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The Laws of Reflection and Refraction of Light Waves within the Framework of a New Interpretation of Ballistic Photons

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ABSTRACT

The work relates to the fundamentals of quantum physics and photonics, in particular to the formation of processes of reflection, refraction and absorption of waves of ballistic photons. The study of these problems is an important and urgent task for understanding the foundations of the material world, which has not yet been fully resolved. An important property of ballistic photons is their motion in a straight line, which can be curved under the action of physical fields on the photons and the parameters of the medium of their motion. However, if external factors remain constant, their motion continues in a straight line, which allows us to apply the laws of geometric optics to them. The fundamentals of the geometric wave laws of reflection and refraction of light are laid down of the Young and Fresnel. However, they used sinusoidal waves similar to transverse waves in the of musical strings, which contradicts the motion of spherical waves of ballistic photons. Elimination of these shortcomings is the main goal of the work, and its scientific novelty is the substantiation and development of new geometric models of light motion.

Research Methods: Since this work has the level of scientific discovery, for finding which strict methods have not yet been created, therefore, general principles of development of the theory of scientific knowledge were used, based on the laws of dialectics and consistency with the basic laws of physics. The author's research methodology was also used, based on the transition to the initial quantum level of the material world.

New Results of the Work and their Discussion: It is shown that the first point of contact of photon waves lies on the unified normal to their spherical surface and the contact surface. This shifts the real normal of wave reflection relative to the traditional normal from the point of intersection of the axis of the tube of incident waves with the surface of reflection by the value of $-\Delta = \lambda_{max} \sin \alpha$. The real axis of reflection of spherical waves is associated with the crests most distant from the initial point of their reflection. When photon waves are refractional, their total deviation is formed from the last point of their incidence on the refraction surface. This shifts the real point of the normal of wave refraction relative to the traditional normal from the point of intersection of the axis of the tube of incident waves with the surface of reflection by the value of $+\Delta = \lambda_{max} \sin \alpha$. Geometric models of all these processes at different angles of incidence of photon waves are developed and their simplified schemes are given.

Conclusions: The proposed models and schemes of reflection and refraction of spherical photon waves significantly clarify and change previously known schemes and do not contradict the real laws of physics and optics, therefore they have the level of scientific discoveries and should replace previously known processes and schemes.

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Introduction

The work relates to the fundamentals of quantum physics and photonics, in particular to the processes of reflection, refraction and absorption of light, as well as to the parameters of the structure and processes of movement of ballistic photons. The study of these problems is an important and urgent task for understanding the foundations of the material world, which has not yet been fully solved. Ballistic photons or wave radiation quanta include those that move in a straight line after their emission and before they are absorbed or deflected at the boundaries of physical fields and media [1]. Discussion of this problem has caused a debate on the ResearchGate platform, so it requires special attention [2-4]

Analysis of the State of the Problem, Substantiation of the Purpose and Objectives of the Work

In understanding and studying the nature of light, 6 periods can be distinguished:

- From ancient times to the 17th century - philosophical, in which mainly general ideas about the nature of light were interpreted [5,6].
- The primary substantiation of the wave theory in the 17th century in the works of René Descartes, Robert Hooke and Christiaan Huygens, which was replaced by the corpuscular theory, laid down in the works on the "atomism" of Pierre Gassendi and dominant for the next 100 years, after the works of Isaac Newton, published by him in 1704 [7-11].
- The revival of wave theory in the 19th century in the works

of Thomas Young and Augustin Fresnel, and its dominance after the works of James Clerk Maxwell, who theoretically substantiated the electromagnetic basis of light waves in 1865, and Heinrich Hertz confirmed it experimentally in 1888 [12-15].

- Doubts about the wave theory at the end of the 19th and beginning of the 20th century after the Michelson-Morley experiments, which failed to find "ether" for the propagation of light waves and the revival of the corpuscular theory in the works of Professor Lebedev on light pressure, in the foundations of quantum physics laid in 1900 by Max Planck, in the quantum principles of explanation of the photoelectric effect by Albert Einstein and the effect of photon scattering discovered in 1923 by Arthur Compton [16-20].
- Dualism in the interpretation of the nature of physical particles and light in the 20th century after the work of Louis de Broglie and a new struggle with the photon as a substance particle in the works of many scientists lasting almost 100 years, since it had no mass [21-24].
- The end of the 20th, beginning of the 21st century after works on the presence of a substance part and the mass of the photon, and new justifications for ballistic photons and their mass [25-30].

Without diminishing the importance of other works on photon research, their detailed analysis is not given, since it goes beyond the scope of the problems solved in this work. Further, they are based on the analysis of the author's works on ballistic photons [28,29]. Their important property is movement along a straight line [1], which can be curved only when photons are exposed to strong physical fields and the parameters of the environment of their movement [1]. But if these external factors remain unchanged, their movement then continues in a straight line, which allows the laws of geometric optics to be applied to them.

Within the duality of the existence of physical particles in the material world, a photon has a wave structure during its motion, and waves are transformed into a substance particle at the moment of their deceleration upon encountering an obstacle [30]. This corresponds to the general characteristics of elementary particles of the material world, whose wave properties increase with the growth of their speed of motion, and with its decrease, the properties of a particle and substance are more pronounced [1]. Therefore, a photon, having in its motion the maximum possible speed equal to the speed c of light in a vacuum, is only a wave, and upon encountering an obstacle its speed is damped to 0 and it degenerates into a particle. However, in modern concepts of the motion of photons as electromagnetic waves, they are depicted as spirals, examples of which are shown in Figure 1 [1,31]:

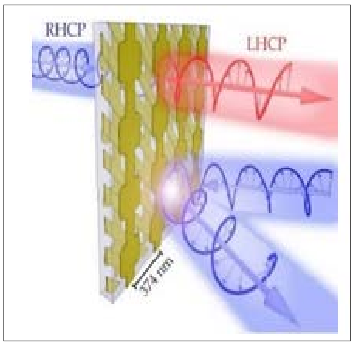

Figure 1: Modern Concept of the Shape and Movement of Light Waves and their Transformation When Encountering an Obstacle.

But the motion of light waves in the form of continuous spirals contradicts the quantum principles of radiation, proven by M. Planck in 1900 [18]. In [30] it is shown that within the framework of Lorentz γ-relativism, with an increase in the speed of motion of physical particles formed by a clot of electromagnetic field closed in a ball, their sizes are compressed in the direction of their motion vector and their sizes increase in the radial direction to the motion vector [30,32]. Such a transformation leads to a change in the original spherical structure of physical particles into an ellipsoid, which, upon reaching the speed of light c, is compressed along into a sphere (or wave front) of the minimum Planck length l_P in the material world, and expands in the transverse direction to a surface of 1 steradian radius R_{max}, equal to the real wavelength of a photon λ_{max} [33]. Their formation and motion pattern are shown in Figure 2 [30], there are no sine waves in them.

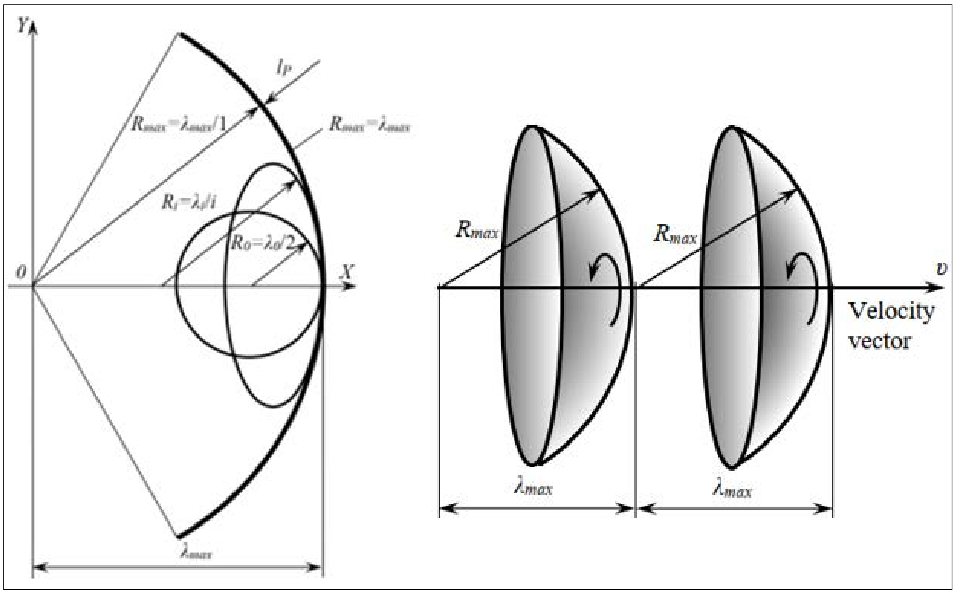

Figure 2: Scheme of Transformation of a Physical Particle, Formation of its Wave and Scheme of their Movement When Approaching the Speed of Light

The minimality of the Planck value l_p is due to the fact that it is obtained on the basis of 3 fundamental physical constants *c, h, G* according to a strict physical dependence (1); there are no other strict physical dependences for the minimum length [34].

$$l_p = \sqrt{\frac{hG}{c^3}} = \sqrt{\frac{6.62607015 \cdot 10^{-34}\left(\frac{kg \cdot m^2}{s}\right) \cdot 6.67430 \cdot 10^{-11}\left(\frac{m^3}{kg \cdot s^2}\right)}{\left[0.299792458 \cdot 10^9 \left(\frac{m}{s}\right)\right]^3}} = 0.405135 \cdot 10^{-34}\,(m), \quad (1)$$

where h - Planck's constant [35]:

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

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

c – speed of light in vacuum: $c = 0.299792458 \cdot 10^9\,(\text{exactly})\frac{m}{s}$, [35]

Based on the proposed spherical wave front of a photon of 1 steradian, it is shown in [30] that its motion occurs in quantum jumps equal to the wavelength λ_{max}, with rotation in the direction of the velocity vector υ, within the framework of the gimlet rule (Fig. 2).

The quantum structure of photon waves distinguishes them from light beams that make up a packet of ballistic photons, so their oscillation and motion differ from the oscillations of the "musical string" proposed by Yang [12], such a physical model is acceptable for macro-level objects. The "tubes" during quantum motion of waves have a sphere radius R_{max} with a step of the length of these waves $R_{max} = \lambda_{max}$ (Fig. 2). But there are no transverse vibrations of the quantum "photon string", they require additional energy, which is spent, and when rotating the quark hexagonal shape of the photon spheres, there is no energy consumption, it is only virtual [26, 27]. Therefore, the screw (or entangled) motion of photons (Fig. 1) should be replaced by quantum jumps of wavelength λ_{max} with their rotation across the axis (Fig. 2) [26 – 30].

It is known that the geometric laws of light reflection were known by Euclid in the 4th century BC, and before him they may have been known by Pythagoras [6] and the Egyptian and Babylonian priests [36]. Archimedes not only knew these laws, but also successfully applied them in practice as early as the 3rd century BC [37]. These laws were revived by Huygens in 1678 [9], and in 1815 they were supplemented by Young and Fresnel [12, 13]. In the original version, the laws boiled down to the fact that the angle of incidence Θ_i of a ray of light *P* is equal to the angle Θ_r of its reflection *Q* and both of these rays are located in the same plane. In the modern interpretation of this process, the normal to the surface of reflection was taken as a basis, which divides the angles Θ_i and Θ_r of incidence and reflection of light into equal values, while the reflection process occurs at point *O* [1]. Since the dimensions of the point tend to 0, this contradicts the spatial form of photon waves having a real length, so the basic scheme (Fig. 3.a) was replaced by a spatial wave form (Fig. 3.b) [30].

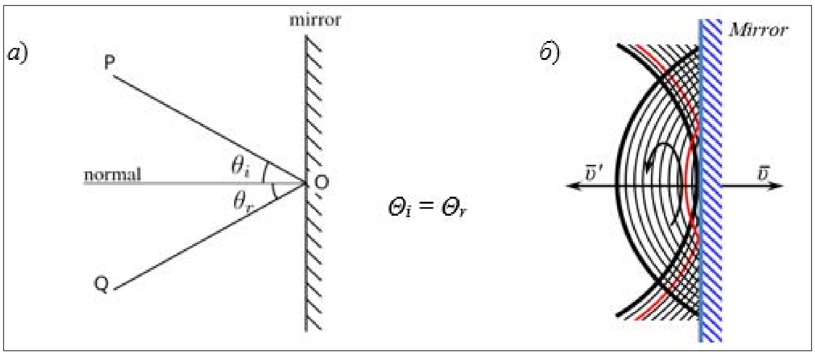

Figure 3: Representation of the Process of Reflection of a Beam of Light in the Classical (a) and New (b) Versions

In [30] it is also shown that when spherical waves of a photon meet a mirror surface, the microroughness of which is smaller than the photon wavelength λ_{max}, the crest of the wave makes contact first, and then the wave is successively reflected from all points of contact with the mirror and turns inside out in their central part, which is shown in red in Figure 3. Then it moves in the direction of the reflection vector υ' [30]. But with the same rotation of spherical waves, due to the change in the direction of their motion vector, the photon is transformed into an antiphoton and all reflected light rays change their structure from left to right (or vice versa), which is confirmed by mirror images of objects [30]. Such an explanation of the antiphoton was proposed in [30] for the first time; usually, a photon was distinguished from an antiphoton only by the processes of their occurrence.

However, the issues of reflection, refraction and absorption of light in [30] are not fully resolved. Filling this gap is the **main goal** of the work being performed, and the development of new models and schemes of these processes and their physical and mathematical justifications constitute its **scientific novelty.**

Research Methods

When choosing them, it was taken into account that this work has the level of a scientific discovery, for the detection of which strict methods have not been created [38,39]. Therefore, general principles of the development of the theory of scientific knowledge were used, based on the laws of dialectics and consistency with the basic laws of physics [1,40]. The author's research methodology was also used, based on the transition to the initial quantum level of the material world within the framework of the processes occurring in this case [33,41].

New Results of the Work and their Discussion

In the work only waves of light are considered. Based on the representation of ballistic photons as quantum spherical waves, (Figure 2) [30] a geometric model of its reflection from a mirror surface was proposed, in which all waves are separated in space and time (Figure 3). However, this scheme is limited only by the normal direction of incidence of quantum waves of a photon, which does not give a complete idea of other options. The solution to this problem is proposed in this work. It was taken into account that light rays represent packets of photons, therefore there are differences in the processes of their reflection, compared to single photons. But the general laws of reflection are preserved - the angle of incidence of the wave α and the angle of its reflection β are equal to each other.

For the research, the method of geometric modeling of the motion of the front of a spherical wave of a single ballistic photon of size 1 steradian was used. When it is emitted from point O_i at an angle α and then moves, the first to contact is the crest or top of the wave at point O_a, located on the unified normal of the wave with the reflection surface (Figure 4), and after that the wave creates zones (in Figure 4 these are points) broken line on the surface and is reflected from it in the form shown in bright color.

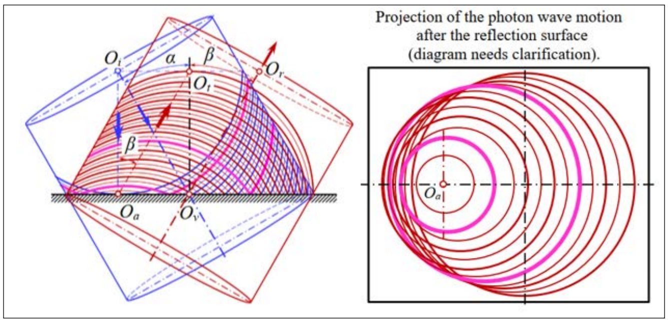

Figure 4: Model of Inclined Incidence and Reflection of Spherical Waves of a Single Photon

Here and below in all models the traditional motion of light waves is shown by thin arrows, and the true motion of spherical waves of a photon is shown by thick arrows, which are their motion vectors. In this case, the total wavelength of a photon before and after their brokens zone brokens unchanged λ_{max}, since any change in wavelength leads to a change in their energy, which is not present in reflection processes. The initial position of the spherical wave of a photon is formed in the incidence tube at an angle α to the reflection surface and contacts it along the normal O_iO_a. When the wave is reflected, the crests of its spheres shift in the direction from point O_a to point O_t and form the reflection angle β due to a change in the current positions of the projection of the photon waves. The longitudinal shift of the brokens zone (point) of the incident and reflected wave on the reflection surface shifts the reflected wave in the direction of the reflection angle β. In this case, the general principles of reflection are strictly followed - the orientation of the waves along the normal to the reflecting surface.

These are the differences between the real scheme of the process of incidence and reflection of photon waves and the previously known one [1,12], therefore the point O_v is only a virtual point of reflection of waves at an angle β with their arrival at the point O_r, which is associated with the axis O_vO_r of the wave reflection tube. This is the axis of the general direction of the process of reflection of photon waves of light rays, but it does not coincide with the real process of reflection of waves, in which the vector of their reflection is associated with the movement of the convex vertices of spherical waves along the new axis O_aO_t. The reflection of the wave occurs from the first point of incidence O_a, earlier than in the Fresnel scheme. Between the real O_a and virtual O_v points of reflection of photon waves there is a distance $-\Delta$ (2), which can be measured experimentally.

$$-\Delta = \lambda_{max} \sin \alpha. \qquad (2)$$

But so far, no one has ever measured Δ, because they did not know about its existence. However, to conduct such experiments, their planning and the actual development of processes and devices that have an inventive level are still necessary. This requires significant time and the involvement of highly qualified researchers. Therefore, this paper offers only a general formulation of the problem for conducting these studies.

A similar model of the incidence and reflection of spherical waves of a photon is formed for other angles of their incidence, in particular for the angle α =1 rad = 57.2958°, which is the limiting one for the formation of a spherical wave in a segment of 1 steradian (Figure 5).

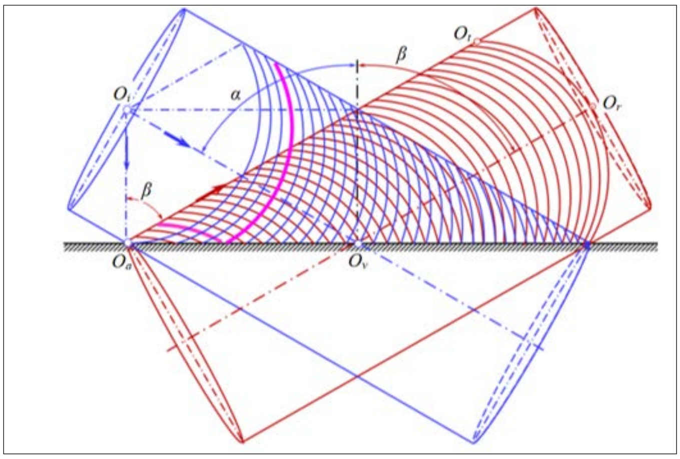

Figure 5: Model of Incidence and Reflection of the Front of a Spherical Photon Wave at an Angle α = β = 1 rad = 57.2958°

This model also strictly adheres to the principle of the unified normal for performing the process of wave reflection and all positions of the base points O_i, O_a, O_t, O_v, O_r, and the angles of incidence α and reflection β of the waves are identical to the previous version (Figure 4). Only the axis O_a, O_t, of reflection of the convex vertices of the spherical waves is shifted to the periphery of the tube. The coincidence of the specified parameters proves the correctness of the proposed scheme.

However, at angles of incidence $\alpha > 1$ rad $= 57.2958^o$, the condition of the unified normal for the photon wave and the reflection surface is not observed, which requires additional analysis of this process. Its geometric model is shown in Figure 6, for the incidence and reflection of the front of photon waves at angles α and β.

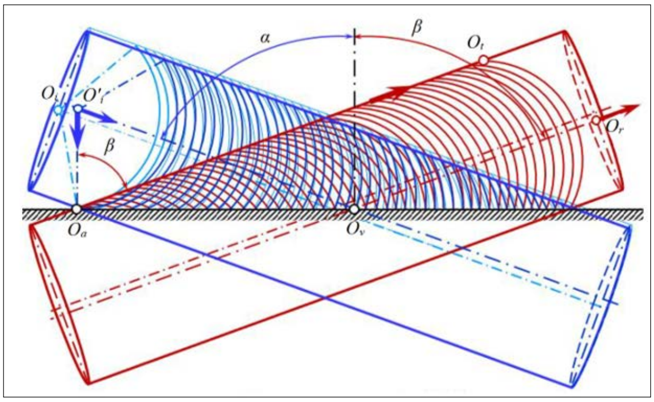

Figure 6: Model of Incidence and Reflection of a Spherical Wave of a Photon at an Angle $\alpha > 57{,}2958^o$

When the incidence tube is inclined at an angle $\alpha > 57.2958°$, the wave motion (shown in Figure 6 by thin blue lines) encounters an obstacle on its path - a reflecting surface that interferes with it. This causes the wave to rotate from the center of curvature O_i to the position O'_i, in which the wave becomes perpendicular to the reflecting surface (shown by thick blue lines in Figure 6), due to which the parameters of the incidence tube of waves and the position of its axis change with the same wavelength. This ensures that the condition of unified normal of the wave and the reflection surface is met, and until this happens, there will be no reflection. Then the process of incidence and reflection of waves automatically repeats all the stages and positions of the previous version (Figure 5), with complete identity of the location of the base points O_i, O_a, O_t, O_v, O_r and the rotation angles α and β. This coincidence is another confirmation of the correctness of the proposed model, in which the real reflection angle β has a direction that coincides with the displacement of the vertices O_t of the reflected spherical waves of the photon. Similarly, there is a displacement of the real reflection point O_a relative to the virtual point O_v by the value $-\Delta$ (2).

However, the processes of photon reflection at large angles of incidence still require further research, which is beyond the scope of the work being performed. The variant of photon wave reversal on an obstacle proposed in it is still a hypothesis, requiring its further experimental confirmation, taking into account all the above-mentioned problems of conducting such experiments. But it does not contain any obvious contradictions or violations of known physical laws related to optics. In addition, the viability of this hypothesis is ensured by its coincidence with the two previous variants of photon wave reflection (Figures 4,5).

In general, the patterns of reflection of ballistic photon waves (Figures 4-6) are the result of geometric modeling of the quantum motion of the fronts of spherical waves of radius $R_{max} = \lambda_{max}$. They are similar to previously known patterns (Figure 3.a), which are based on the normal to the reflection surface. The main difference is that this normal is of unified to the direction of motion of spherical waves (Figure 2) at the first point O_a of contact of the waves with the reflecting surface (Figures 4-6). After the extreme positions of the waves, they move in a tube similar to the approach tube. Simplified patterns of motion of photon waves at any angles of their incidence, with fixation of their initial and final positions associated with the unified normal and the real normal, are shown in Figure 7.

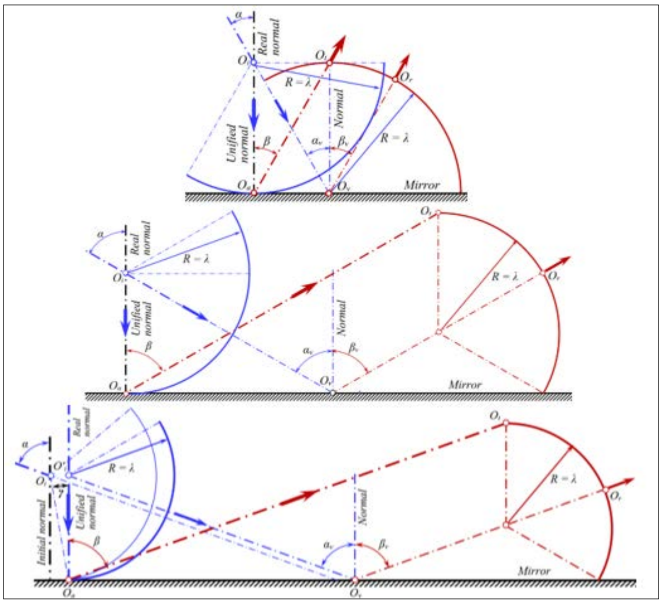

Figure 7: Main Variants of Simplified Schemes for the Reflection of Wave Fronts of Ballistic Photons at Different Angles of their Incidence.

In all schemes: O_i is the center of photon wave radiation, O_a is the real point of the normal to the wave surface and the reflection surface, O_t is the point of the real direction of movement of reflected waves, O_v is the point of the virtual normal to the reflection surface of the waves, O_r is the axial point of the shift on the spherical surface of the reflected waves. In the last scheme with an additional rotation of the waves, O'_i is the point of displacement of the photon wave radiation center relative to the point O_a of the unified normal to the radiation surface, γ is the angle of rotation of the waves, which is formed automatically, due to the difference between the angle α of incidence and the angle of 1 radian, according to the dependence (3):

$$\gamma = \alpha - 57{,}2958^o \qquad (3)$$

In other cases, the parameters of the angles remained unchanged with the previously known ones, therefore, the already existing mathematical apparatus can be used for them [1]. The reflected waves are mirror images of the incident ones, which is another confirmation of the correctness of the proposed geometric models and schemes and the transformation of a photon into an antiphoton, given in [30]. The values of the angles of incidence and reflection of the waves formed in this case are the same as the previously known variants of incidence and reflection of light, which follows from the schemes shown in Figures 3 and 7.

All processes (Figure 4-7) are considered for a single photon, and light rays have packets of such photons. This expands the spot of their interaction with the reflection surface, but the process itself occurs in similar variants. If the packet contains photons of different wavelengths, then only scaling of the proposed schemes within these lengths occurs, but their path, starting point and reflection angles remain identical. If the photons are parallel, then the decomposition of the light ray packet into a spectrum does not occur upon reflection. The proposed models and schemes of light wave reflection more accurately explain this process for any values of the angles of incidence α, therefore they are recommended for use in further studies.

In addition to the processes of reflection of light rays, the refraction of rays (change in the direction of their movement) when passing through optical media with different physical and mechanical properties is of great importance for the development of science and technology [1]. Well-known diagrams explain the movement of the vectors of the original light beam $\boldsymbol{P}$ at an angle of incidence Θ_a, the refracted beam $\boldsymbol{T}$ at an angle Θ_τ and the secondary beam $\boldsymbol{P'}$ at an angle Θ_a [1]. In addition to these options, partial reflection of rays $\boldsymbol{Q}$ at an angle Θ_a is possible, which affects their intensity, as shown by the different brightness of these rays, and their sum is equal to the original intensity (Figure 8).

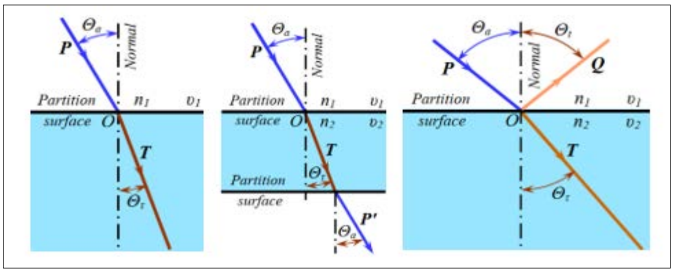

Figure 8: Basic Schemes of Light Refraction.

The magnitude of the angle of incidence Θ_a and refraction Θ_τ of light rays depends on the parameters n_1, n_2 of the optical density of the medium of their propagation, which affects the speed υ_1 and υ_2 of their movement.

However, the disadvantage of these schemes is also the process of transformations at a point, therefore in the Huygens-Fresnel postulates the points are replaced by the front of wave motion [12,13]. But they are based on the original sinusoidal waves of length λ in the transverse direction of their motion, similar to the oscillations of waves in a musical string, which significantly distinguishes this process from the motion of the front of spherical waves of a ballistic photon. The scheme of wave refraction according to Huygens-Fresnel is shown in Figure 9a, its new version is in Figure 9b, but these are only geometric constructions, which differ from the real laws of physical optics [1]. The wave scheme shown in Figure 9c is similar to the motion of a ballistic photon if we select a segment of 1 steradian in it [42].

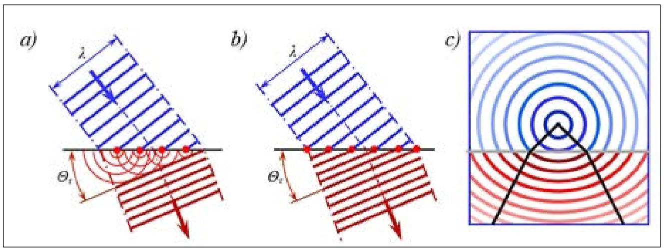

Figure 9: Refraction of Light according to Huygens-Fresnel (a, b) and in the form of Spherical Waves (c)

In Figure 9a, the blue lines and blue arrow show the light of the incident wave λ and the direction of the phase velocity vector in the first medium; the red dots and semicircles are the secondary wave sources at the interface between the two media and the fronts of the spherical waves generated by them in the second medium. The brown lines and brown arrow are the fronts of the refracted wave and the direction of the phase velocity vector in the second medium.

However, Huygens' postulate that "each point of the front on the surface reached by the wave is a secondary (i.e., new) source of spherical waves" is highly questionable, since energy sources are needed to generate new waves [1,13]. But the postulate is confirmed by an explanation of the diffraction of light waves based on it, which may be true for a packet of photons, and not for a single photon.

It is not clear how sinusoidal waves generate new points and how they are transformed into a sinusoidal wave again. However, the biggest drawback of all the schemes in Figure 9 is that due to the tilt by the angle of refraction Θ_τ, the original transverse length λ of the sinusoidal wave increases. This contradicts the energy laws of light within the framework of the quantum theories of Planck and De Broglie, since the change in the parameters of the original wave to a new λ_τ according to the geometric dependence (4) leads to a change in its energy, which is not observed in this process.

$$\lambda_\tau = \lambda_i / cos\ \Theta_\tau \,. \qquad (4)$$

In Figure 9.b, the spherical waves emitted from the points have disappeared, and reflection occurs immediately from the refraction points of the incident transverse waves, which is a more correct scheme, but not for ballistic photons, which do not change the parameters of the light waves.

In Figure 9.c, the incident spherical waves are shown in blue, which within the black sector resembles ballistic photons, and the waves after refraction are shown in brown. But at the same time, the light waves are scattered, losing their energy, since the new sphere is a new wave with a new length, which contradicts their real propagation from distant stars. The length of the refracted waves also changes. This is impossible within the framework of a significant change in their energy, which is not observed in these processes.

In experiments, for example, when the original beam of green light from a laser pointer falls, the refracted beam remains green without changing its energy (Figure 10), [43].

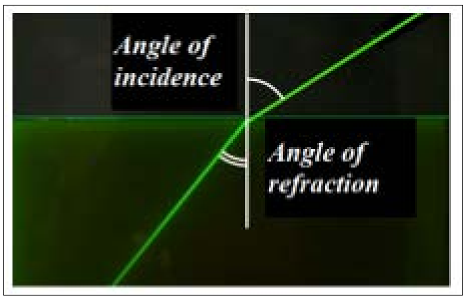

Figure 10: Real Picture of Incidence and Refraction of Green Beam of Light from Laser Pointer

In the proposed new model of refraction of spherical waves of single photons, all the above-mentioned shortcomings are eliminated. It is based on the models and schemes shown in Figures 4-7, in which the original spherical wave is transformed into a new one in the zone normal to the interface, since, like reflection, the penetration of waves into another medium is possible only from the normal position. This condition can still be considered a new postulate, but it is confirmed by the subsequent process of wave motion in different media. For photon waves, the critical angle is Θ_a = 1 rad, after which its relationship with the refraction angle is not linear, which can be an indirect confirmation of the process of additional beam rotation shown in the scheme of Figure 6.

Geometric model of refraction of ballistic photon waves in the incident and refraction medium, for which the velocities are $\upsilon_1 > \upsilon_2$, the incident photon waves are shown in blue, and the refracted ones in brown, as shown in Figure 11.

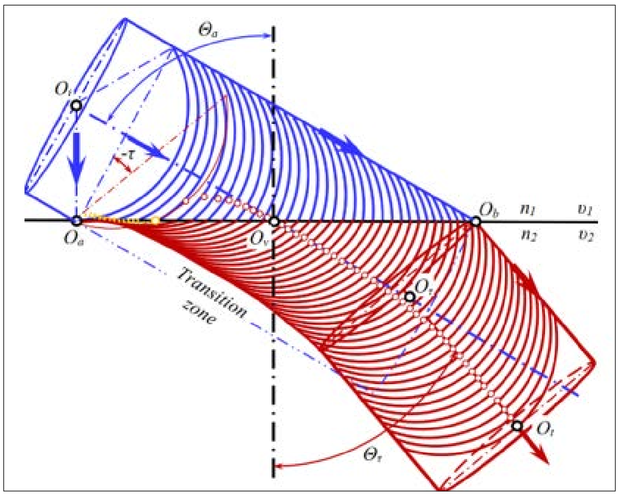

Figure 11: Model of Motion and Refraction of Waves of Ballistic Photons for $\upsilon_1 > \upsilon_2$.

All basic points remain the same: O_i is the center of photon wave radiation, O_a is the real point of the normal to the wave surface and the refraction surface, O_v is the point of the virtual normal to the refraction surface of the waves, O_t is the point of the real direction of movement of the refracted wave crest. However, new points have been added to them: O_b is the final point of refraction of the photon waves and the point O_τ is the real intersection of the axes of the incident and refracted waves. In this case, the angles of incidence Θ_a and refraction Θ_τ of the waves are formed between these axes and the normal to the refraction surface. The numerical values of these angles are identical to the known variants, the ratio of which is determined by the refractive indices n_1, n_2, which affect the speed υ_1 and υ_2 of their movement in the basic variants [1]. However, the virtual point O_v is not common for these angles. The real point for the common normal is the final point O_b of incidence of the waves, shifted from it by a distance of $+\Delta$ (2).

The turn between the angle of incidence and refraction is the value of the angle $\pm\tau$. For a denser refractive medium, it is negative, since it decreases the angle of incidence, and for a less dense refractive medium, it is positive, since it increases the angle of incidence. The turns of the refractive waves by an angle of τ begin with the first point O_a of contact of the incidence waves with the common normal to the refraction surface and end at the last point O_b of incidence of the waves within the framework of dependence (5).

$$\Theta_\tau = \Theta_a \pm \tau. \quad (5)$$

In this case, the total length of the incident and refracted photon wave is again constant, which corresponds to the real condition of constancy of their energy states at all stages of the process of movement and refraction of waves. However, the results of the modeling show that at the initial stage of refraction, there is no entry of waves into the new medium, since they are reflected (this section is shown by the yellow dotted line), and after it, a transition zone of wave transformation is formed until their complete refraction after the point O_b.

The main advantage of the proposed model is that the wavelength at all stages of refraction remains constant, only its speed of movement changes. This occurs automatically due to the reduction of the step of the quanta of the path p_τ of their movement along the refraction axis, as along the leg of a triangle, relative to the initial step p_i along the axis of movement of the incident wave along the hypotenuse of this triangle (6):

$$p_\tau = p_i \cos\tau \quad (6)$$

A change in the path length p_τ of the ballistic photon waves with a constant period of time t of their motion before and after refraction automatically leads to a change in the speed of motion υ_2 compared to the initial speed υ_1.

On the Figure 11 shows a variant for a critical angle of incidence of waves of 1 rad at a speed $\upsilon_1 > \upsilon_2$. Like the simplified diagrams shown in Figure 7, Figure 12 also shows simplified diagrams of refraction and motion of waves for the remaining angles of incidence, in which the discrepancies between the base normal and the unified normal and the real normal are clearly shown.

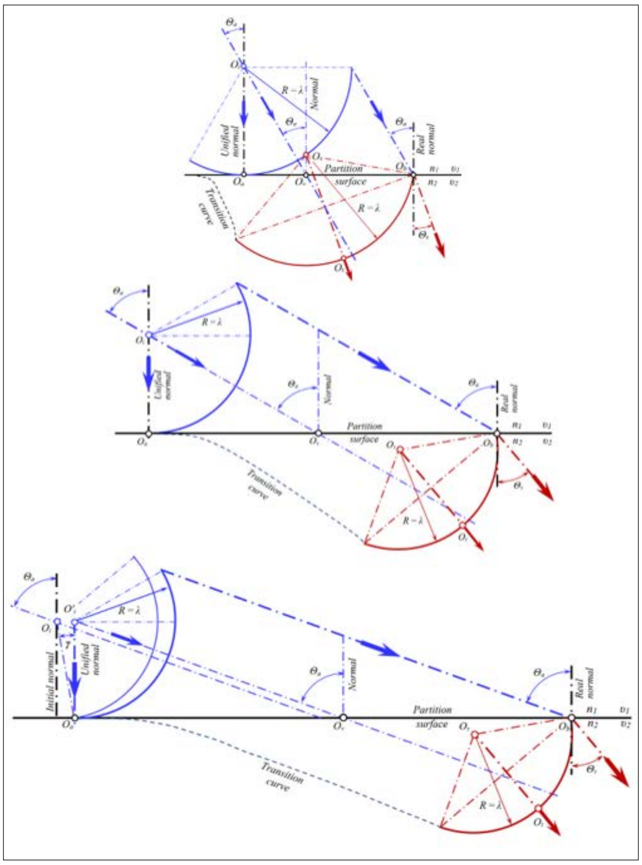

Figure 12: Main Scheme of Refraction of Photon Waves at Different Angles of their Incidence

For incidence angles greater than the critical value Θ_a = 1 rad, at the first undergo an additional rotation wave by an angle γ within the framework of dependence (3). In this case, the process of incidence of the spherical wave front of a ballistic photon occurs similarly to the same stage in the reflection process - along the normal to the refraction surface, without this, the penetration of waves into the refraction medium does not occur.

The geometric model of the motion and refraction of photon waves during their transition from a denser medium to a less dense one, for which the speeds $\upsilon_1 < \upsilon_2$, is shown in Figure 13.

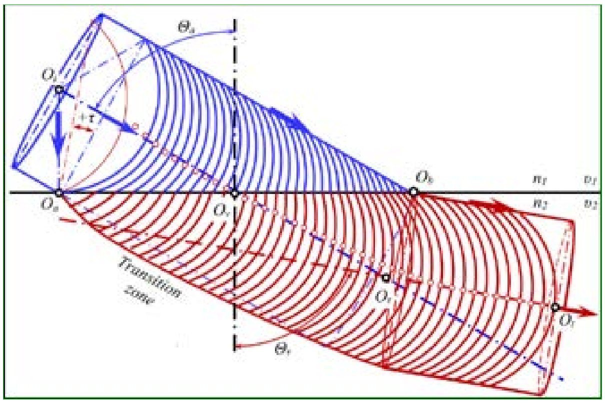

Figure 13: Model of Motion and Refraction of Waves of Ballistic Photons at $\upsilon_1 < \upsilon_2$

All base points in this model are identical to the base points shown in diagram 11. Their coincidence is a sign of the correctness of the proposed model of motion and refraction of ballistic photon waves. In this case, the beginning of their refraction occurs from the first point O_a of contact of the waves with the refraction surface and ends at the point O_b, and the virtual point O_v is not common for the angles of incidence and refraction of the waves. Differences from the variant in Figure 11 arise only in the refractive indices of the medium n_1, n_2, which affect the velocity υ_1 and υ_2 of their motion and lead to a change in their turn between the angle of incidence and refraction by an angle of $+\tau$ within the framework of dependence (4). The angle τ is positive due to the transition from a denser refractive medium to a less dense one. The transition zone also has an opposite "convex" appearance, compared to the concave one in Figure 11.

The main advantage of all the proposed models is also repeated - the constancy of the wavelength λ at all stages of refraction, only its speed changes. This change also occurs automatically due to the increase in the step of the quanta of the path pτ of their movement along the refraction axis, as along the hypotenuse of a triangle, relative to the initial step p_i along the axis of movement of the incident wave along the leg of this triangle, within the framework of dependence (6):

$$p_\tau = p_i / \cos \tau. \qquad (6)$$

Consequently, the quantum changes in the path length p_τ of the ballistic photon waves with an unchanged quantum period t of their time of motion before and after refraction automatically leads to an increase in the velocity of motion υ_2 in the new medium compared to the initial velocity υ_1, with the exclusion of the change in the wave parameters.

On the Figure 13 shows a model for the critical angle of incidence of waves Θ_a = 1 rad. For the remaining angles of incidence of waves, simplified schemes of refraction and motion at a velocity $\upsilon_2 < \upsilon_1$ at the extreme positions of the waves are obtained, which are similar to the simplified schemes shown in Figure 12. They confirm the differences between the unified normal and the real normal with its general position to the surface of incidence of the refraction of the waves, which is shown in Figure 14.

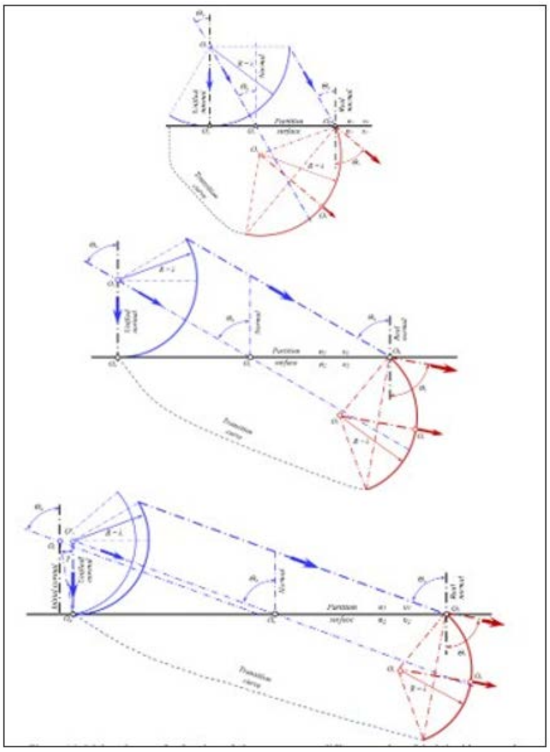

Figure 14: Main Scheme of Refraction of Photon Waves at Different Angles of their Incidence and Transition from a Denser Optical Medium to a Less Dense One.

After the extreme positions of the refracted waves shown in models and schemes 11-14, their further movement occurs in a tube similar to the tube of photon approach to the refraction surface.
Experimental studies of photon wave refraction processes to identify transition zones are possible. The basic devices for their formation can be those given in [30,44], in which the targets can be glass prisms for fixing the quantum positions of wave refraction in them during high-speed photography through a microscope, as shown in Figure 15.

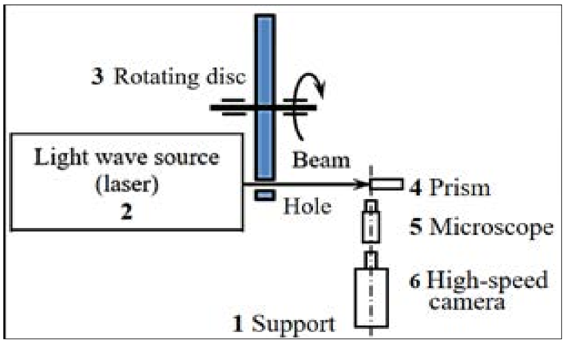

Figure 15: Device for Experimental Study of Transition Curves at the Point of Entry of Photons into the Physical Medium of their Refraction.

The device has a support 1, on which a laser 2 is installed and a rapidly rotating disk 3 with an opening through which a single photon passes in the laser beam, the rest are cut off by the disk. The photon is directed to the refractive surface of the prism 4, the photon's contact with it is observed through a microscope 5 with a High-Speed Camera 6.

This diagram is a statement of the problem for the development and conduct of experiments, to which all researchers and laboratories with such capabilities are invited.

New geometric models and patterns of light wave refraction shown in Figure 11 - 14 clearly show the fallacy of the schemes shown in Figure 10. All spherical waves in the Young and Fresnel schemes are new waves with a new length and new energy; there are no such waves of light, there are waves of a ballistic photon Figure 2 [30]. Therefore, works of Young and Fresnel contributed to the development of optics, but they became outdated within the framework of the development of quantum physics and photonics after the work of Planck, Einstein, Compton and the new wave theory of quantum light [18-20,26-30]. Known models they become the historical past of the development of optics, a new round of it begins, which corresponds to the laws of dialectics [40]. There are also no spiral waves of the photon (Figure 1), there are waves Figure 2.

In addition to reflection and refraction, light is also characterized by scattering processes at the interface of media, as well as absorption by an optically opaque medium. It should be taken into account that a polished surface is needed to reflect light, the microroughness of which is smaller than the wavelengths. Even on a black polished car body, you can see reflections of surrounding objects, and making the glass surface matte (rough) will make it opaque. All these processes can be partial, but their full study is beyond the scope of the tasks solved in this work.

It is known that light scattering will occur on an optically opaque boundary of media, the microroughness of which will chaotically change the direction of the unified normal to them and to the motion of the waves. This does not introduce significant changes to the models and schemes shown in Figs. 4 - 7, so they are not considered further in this paper.

In the processes of absorption of light waves, their physical essence is not considered, since it goes beyond the scope of the tasks solved in this work. Chromatography, as a process of partial absorption of light waves and reflection of waves of a certain length, is also not considered. Therefore, further limited ourselves only to the geometric characteristics of photon waves during their interaction with the absorption surface.

The models shown in Figure 11 and 12 were then used as the basis for the absorption process under study. If the wave incident medium is optically opaque, then after refraction they cannot penetrate into it and remain on its surface. If the wave can penetrate deep into the absorbing medium, then it will transfer its energy to its atoms and molecules. This will transfer them to an excited state, leading to subsequent heat release. However, this occurs mainly with frontal incidence of photon waves (normal to the surface), since at other angles the penetration of waves is difficult.

With an oblique incidence of the wave and the absence of reflection, according to the models in Figures 11, 12, it will remain on the interface and will completely pass to it. Within the framework of the quantum principles of the structure of light waves, they cannot be destroyed into smaller ones, since this requires the supply of energy. Therefore, the waves are projected onto the boundary of the absorption medium as a whole, and their speed will slow down from the speed of light c to 0 and the wave will turn into a material particle - a photon, which was substantiated in [29,30]. The greater the angle of incidence of the waves, the less the possibility of their transition to a new medium and the stronger the process of their accumulation on the interface. Then they are contracted into photons particles, but these processes go beyond the scope of the geometric transformation of waves, so they are not considered further, since they require special research.

Thus, the main goals and objectives of this work have been achieved - the geometric processes of transformation of waves of ballistic photons during their reflection, refraction and absorption have been substantiated. The appearance of this article became possible after the explanation of the wave parameters of a ballistic photon, and the coincidence of the proposed models and schemes with the real processes of reflection and refraction of light waves confirms the correctness of the ballistic photon model itself and the scheme of its motion, on the basis of which they were performed [30]. Since there are no contradictions with the real laws of physics and optics, the models and schemes proposed in Figures 4-7 and 11-14 are recommended for use in further research. They introduce fundamental changes in the optics of light waves and should replace the known schemes in all textbooks and reference books on physics, including the corresponding sections in special and general encyclopedias, including the British one, since they significantly change the previously known schemes and processes, which meets the criteria of a scientific discovery [45].

Conclusions

1. The ballistic principles of rectilinear motion of photon waves make it possible to apply the laws of geometric optics to their study, which were laid down in the works of Thomas Young and Auguste Fresnel and were further developed in new studies.
2. The real wave parameters of ballistic photons and the processes of their movement change the known laws of reflection and refraction of light; therefore, the lack of their consideration is a shortcoming of all basic wave theories that currently exist.
3. Wave processes of motion of ballistic photons can be obtained by geometric modeling, since their motion is rectilinear, and the wave parameters are based on strict laws of quantization of their energy and transformation of shape within the framework of the γ-factor of Lorentz relativism.
4. Ballistic photons have spherical waves of radius R equal to the wavelength λ_{max} in the segment of 1 rad, and the real processes of their reflection occur in the direction of the unified normal to the reflection surface and to the contact surface of these wave spheres.
5. The process of reflection of wave spheres begins from the first point of their contact along the normal to the reflection surface, and not from the virtual midpoint, as previously thought, which is connected to the central axis of the wave incidence tube at an angle α, therefore, there is an actual shift of the initial reflection point from the virtual one by the value of $-\Delta = \lambda_{max} \sin \alpha$.
6. The real axis of reflection of spherical waves of a photon is connected not with the center of the tube of their incidence and movement, but with the movement of their crest for the most distant vertex of the sphere.
7. The assumed critical angle of incidence α and reflection β of spherical waves of photons is the angle α = 1 rad = 57.2958°; when it is exceeded, the directly proportional relationship between the real angles α and β is violated, since first it is necessary to rotate the spherical waves by an angle γ =

α - 57.2958° until their spheres coincide with the common normal to the reflection surface, and the remaining angular parameters of reflection identical to the basic options, which allows them to be used in further research.

8. Known schemes of the process of light refraction are associated with a flow of transverse sinusoidal waves similar to the oscillation of waves in the strings of musical instruments, which contradicts the spherical shape of photon waves and they're of translational and rotational motion by quantum leaps in the direction of their incidence and refraction vectors.
9. Known schemes of the process of light refraction led to a change in the length, pitch and period of sinusoidal waves, which contradicts the laws of wave energy, therefore there is no real change in their parameters, which is confirmed by experimental data.
10. The processes of refraction of spherical waves of a photon and their penetration into the refractive medium occur in the direction of the unified normal to the surface of the wave spheres and to the surface of their contact.
11. The assumed critical angle of incidence of spherical waves of photons is 1 rad = 57.2958o, when it is exceeded, the directly proportional relationship between the angles of incidence Θα and refraction Θ_τ is broken, therefore, at first, the spherical waves rotate by an angle $\gamma = \Theta_\alpha$ - 57.2958o until their spheres coincide with the common normal to the refraction surface, and the remaining angular parameters are identical to the basic refraction variants, which allows them to be used in further studies.
12. The process of refraction of the waves of a ballistic photon begins from the first point of their contact with the refraction surface, and not from the virtual midpoint associated with the axis of incidence of the wave tube, and ends at the last point of contact of the incident wave, and only after this is the tube of refracted photon waves finally formed.
13. In the interval between the first and last refraction points of photon waves, a transition zone is formed, which has a concave shape when transitioning from a less dense optical medium to a denser one and a convex shape when transitioning from a denser optical medium to a less dense one; however, experimental studies are necessary to identify and confirm them.
14. The point of real intersection of the axes of the incident and refracted waves of the photon does not coincide with the virtual point of the axis of the tube of incidence on the refraction surface; the real point is the final point of incidence of the waves, therefore, for all refraction variants, it is necessary to shift the common normal of the incident and refracted waves to the final point of their refraction relative to the virtual point by a value of $+\Delta = \lambda_{max} \sin \alpha$.
15. In the proposed models there is no change in the parameters of the incident and refracted waves, and the change in the speed of their movement is provided automatically by the ratio of the length of the path of movement in the triangle of the incident and refracted waves: when moving from a less dense medium to a denser one, this is the ratio of the hypotenuse to the leg, and when moving from a denser one to a less dense one, this is the ratio of the leg to the hypotenuse, which adequately changes their speed.
16. The scattering of light waves occurs on a surface whose microroughness chaotically changes the direction of the unified general normal to them and to the vector of wave movement, therefore it actually comes down to the processes of wave reflection on local areas of this surface.
17. The geometric parameters of absorption of photon waves are similar to the processes of their refraction to enter an opaque medium, and occur at unified normal to the spherical surface of the wave and the surface of its absorption; at other angles, the wave passes to it with its full length and is slowed down, as a result of which its speed drops from the speed of light c to 0 and it is contracted into a quantum material particle - a photon, however, these processes require special research.
18. The fidelity of the proposed models and schemes to the real processes of reflection and refraction of light waves confirms the fidelity of the proposed model of a ballistic photon and the scheme of its movement, on the basis of which new models and schemes were made.
19. The proposed models and schemes of reflection and refraction of the front of spherical waves of a photon significantly clarify and change previously known schemes and do not contradict the real laws of physics, optics and photonics, and have the level of scientific discoveries.
20. Given the importance of the proposed models and schemes for the development of physics, optics and photonics, that should replace previously known processes and schemes in all textbooks and reference books on physics, including the corresponding sections in encyclopedias, including the British Encyclopedia.

Conflict of Interest

This work was carried out by the author alone, on his own initiative, on the basis of personal scientific works: [26-30,33,38,41,44]. It uses literature sources from open databases, so permission for their publication is not required.

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