Research Article

New Evidence for the Presence of Photon Mass and Experiments to Reveal It

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Abstract

Introduction: The work relates to the basics of quantum physics, photonics and optics, in particular – to photons in their two states: as elementary particles and their electromagnetic radiation. The study of these problems is necessary for a better understanding of the basics of the structure of the material world and the general development of scientific knowledge about the Universe, which is an urgent and important task, to which the works of many scientists of the world throughout the recorded history of mankind. However, all the problems of determining the parameters of photons have not been fully resolved. Especially for the mass of photons, since its absence is a unique phenomenon in the Universe and no other free physical particle has such properties. This contradiction to the general rules of the existence of known physical particles in the material world, as electromagnetic field waves and as matter particles, requires its thorough justification, which is the main goal of the work being performed. Its scientific novelty is the justification of the existence of the mass of photons and the development of an experiment for its detection. The research is based on the parameters of the light range of 380...760 nm, for which the speed of movement is strictly known, equal to the speed of light c, but the energy indicators are not infinite, which contradicts the Lorentz γ-factor.

New Results of The Work: More than 20 experiments are known that show the presence of photon mass based on its secondary features. In this case, the 1st experiment is the curvature of light rays revealed in the solar eclipse of 1919, since the error in calculating the deviations of the rays based on Newton's law of universal gravitation was corrected for them. In addition, the errors of the relativistic mass and energy of photons based on the tendency to 0 of the Lorentz γ-factor were corrected, since there are no 0 quantities in the real material world. With in the framework of the laws of dialectics, 0 is the absence of everything, including matter, which contradicts the laws of conservation of energy and mass. It follows from this that all zero values are overcome by a quantum leap and these final values for length, time, energy and mass were found. On this basis, the photon mass is strictly substantiated and an experiment for its determination is proposed.

Conclusions: Strict substantiations for the presence of the photon mass have been found, which do not contradict the known real laws of physics. All laboratories and researchers with such capabilities are invited to conduct an experiment to identify it.

Keywords: Photon as a Wave and Elementary Particle, Lorentz γ-Factor and Its Real Connection with the Size, Mass and Energy of Photons, Energy Mass of Photons, Its Calculation and Experimental Determination

1. Introduction

The work concerns the basics of quantum physics, photonics and optics, in particular – to photons in their two states: as elementary particles and their electromagnetic radiation. The study of these problems is necessary for a better understanding of the basics of the structure of the material world and the general development of scientific knowledge about the Universe, which is an urgent and important task, to which the works of many scientists of the world throughout the entire recorded history of mankind [1-3]. However, all the problems of determining the parameters of photons have not been fully resolved. This is especially true of the mass of photons, since its absence is a unique phenomenon in the Universe and no other free physical particle has such properties, except for hypothetical gluons, which do not exist in a separate state, but exist only inside the nuclei of atoms, as products of their interaction [4]. All other physical

particles exist in two forms of matter: as waves of the electromagnetic field and substance particles. This contradiction to the general rules of the existence of known physical particles in the material world and the exception for photons requires its thorough justification, since there are no explicit physical laws prohibiting the mass of photons, there are only 2 axioms:

1st axiom – if there is a gravitational mass of photons (rest mass $m\gamma_0$) moving at the speed of light c, it must be infinite within the framework of the relativistic γ-factor of Lorentz 2nd axiom – photons do not have a rest mass $m\gamma_0$, since without movement at a speed $v\gamma$, which is equal to the speed of light c, they do not exist [1,5].

In addition to these axiomatic confirmations of the absence of a gravitational rest mass of photons, there are a number of others that are substantiated by the physical laws of light diffraction on its way from distant stars and its deviation when passing near massive astronomical objects, which are galaxies and stars [1]. However, there are deviations in motion, which are confirmed by the experiments of Eddington and Davidson, which were conducted during the Solar Eclipse of May 29, 1919, but they were recognized as confirmation of Einstein's general theory of relativity, in which the action of gravity was replaced by the curvature of space [6,7]. It was after this experiment that the validity of the theory of relativity was finally recognized and as an addition to it - the mass lessness of the photon [8]. It should be noted that this recognition did not eliminate the contradictions between the mass lessness of photons and the dual basis of all other physical particles of the material world. The elimination of these contradictions is the main goal of the work being carried out. However, this requires a thorough analysis of the state of this problem.

1.1. Analysis of the State of the Problem

It is known that in modern scientific theories, a wide range of electromagnetic radiation with wavelengths from $\lambda > 10^8$ m to $< 10^{-16}$ m and the oscillation frequency of their waves $v < 100$ Hz to $> 10_{24}$ Hz without strict limits s, which is shown in Figure 1 [1,9].
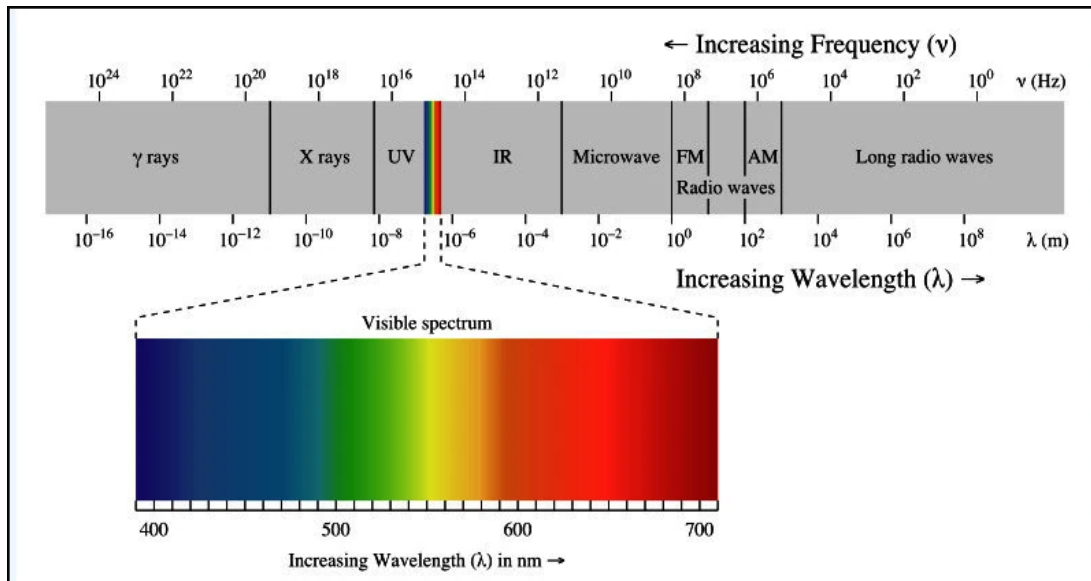
Figure 1: Modern Understanding of Wavelengths and Frequencies of their Oscillations within the Framework of Electromagnetic Radiation [9].

However, in [10-12] these limits were expanded and the boundaries of the maximum possible wavelengths of electromagnetic radiation and their oscillation frequencies in the entire material world were found. For the lower threshold, they are determined from the dependence (1) of the relationship between wavelengths l and their oscillation frequencies v [1]. It was taken into account that the frequency cannot be less than $v_{min} = 1$ Hz. or 1 s^{-1} and $t_{max} = 1/v_{min} = 1$ s. since at smaller values the speed of light in a vacuum $c = 0.299792458 \cdot 10^9$ m/s [7, 13] will be exceeded, which limits the speeds of all known interactions in the material world, which follows from the dependence (1), which gives the maximum wavelength (2) [1]:

$$c = \frac{\lambda_{max}}{t_{max}}\left(\frac{m}{s}\right). \tag{1}$$

$$\lambda_{max} = ct_{max} = 0.299792458 \cdot 10^9 \ (m/s) \times 1(s) = 0.299792458 \cdot 10^9 \ (m). \tag{2}$$

When determining the upper limit of wavelengths and frequencies of their radiation, the previously known Planck values of length l_P

(3) and time t_P (4) [14] were taken into account, which were obtained on the basis of only three fundamental physical constants c, h, G:

$$l_p = \sqrt{\frac{hG}{c^3}} = \sqrt{\frac{6.62607015 \cdot 10^{-34} \left(\frac{kg \cdot m^2}{s} \right) \cdot 6.67430 \cdot 10^{-11} \left(\frac{m^3}{kg \cdot s^2} \right)}{\left[0.299792458 \cdot 10^9 \left(\frac{m}{s} \right) \right]^3}} = 0.405135 \cdot 10^{-34} \, (m), \quad (3)$$

$$t_p = \sqrt{\frac{hG}{c^5}} = \sqrt{\frac{6.62607015 \cdot 10^{-34} \left(\frac{kg \cdot m^2}{s} \right) \cdot 6.67430 \cdot 10^{-11} \left(\frac{m^3}{kg \cdot s^2} \right)}{\left[0.299792458 \cdot 10^9 \left(\frac{m}{s} \right) \right]^5}} = 0.135138 \cdot 10^{-42} \, (s), \quad (4)$$

where h– Planck's constant [13]:

$$h = 6.62607015 \cdot 10^{-34} \, (exactly) \, J \cdot s = 6.62607015 \cdot 10^{-34} \, (exactly) \frac{kg \cdot m^2}{s},$$

$$G - \text{gravitational constant: } G = 6.67430(15) \cdot 10^{-11} \frac{m^3}{kgs^2}. \, [13],$$

Planck himself considered l_p, t_p to be only abstract mathematical quantities with dimensions m and s, since he did not find their analogues in the material world [14]. However, the reality of l_p was first substantiated in [15] due to its connection with the spheres of Planck thickness, which, layer by layer, one after another, cover the entire spherical space of the visible Universe, and the reality of t_P follows from the time of passage of this layer at the speed of light c (5):

$$t_P = \frac{l_P}{c} = \frac{0.405135 \cdot 10^{-34} \, (m)}{0.299792458 \cdot 10^9 \left(\frac{m}{s} \right)} = 0.135138 \cdot 10^{-42} \, (s). \quad (5)$$

Further, their reality is confirmed by the connection with the wave parameters of the gravitational field of the Universe through the oscillation frequency of their wave's v_G (6), which was obtained in [16] on the basis of the same fundamental physical constants c, h, G, as well as its connection with the Unified Field of the Universe, substantiated in [17]:

$$v_G = \sqrt{\frac{c^5}{Gh}} = \sqrt{\frac{\left[0.299792458 \cdot 10^9 \left(\frac{m}{s} \right) \right]^5}{6.67430^{-11} \left(\frac{m^3}{kg \cdot s^2} \right) \cdot 6.62607 \cdot 10^{-34} \left(\frac{kg \cdot m^2}{s} \right)}} = 7.39982 \cdot 10^{42} \, (s^{-1}). \quad (6)$$

The final recognition of the reality of l_p, t_p, v_p is their derivation only on the basis of real physical constants c, h, G, according to strict physical dependencies, which makes them real secondary constants of the material world [18].

The complete scheme of waves and frequencies of electromagnetic radiation is shown in Figure 2. In this case, the upper limit of the wavelength is limited by the value $\lambda_{min} = 4.05 \cdot 10^{-35}$ m, and the frequency of their radiation is limited by the value $v_{max} = 0.74 \cdot 10^{42}$ Hz, which is associated with the low accuracy of determining the gravitational constant G. As it increases her, the accuracy of the upper limits of the wavelengths and frequencies of their radiation will be increased.
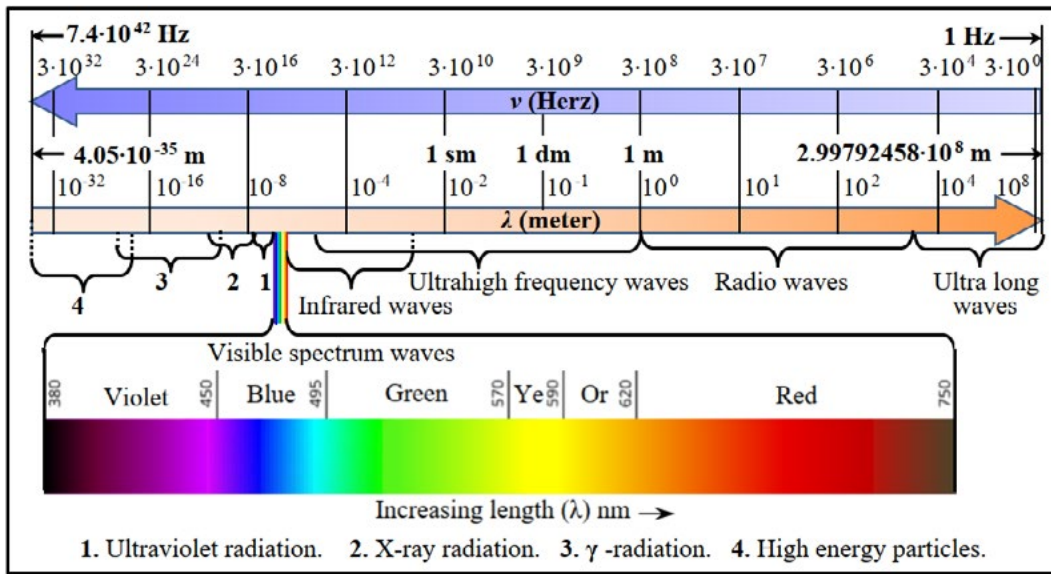
Figure 2: The Full Range of Wavelengths and Frequencies of their Oscillations in Electromagnetic Radiation.

The establishment in [10-12] of the limiting values of wavelengths and frequencies of electromagnetic waves, within the framework of modern ideas about the infinity of the parameters of the material world, is a new scientific achievement. Further, the principles of the finiteness of physical quantities in the material world are the basis of the work being performed, the main attention in which is paid to the size-mass indicators of photons within the framework of Lorentz's γ-relativism [5]. It is based on the γ-factor (7), which leads to the emergence of infinite quantities of length (8), time (9), mass (10) and energy (11) when the speed v_i of motion of a physical object approaches the speed c of light in a vacuum, which is recognized as one of the main provisions of GTR [7]:

$$\gamma = \sqrt{1 - \frac{v_i^{\,2}}{c^2}}. \tag{7}$$

$$l_\gamma = \frac{l_o}{\sqrt{1 - \frac{v_i^{\,2}}{c^2}}}\,(m). \tag{8}$$

$$t_\lambda = \frac{t_o}{\sqrt{1 - \frac{v_i^{\,2}}{c^2}}}\,(s). \tag{9}$$

$$m_\gamma = \frac{m_o}{\sqrt{1 - \frac{v_i^{\,2}}{c^2}}}\,(kg). \tag{10}$$

$$E_\gamma = \frac{E_o}{\sqrt{1 - \frac{v_i^{\,2}}{c^2}}}\,(J). \tag{11}$$

where l_0, t_0, m_0, E_0 – initial length, time, mass and energy of the physical object;
l_γ, t_γ, m_γ, E_γ – are the relativistic length (m) time (s), mass (kg) and energy (J) of the physical object;
v_i – is the real speed of the physical object.

In the general wave range (Figure 2), one should distinguish the spectrum of light from 0.380 to $0.760 \cdot 10^{-6}$ m, which is visible to the human eye. It was from this spectrum that the research and study of the parameters of light began, and it was for this spectrum that the speed of light was determined in the experiments of Fizeau [19], Foucault [20] and others [21], which in the 20th century led to the value $c = 0.299792458 \cdot 10^9$ m/s (exact), which is recognized as an exact value in SI [22].

The choice of this wave range in further research is due to the fact that the speed of light, the length and energy of their waves are reliable values, which are confirmed by a large number of experiments. It is proposed to call them photons, and all other values of wavelengths and their frequencies – quanta of electromagnetic radiation. This allows to avoid ambiguity in the interpretation and understanding of a number of scientific results, where X-ray and γ radiation are considered to be photons. Therefore, photons should be considered a dual state of physical objects in the wavelength range from 0.380 to $0.760 \cdot 10^{-6}$ m, in which a photon is a wave of electromagnetic radiation

when it moves at the speed of light c and when it decelerates and its speed is reduced to 0 at the moment the photon meets an obstacle, it becomes a real of substance particle. This reduces the photon to ballistic photons, the parameters of which and the scheme of their motion are given in [11, 12]. This approach meets the general features of dualism of all known physical particles, in which, as their speed increases, wave properties are more pronounced, and as their speed decreases, the properties of particles and substance are more pronounced [1]. The identification of the photon as a physical particle is confirmed in [23] and in a number of other works, the analysis of which goes beyond the scope of the tasks of the work being performed.

The study of light has been studied by philosophers and thinkers since ancient times [2, 3]. However, these were mainly philosophical arguments. The real scientific foundations were laid in the 17th century. At first, these were the wave principles introduced in the works of René Descartes (1637) [24], Robert Hooke (1665) [25] and Christiaan Huygens (1678) [26]. But they were pushed into the background by the "atomism" of Pierre Gassendi (1649) [27] and the corpuscular theory of light proposed by Isaac Newton, presented in 1704 [28]. Newton's authority gave great advantages to his theory, which faded into the background only in 1800-1801, after the experiments of Thomas Young [29] and Augustin Fresnel (1816) [30], which proved the wave nature of light. Since then, the masslessness of the photon has been recognized. In 1865, James Clerk Maxwell theoretically substantiated the parameters of electromagnetic radiation and light waves [31], which were confirmed experimentally in 1888 by Heinrich Hertz [32]. However, the complete triumph of the wave theory was shaken in 1887, when the Michelson-Morley experiments did not reveal the presence of the "ether" necessary for the transmission of electromagnetic waves [33]. Further experiments in 1899 by Pyotr Lebedev on light pressure [34], the substantiation of the photoelectric effect in 1905 by Albert Einstein [35], the effect of photon scattering discovered in 1923 by Arthur Compton [36] and the development of quantum theory after the work of Max Planck in 1900 [37], led to a complete confrontation of the wave and corpuscular theories of light, and this quantum principle extends to the entire range of electromagnetic waves. And only in 1928 the work of Louis de Broglie on the corpuscular-wave duality of physical particles [38], within the framework of which visible light simultaneously has both wave properties, explaining its ability to diffraction and interference, and corpuscular properties, explaining its ability to absorb and emit, led to the unification of both theories.

However, currently attempts are continuing to replace the dual basis of light with only a wave basis, with the rejection of the photon as a physical particle, which follow from the absence of its mass, which is the subject of heated debates on the ResearchGate platform [39-41]. But they led to a final understanding of the dual nature of the photon: as a wave when it moves at the speed of light c, and as a particle when it slows down to 0 when it encounters an obstacle. Therefore, the main problem remains the proof of the presence of mass in photons. Louis de Broglie also assumed the presence of mass in photons [38].

The totality of the presented data testifies to the need to conduct new studies to determine the mass of the photon, which is the main goal of the work being performed. Its scientific novelty is the justification of the studies being conducted and the results obtained on the basis of strict physical laws, repeatedly verified in other reliable experiments.

1.2. Research Methods
The work being performed has the level of a scientific discovery, for the discovery of which strict methods have not yet been developed [42]. Therefore, general principles of scientific research were used: deduction and induction, based on the application of the laws of dialectics [43] and general principles of the development of the theory of knowledge [44, 45]. The author's method of transition to the initial quantum level of the material world and the reliable laws of physics operating in it [1], substantiated was also used in [46, 47].

2. New Results and their Discussion
In addition to the work of Louis de Broglie [38], doubts about the absence of photon mass did not leave researchers in the 20th century, and the creation of lasers, opening up wide possibilities for conducting experiments with light beams, contributed to this. In the 70s of the 20th centuries, experiments were conducted proving the presence of inertial mass of the photon, in which a light beam was sent from a rapidly rotating upper disk to a lower one, installed at a distance of 15 m with their common vertical axis. The deflection of a light beam greater than the distance associated with the passage of this path with speed c confirms the inertia of photons, which is due to the presence of mass in them. However, this experiment was consigned to oblivion and is not mentioned in modern publications.

In addition to this experiment, other indirect signs associated with astronomical observations have been used for more than 50 years to substantiate the photon mass. In particular, the work of Sichuan University of Science and Technology, Chinese Academy of Sciences and Nanjing University appeared [48]. It analyzed data obtained from the collected array of Parks pulsar synchronization observations, as well as data on fast radio bursts from a number of sources. Having carefully studied these data, the team of researchers was able to deduce the upper limit of the photon mass in 9.52×10^{-46} kg, or 5.34×10^{-10} eV [48]. If photons have mass, then their propagation through a space filled with plasma will be affected by both the mass and the free electrons in the plasma. This will lead to the appearance of a delay time in radio signals proportional to the photon mass.

There are also more than 20 other known experimental measurements of the photon mass based on indirect signs given in [49] and in Table 1.

Table 1: Known Experiments to Determine the Parameters of the Photon Mass,
Where 1 $eV = 1.783 \times 10^{-36} kg = 1.957 \times 10^{-6}$ me; $\lambda^- C = (1.973 \times 10^{-7} m) \times (1\ eV/m\gamma)$:

№	Value (eV)	CL%	Dokument	Identifier	Comment
1	<1 × 10⁻¹⁸		RYUTOV	2007	MHD of solar wind (most reliable version)
2	<2,2 × 0⁻¹⁴		BONETTI	2017	Fast Radio Bursts, FRB 121102
3	<1,8 × 10⁻¹⁴		BONETTI	2016	Fast Radio Bursts, FRB 150418
4	<1,9 × 0⁻¹⁵		RETINO	2016	Ampere's Law in solar wind
5	<2,3 × 10⁻⁹	95	EGOROV	2014	Lensed quasar position
6			ACCIOLY	2010	Anomalous magn. mom
7	<1 × 10−26		ADELBERGER	2007A	Proca galactic field
	no limit feasible		ADELBERGER	2007A	γ as Higgs particle
8	<1 × 10⁻¹⁹		TU	2006	Torque on rotating magnetized toroid
	<1.4 × 10⁻⁷		ACCIOLY	2004	Dispersion of GHz radio waves by Sun
9	<2 × 10⁻¹⁶		FULLEKRUG	2004	Torque on rotating magnetized toroid
10	<7 × 10⁻¹⁹		LUO	2003	Torque on rotating magnetized toroid
11	<1 × 10⁻¹⁷		LAKES	1998	Torque on toroid balance
12	<6 × 10⁻¹⁷		RYUTOV	1997	MHD of solar wind
13	<8 × 10⁻¹⁶	90	FISCHBACH	1994	Earth magnetic field
14	<5 × 10⁻¹³		CHERNIKOV	1992	Ampere's Law null test
15	<1.5 × 10⁻⁹	90	RYAN	1985	Coulomb's Law null test
16	<3 × 10⁻²⁷		CHIBISOV	1976	Galactic magnetic field
17	<6 × 10⁻¹⁶	99.7	DAVIS	1975	Jupiter's magnetic field
	<7.3 × 10⁻¹⁶		HOLLWEG	1974	Alfven waves
18	<6 × 10⁻¹⁷		FRANKEN	1971	Low freq. res. circuit
19	<2.4 × 10⁻¹³		KROLL	1971A	Dispersion in atmosphere
20	<1 × 10⁻¹⁴		WILLIAMS	1971	Tests Coulomb's Law
	<2.3 × 10⁻¹⁵		GOLDHABER	1968	Satellite data

RYUTOV, BONETTI, RETINO and other – these are the authors of the work who performed the measurement. More detailed characteristics of measurement processes are given in [49]

However, all these experimental results were rejected because they did not meet the conditions of relativity and the Lorentz-Einstein γ-factor [5, 7].

The author also has personal experience in determining the mass of a photon [10, 50], these works provide descriptions based on the experiments of Professor Lebedev [34] of new real physical experiments [51, 52], the difference of which is:
1) horizontal installation of the suspension axis of pairs of balanced irradiated plates, one of which is open and the other is closed by a screen that prevents its irradiation with light;
2) irradiation of an open plate from above and below with equal flows of light, which balances its pressure and temperature effects on both surfaces.

In the case of accumulation of photons with mass on these surfaces, the equilibrium of the pair of plates is disturbed, and their tilt will be visually noted after some time of irradiation. However, their implementation is complicated by the author's lack of an experimental base.

Further in the work it was taken into account that the above axioms of mass lessness of photons recognized by most scientists in the world, including Einstein in the general theory of relativity (GTR) [7], in which gravity is replaced by the curvature of space, which made it possible to explain the deviation of the motion of light rays, which have no mass, when they pass near massive objects. It is believed that such a calculation of the deflection of the beam, performed by Einstein in 1915, was experimentally confirmed when observing the solar eclipse of May 29, 1919 [6]. This experiment compared the deflection of light rays as they passed the Sun by an angle of 1.75", which was predicted by Einstein, with the results of actual measurements by Eddington and Davidson, which were 1.61"

(Principe) and 1.93" (Sobral), as well as calculations based on the work of Johann Georg von Soldner in 1804, which gave a result of 0.87" [53], in which he used Newton's law of universal gravitation [54].

It should be noted that after Young's experiments in 1801 [28], which proved the wave nature of light, Soldner also believed that light is a wave that has no mass. Therefore, in his calculations (1804), he took into account only the kinetic energy of light $E_k = mc^2/2$ and obtained a deflection angle of the light beam of 0.84" (within the framework of modern knowledge about the speed of light and the mass of the Sun, it is 0.875"). The "5" sign was omitted in the 1919 reports [8], which concealed the possibility of obtaining Einstein's result of 1.75" by simply doubling 2×0.875, within the total energy of physical objects $E = mc^2$. But if we assume that light (photons) has mass, then their kinetic energy must be supplemented by potential energy E_G, which reflects the state of any amount of matter (mass) within the action of gravity on it. In this case, the total energy of the photon is doubled and equals the value (12), which leads to the same value of the beam rotation angle of 1.75" that Einstein obtained:

$$\Sigma E = E_k + E_G = mc^2 \qquad (12)$$

Thus, the conducted research shows that the 1919 experiment did not disprove Newton's gravity, but only confirmed the coincidence of Einstein's theory with Newton's theory [54]. But this result has a different level of significance for the development of science than the one it received after the experiment [8], since until that time the theory of relativity was considered abstract and even questionable, which is confirmed by the awarding of the Nobel Prize to Einstein not for the general relativity, but for the substantiation of the photoelectric effect [55].

From the conducted analysis of the sum of energies ΣE it strictly follows that the photon has mass, and Eddington's experiment is in fact the first case of its confirmation (at the moment there are more than 20 such experimental data, Table 1). Therefore, the 1919 experiment is not a "pure confirmation" of Einstein's theory [7], and requires the rehabilitation of Newton's theory of gravitation [55]. As the 1st experiment out of 24 subsequent ones confirming the presence of photon mass, it should be entered in Table 1.

But there is another, 25 confirmations, which is considered reliable - different speeds of light rays from one and the other edge of the galaxy during their lensing [56]. In the presence of photon mass, they are affected by the gravitational field of rotation of galaxies. The joint direction of rotation of the gravitational field and the movement of the photon slows it down less than the opposite rotation. Therefore, the value of the theory of the presence of photon mass is that it allows us to very simply explain previously incomprehensible effects occurring with light rays.

Another feature of using visible light waves is that their speed of movement is strictly defined within the speed of light $c = 0.299792458 \cdot 10^9$ m/s, which depends on the state of the medium and the influence of induced external physical fields (gravitational and electromagnetic). However, it is known that the energies and wavelengths of the light range of radiation are not infinite quantities, which contradicts the principles of γ-relativism, since photons in a vacuum actually move at the speed of light c. Therefore, it is necessary to eliminate this contradiction, which is the next task of the work being performed.

When solving it, it was taken into account that, within the framework of the current level of scientific knowledge about light and electromagnetic radiation, the energy E of light waves is strictly determined by quantity (13), which depends on the radiation frequency v and their wavelength λ, which for physical particles is related to their mass m in within the framework of Einstein's energy law [1]:

$$E_{\max} = mc^2 = hv = \frac{h}{t}(J), \qquad (13)$$

E_{max} – is the photon energy mass, which is the real value of its mass. The concept of the "rest mass" of a photon is absurd. But a photon has no relativistic mass, everything comes down to the energy mass, as shown in [50], which follows from the energy E_{max}. Photons cannot have a greater energy value, since with its increase, the oscillation frequency of their waves v increases adequately and their length λ decreases, which makes the original photons radiation of a different "color". Therefore, the value of the photon energy $E = hv$ is the maximum possible for waves of a real "color", which allows us to consider it as relativistic energy taking into account the Lorentz γ-factor. In this case, the value of their mass will also be finite, within the framework of the law on the relationship between the energy and mass of physical objects (13) [1], which is the energy mass of photons m_E (14),

$$m_E = \frac{E}{c^2} = \frac{hv}{c^2} = \frac{h}{c\lambda}(kg), \qquad (14)$$

A photon is a quantum physical value that cannot be divided further. For example, a photon of red light with a wavelength of 760 ηm cannot be divided into 2 photons with a wavelength of 380 ηm, since this does not reduce its energy, but, on the contrary, requires an

increase in its costs by $2 \times 2 = n^2$ times.

Dependence (14) on a strict physical basis allows us to consider m_E as a relativistic mass of photon. Thus, on the basis of repeatedly verified physical laws (13), (14), the presence of infinite values of energy and mass in photons is excluded, which contradicts the γ-factor Lorentz [5].

The elimination of this contradiction is proposed in the works [10, 47, 50] by means of the transition to the quantum foundations of the material world, within the framework of which there are no zero parameters in the real Universe. This is confirmed by the laws of dialectics, according to which 0 is the absence of anything, including matter, and contradicts the physical laws of conservation of mass and energy. Therefore, the compression of physical objects to zero parameters of length and mass is impossible. Zero, as a state of the absence of anything, is overcome in the real Universe by quantum leaps. For length, a quantum leap is the minimum value (3) to which a photon is compressed in the direction of its motion, forming a spherical wave in a solid angle of 1 steradian, the radius R_{Max} of which is equal to the photon wavelength λ_{Max} in the direction perpendicular to its motion (Fig. 3), which was first shown in [12]:
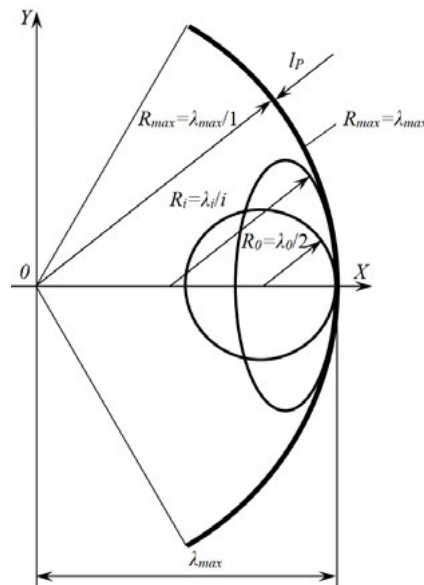
Figure 3: Transformation of the Initial Spherical Shape of a Physical Particle When its Speed of Motion Increases to the Speed of Light c.

Therefore, the conclusion follows that, by analogy with the minimum length (3), there is no 0 for energy and mass, the minimum quanta of which are determined at the maximum possible frequency of wave oscillations $v_{max} = 1$ s^{-1} according to dependencies (15), (16,), which was first substantiated in [57].

$$E_{min} = \frac{h}{T_{max}} = \frac{6.62607015 \cdot 10^{-34}\,(Js)}{1\,(s)} = 6.62607015 \cdot 10^{-34}\,(J). \qquad (15)$$

$$m_{min} = \frac{E_{min}}{c^2} = \frac{hv_{min}}{c^2} = \frac{\left[6.62607015 \cdot 10^{-34}\left(\frac{kgm^2}{s}\right)\right] \cdot 1\left(s^{-1}\right)}{\left[0.299792458 \cdot 10^9 \left(\frac{m}{s}\right)\right]^2} = 0.73724973 \cdot 10^{-50}\,(kg). \quad (16)$$

On this basis, a working hypothesis was put forward that in the real Universe, which has quantum parameters of all its constituent physical quantities, the γ factor cannot be equal to 0, but tends to the minimum quantum value of this parameter, for example, length (17), time (18), energy (19) and mass (20):

$$l_\gamma = \frac{l_o}{\sqrt{1 - \frac{v_i^2}{c^2}} + \left|l_{min}\right|}\,(m). \qquad (17) \qquad\qquad t_\lambda = \frac{t_o}{\sqrt{1 - \frac{v_i^2}{c^2}} + \left|t_{min}\right|}\,(s). \qquad (18)$$

$$m_\gamma = \frac{m_o}{\sqrt{1 - \dfrac{\upsilon_i^2}{c^2}} + |m_{min}|} \, (kg). \qquad (19)$$

$$E_\gamma = \frac{E_o}{\sqrt{1 - \dfrac{\upsilon_i^2}{c^2}} + |E_{min}|} \, (J). \qquad (20)$$

In general, the γ-factor can be expressed by dependence (21), in which Δ_{min} is the minimum quantum value of any specific physical parameter of the material world.

$$\gamma = \sqrt{1 - \frac{\upsilon_i^2}{c^2} + |\Delta_{min}|}. \qquad (21)$$

In the framework of (17) … (20), the laws of γ-relativism (7) … (11) cannot be infinite and cannot be associated with zero values. For photons of visible light $(0.380…0.760)\cdot10^{-6}$ m, the numerical values of γ-relativistic energy and mass are (22), (23), which already take into account the γ-factor:

$$E_{(380…760)} = \frac{hc}{\lambda_{(380…760)}} = \frac{6.62607015\cdot10^{-34}\left(\dfrac{kgm^2}{s}\right) \times 0.299792458\cdot10^9\left(\dfrac{m}{s}\right)}{(380…760)\cdot10^{-9}\,(m)} =$$

$$= (0.5227489…0.2613745)\cdot10^{-18} \, (J) \qquad (22)$$

$$m_{(380…760)} = \frac{h}{c\lambda_{(380…760)}} = \frac{6.62607015\cdot10^{-34}\left(\dfrac{kgm^2}{s}\right)}{0.299792458\cdot10^9\left(\dfrac{m}{s}\right)\times(380…760)\cdot10^{-9}\,(m)} =$$

$$= (5,816366…2,908183))\cdot10^{-36} \, (kg) \qquad (23)$$

The conducted studies allow us to conclude that the photon has mass, but this requires its confirmation in real experiments. Their development was based on Lebedev's experiments to determine the pressure of light [34], in which a pair of plates (one mirror and the other an absolutely black body) were irradiated, freely suspended on a vertical axis. In this case, the momentum of light reflection doubled compared to the momentum of light absorption, and the plates rotated. However, in the classical version of physics, the momentum of motion p is determined by the dependence (24), which includes the mass m:

$$p = mc. \qquad (24)$$

In order to eliminate the mass in the momentum p_γ (24) for the photon, it was replaced by the momentum energy E (25):

$$p = \frac{E}{c} = \frac{h}{tc} = \frac{h}{\lambda}\left(\frac{Js}{m}\right). \qquad (25)$$

However, the expression of momentum through energy is only a physical and mathematical method of moving away from mass, but not a solution to the problem of the absence of photon mass. However, the main problem in this case should be considered the dimensionality of the momentum value p, since for energy it is the value $J = Nm = kg\cdot m^2/s^2$, and the kilogram in the momentum dimension, as a sign of mass, does not disappear anywhere, like the "donkey ears of King Midas". The dimensionality of all quantities in physics is a strict criterion for their correctness, which is not fulfilled in the momentum dimension p, which includes units of mass.

When conducting experiments to determine the mass of a photon, it was taken into account that, within the framework of the absence of zero parameters in the real material world, the presence of a photon mass can be considered a reliable fact. Therefore, the total energy of particles with mass is the value (12), consisting of kinetic and potential energies. Thermal heating during radiation occurs due to the transfer of the kinetic energy of photons to the atoms of the irradiated medium. But this is only a part of the total energy of photons (12), the second part is the potential energy of the photon mass, which is the source of their formation and accumulation as physical particles, which requires confirmation in the proposed experiments [50-52].

In the attached experiments [12, 50-52] the plates are located on both sides of the horizontal axis, one of them is shielded, and the other is irradiated with light from above and below, which balances the light pressure and thermal effects on it. However, they require additional analysis. It took into account that the rebound of photons from the plate in Lebedev's experiment allows us to consider them as real physical objects. The proposed transition of the light wave to the particle phase for ballistic photons [12] gives grounds to assume the possibility of their accumulation, In a new experiment [58] it was taken into account that irradiation of plates with laser beams requires the use of optical systems for directing and scattering them on the surface of the plate, which will change the energy parameters of the beams. Therefore, in [58] direct irradiation of horizontally suspended plates with visible light sources in the device shown in Fig. 4 was proposed.
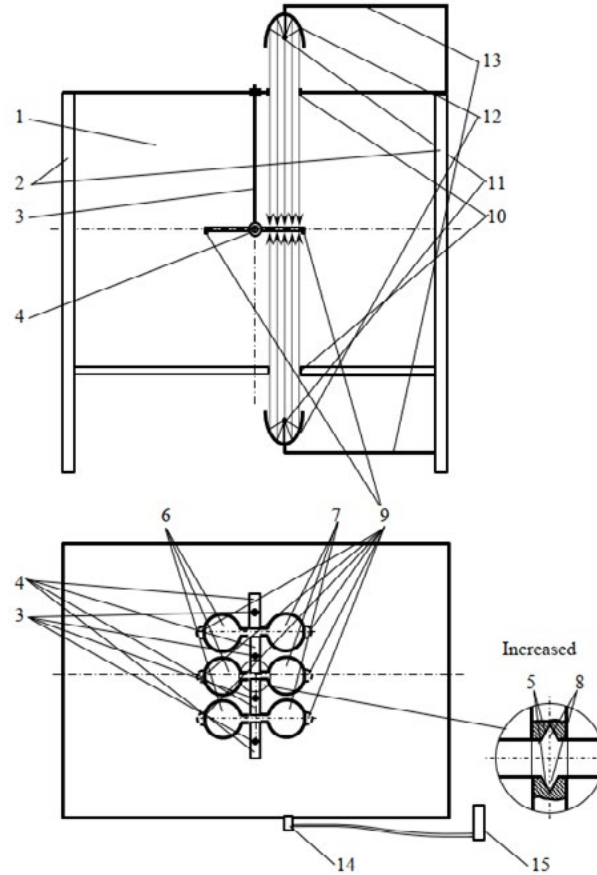
Figure 4: Device for Open Irradiation of Plates with Visible Light.

The light-tight container 1 is mounted on posts 2, in the middle of which, on rods 3, horizontally placed supports 4 with conical holes 5, in which paired left 6 and right 7 plates with triangular protrusions 8 on a common axis are freely inserted. On the opposite sides from the axis of symmetry of these plates, additional protrusions 9 are made, which are bent downwards relative to the axis of their rotation, which gives them a stable horizontal orientation.

One of these paired plates is irradiated with light. For this purpose, on the upper and lower surfaces of the container, opposite the irradiated paired plates, windows 10 are made, which are open for unhindered irradiation of both surfaces of the plate with photon fluxes, the source of which is open-type emitters 11, with direct open formation of light waves (for example, electric arcs, or open heating elements that emit light and are not covered by glass). The direction of these light fluxes to the upper and lower sides of the plate is provided by reflectors 12, which are fixed at the top and bottom of the container on brackets 13. To observe the rotation of the plates, a television camera 14 is installed with an image fixation on a monitor 15. To compensate for shocks and vibrations, the legs of the racks are mounted on damper supports.

The number of paired plates can be more than one with a corresponding increase in the number of windows and radiation sources, including those of different colors. In this case, each axial pair of windows can be closed with glass filters in different combinations of the selected color of light.

Further calculations show that to create a mass $m = 10^{-8}$ kg, which is guaranteed to be able to bring the plate out of equilibrium, energy is required (26):

$$E = mc^2 = 1 \cdot 10^{-8}\,(kg)\left[0{,}299792458 \cdot 10^9 \left(\frac{m}{s} \right) \right]^2 = 8{,}98755179 \cdot 10^8\,(J). \qquad (26)$$

With a specific power of radiation energy of 1 J/s per 1 cm^2, or 1 W/cm^2, on each side of a plate with a diameter of 7.2 cm with an upper and lower area of 40 cm^2, a power of 2x40 W is required, which can be provided by open thermal heaters that emit light. The power of this heat flux on the surface of the plates is regulated by choosing the distance from them to the radiation source. The time to create such a mass is 130 days, or 0.36 years, with a total consumption of 1 MW of electrical energy for radiation, since their efficiency is close to 50%.

When the power of the light flux increases n times, the irradiation period of the plates decreases, but the proportion of the irradiation energy converted into heat increases, which will affect the final results and the speed of the process. Therefore, the way to increase the area of the irradiation surface is preferable, since its increase by n times leads to a decrease in the irradiation time by $2n$ times. There are no technical obstacles to increasing the area from 2×40 to 2×400 cm^2, but the irradiation power will also increase by 10 times and reach 800 W, and taking into account the efficiency of $\approx$ 50% it will reach 1.6 kW, which may be a real limiting factor. But the fact of the possibility of obtaining a result in 13 days may exceed the costs of electricity, due to the reduction in system maintenance costs and the great scientific significance of the result.

If it is necessary to compensate for the effect of heat flows on non-irradiated plates and air convection, of the testing method's heating of non-irradiated plates is performed by thermal resistors, or water thermal collectors, which are installed above and below the surfaces of these plates.

The cost and complexity of the device are minimal, and electricity costs – are within the household range, so all laboratories and researchers with the appropriate technical and economic capabilities are invited to conduct experiments. The identification of the mass of photons introduces fundamental changes into the theory of physics, which meets all the criteria of a scientific discovery [59] and significantly increases the scientific level and prestige of the researchers and laboratories that have carried out such measurements.

3. Conclusions
1. Strict justifications for the presence of the mass of a photon have been found that do not contradict all known real laws of physics.
2. The maximum possible values of the wave parameters of electromagnetic radiation have been found, the lower limit of which is the wavelength $\lambda_{max} = 0.299792458 \cdot 10^9$ m and the frequency of their oscillations $v_{min} = 1$ Hz, or 1 s^{-1}, and the upper limit is the wavelength $\lambda_{min} = 0.405 \cdot 10^{-34}$ m and the frequency of their oscillations $v_{max} = 7.4 \cdot 10^{42}$ Hz, or $7.4 \cdot 10^{42}$ s^{-1}, while the range of waves of the light range $(0.389 ... 0.760) \cdot 10^{-6}$ m should be considered photons, and the waves of the rest of the range should be considered quanta of electromagnetic radiation.
3. Photons are dual physical structures of the material world, which are waves at a speed of their movement equal to the speed of light in a vacuum c, and particles of matter when they slow down to a speed of 0 m/s.
4. There are more than 20 known experiments confirming the presence of photon mass based on their indirect signs, but they are denied by the contradictions of infinite quantities arising from the γ-factor Lorentz.
5. Waves of the light range $(0.380…0.760) \cdot 10^{-6}$ m, moving at the speed of light c, but they do not have infinite values of energy and mass, which contradicts the Lorentz γ-factor, which is eliminated when taking into account the finite minimum values of length, time, mass and energy.
6. The zero mass of a photon is denied by the laws of dialectics, within which 0 is the absence of anything, which leads to the disappearance of matter itself, and by the laws of physics, within which the disappearance of energy and mass of matter is impossible, while zero physical parameters are overcome by quantum leaps of their minimum values.
7. The solar eclipse of 1919 is not a strict confirmation of the zero mass of photons and a denial of Newton's theory of gravity, due to Einstein's theory of space curvature, since when taking into account the sum of the kinetic and potential energy in the motion of photons, the values of their deflection angles are absolutely the same, which makes both theories equivalent, therefore, the detected deflection of light rays is the 1st strict factor confirming the presence of photon mass.
8. The quantum foundations of light emission exclude zero and infinite values of the γ-factor Lorentz, which reduces the energy of photons $E = hv$ and their energy mass $m_E = hv/c^2$ to relativistic quantities and excludes zero photon mass.
9. Direct experimental confirmation of the presence of photon mass is possible when irradiating them from above and below one of the paired rotating plates installed horizontally on the axis; everyone is invited to conduct these experiments.
10. The discovery of the mass of photons introduces fundamental changes into the theory of physics, which meets all the characteristics of a scientific discovery.

Conflict of Interest

This work was carried out by the author alone, on his own initiative, on the basis of personal scientific works: [10 – 12, 15 – 18, 21, 42, 46, 47, 50 – 52, 57, 58]. It uses literature sources from open databases, so permission for their publication is not required.

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