitch convergent and divergent waves. To do this, we write down a general expression for the space part of the solution in the areas r < rc and r > rc

$$f(r) \sim \exp\left(i\frac{r_c}{r}\right) + R\exp\left(-i\frac{r_c}{r}\right), r > r_c$$
$$f(r) \sim A\exp\left(\frac{r_c}{r}\right) + B\exp\left(-\frac{r_c}{r}\right), r < r_c \tag{17}$$

Stitching these expressions together at r = rc, we find the values of the reflection coefficient R and the coefficient B with decreasing exponent at r → 0 under the additional condition f(r = 0) = 0, ensuring the absence of an electromagnetic field singularity.

[2] This value was chosen based on the goals of further application in cosmology

The last condition immediately allows you to find A = 0. Here is the final result

$$R = -ie^{2i}$$
$$B = (1-i)e^{1+i} \tag{18}$$

Thus, taking into account the intrinsic gravitational field of a spherical electromagnetic wave eliminates the singularity at its focus point. In a sense, this is a kind of analogue of the principle of cosmic censorship [12]: the singularity at the point r = 0 is surrounded by a sphere of radius rc, into which the wave solutions of the ME equations do not penetrate, i.e. there is no information exchange between this sphere and its environment.

Dynamics of the Early Universe

The dynamics of a homogeneous and isotropic universe is described within the framework of the Friedman–Robertson–Walker (FRW) model, the metric of which is given by the expression [12]:

$$ds^2 = c^2dt^2 - a^2(t)\left[\frac{dr^2}{1-kr^2} + r^2\left(d\theta^2 + sin^2\theta d\varphi^2\right)\right] \tag{19}$$

k = (-1, 0, 1) – curvature index determined by the type of Friedman model (open, flat, closed), a(t) is a model parameter (scalar factor) determined from Ein- stein's equations [12].

The evolution of the universe in the FRW model is completely determined by the parameter a(t). Its behavior as a function of time depends on the behavior of densities of matter, radiation and vacuum energy as a functions of a(t). All these quantities are determined based on the first law of thermodynamics, which ex- presses the law of conservation of energy [12]:

$$\frac{d}{dt}\left[\rho_c(t)a^3(t)\right] = -p_c(t)\frac{d}{dt}\left[a^3(t)\right] \tag{20}$$

ρc – energy density, pc – pressure of corresponding component. From Einstein's equations follows the equation for a(t) [12] (k = 0)

$$\dot{a}^2 - \frac{8\pi\rho}{3}a^2 = 0 \tag{21}$$

ρ - total energy density, the dot means the derivative with respect to time t. Equation (21) can be solved for each component separately, which makes it possible to determine the dependence ac(t) for cases of dominance of each component: c = m (dust matter), c = r (radiation), c = v (vacuum) [12]

$$a_m(t) = \left(\frac{t}{t_0}\right)^{2/3}, a_r(t) = \left(\frac{t}{t_0}\right)^{1/2}, a_v(t) = e^{H(t-t_0)} \tag{22}$$

here a(t0) = 1 – normalization condition, и H 2 = Λ / 3, Λ – cosmological constant, t0 – the moment in time at which the observation is performed [12]. Cases of dominance of matter and radiation are characterized by a singularity at t = 0, corresponding to the big bang and characterized by an infinite energy density of both matter and radiation.

Note that the results obtained in Section 3 allow us to obtain information about the behavior of the universe in the immediate temporal vicinity of the big bang.

Let us note that the presented picture of the dynamics of the universe is not applicable for this purpose, since in it matter (including radiation) acts as a background against which gravitational phenomena play out that do not affect the background [12]. Near the big bang, when the energy density, determined mainly by radiation, tends to infinity, the inverse effect of space-time curvature on the behavior of matter (radiation) can no longer be neglected, and a rigorous solution to the problem requires a joint solution of the Einstein equations and the equations of dynamics that determine the behavior of matter (radiation). Such equations in the case of radiation dominance are Maxwell's equations. Thus, we come to the problem considered in the previous section. The main difference is the difference be- tween metrics (19) and (8). But this is not surprising, because they describe the universe at different stages of its development. Metric (19) is applicable to describe the developed universe far (in time) from the big bang, while metric (8) is applicable in the immediate vicinity of it, where metric (19) is generally unfair and, more- over, has a singularity which has no physical explanation. Metric (8) does not have a singularity and is physical, since it allows us to do without the idea of infinite density at the moment of the big bang (as well as the concept of the big bang it- self). It also makes it possible to combine, within a single theory, the behavior of the expanding phase of the universe with the preceding phase, characterized by compression without the emergence of a singularity. For problems describing this process within the framework of traditional classical cosmology, see [12][3].

Thus, metrics (8) and (19) complement each other, and metric (8), by virtue of the above-mentioned generalized principle of cosmic censorship, "corrects" the non-physical disadvantage of metric (19) by "prohibiting" its use in the immediate vicinity of the big bang singularity.

Conclusion

The article discusses issues of information transfer in various physical processes. Quantum tunneling, focusing of a spherical electromagnetic wave, and the physics of the early universe are considered. It has been shown that quantum tunneling is characterized by instantaneous transmission of information about states on opposite sides of the potential barrier through which tunneling occurs. To solve the problem of focusing a spherical electromagnetic wave (EMW), the Maxwell- Einstein (ME) equations are used, which allow us to take into account the influence of the gravitational field of the wave near the focus. Exact solutions of the ME equations and the corresponding metric that determines the structure of space- time are obtained. The

[3]A detailed discussion of these issues is beyond the scope of this article.

presence, along with wave solutions of the ME equations, of non-wave solutions suggests that the process of focusing the EMW and converting a convergent EMW into a divergent one occurs by tunneling between the vacuums corresponding to the convergent and divergent EMW [10]. It is noted that the solutions obtained are applicable to describe the behavior of the universe directly in the temporal vicinity of the big bang, where the contribution to the energy density is determined mainly by radiation and where the generally accepted Fried-man- Robertson-Walker model loses its meaning. The developed method makes it possible to get rid of non-physical singularities that appear within the framework of the traditional approach.

References

1. Wiener N (1948) Cybernetics: Or Control and Communication in the Animal and the Machine. Paris, (Hermann & Cie) & Camb. Mass. (MIT Press) ISBN 978-0-262-73009-9; 2nd revised ed. 1961.
2. Bekenstein JD (1973) Black Holes and Entropy. Phys. Rev. D 7: 2333-2346.
3. Kane EO (1961) Theory of Tunnelling. J. Appl Phys 32: 83-91.
4. Kane EO (1969) Basic Ideas about Tunneling. Tunneling Phenomena in Sol- ids, Ed. by E. Burstein and S. Lundqvist, Plenum Press, NY.
5. Shvartsburg AB (2007) Tunneling of electromagnetic waves - paradoxes and prospects. Rus. Phys. Uspehi 177: 43-58.
6. Hartman TE (1962) Tunneling of a Wave Packet. Appl. Phys 33: 3427.
7. Zayko YN (2014) Synchronization of Sources of Radiation with the Help of Tunneling. Physical Science International Journal 4: 954-961.
8. Kuligin VA (1975) Wave behavior in the vicinity of focus. In Problems of scattering and optimal receiving of radio waves. Proc. of Voronezh state Univ., Voronezh.
9. Zayko Yu N (2010) Exact solutions of the Maxwell-Einstein equations. Proceedings of the Saratov State University. New Series, Physics Series 10: 50-58.
10. Zayko YN (2016) Influence of Space-Time Curvature on the Light Propagation. SCIREA Journal of Physics 1: 83-93.
11. Landau LD, Lifshitz EM (1975) The Classical Theory of Fields. (4th ed.). Butterworth-Heinemann 2.
12. Hartle JB (2003) Gravity. An Introduction to Einstein's General Relativity. Pearson Education, Inc., publishing as Addison Wesley, 1301, Sansome St., San Francisco.