© 2018 IJSRST | Volume 4 | Issue 9 | Print ISSN : 2395-6011 | Online ISSN : 2395-602X
Themed Section: Science and Technology

Some Studies on Photon – A Review

Rampada Misra
Ex-Guest-Teacher, Departments of Electronics, Vidyasagar University, Midnapur, West Bengal, India

ABSTRACT

Discussion of some works related to photon has been made. Different works selected here contain the study of different characteristics of photon. The properties of photon like charge; mass; spin; angular momentum; interaction between light and matter; that between photon and gravitational field; the wave function and gravitational field of photon have been mainly chosen for discussion. Over and above the aforesaid characteristics of photon the wave particle duality; structure of photon motion; pair production by photon ; photon, graviton and their reactions ; radius of photon orbit due to black holes have also been discussed.
Keywords: Gravitational Field, Gauge Boson, Helicity, Extra-galactic Source.

I. INTRODUCTION

From early days study of the properties of photon is of prime interest to the researchers. It was Albert Einstein who considered that light consists of small indivisible particles called 'Photons'. So, all the phenomena of light are nothing but the phenomena with photons. The photon concept, although debatable about its characteristics, has led to momentus advances in the theoretical as well as experimental physics. The characteristics have been adhered to the photons at different times by different workers.

In this review we shall include the works of several authors who discussed the characteristics of photon from different points of view. Here, stresses have been given on charge, mass, gravitational field of photon and the interaction of photon with it. Discussions of several works about other characteristics of photon has, also, been included in this work.

This dissertation has been divided into different sections. In a particular section different works on each characteristic of photon have been presented which are arranged year-wise as far as practicable..

II. GENERAL CONCEPT ABOUT PHOTON

Different authors have defined photon in different ways. Discussion on some of the common characteristics of photon would be included, in brief, in this section which would, again, be discussed in later sections in some details.

A longstanding question is – what is photon?

The answer is as follows:

A photon is an elementary particle. It is the quantum of light as well as of all the other forms of electromagnetic radiation which is, also, the carrier of electromagnetic force even in static condition [1]. It is to be noted here that photon has no rest mass which is responsible for interactions at long distances.

In Physics, a photon is usually denoted by which is, most probably, derived from -rays [2]. The photons may, also, be symbolized by .

The history of photon started in 1901 when Planck put forward his famous formula for black body radiation. Afterwards photon was called the quantum action [3].

However, Einstein gradually developed the modern concept of photon to explain experimental observations. It is to mention that the frequency dependence of light energy was included in the photon model. In 1902 Lenard discovered that in photoelectric effect the energy of electrons depends on the wavelength of light [4]. The nature of photons could be best explained by quantum mechanics since photons exhibit wave particle duality. It is to mention that the term 'photon', in its present concept, was first used by Compton [5]. Einstein and others described the photon not to be a point-like particle. According to Einstein the photons are fully identical and there is non-local interaction [6].

In the article 'conservation of photon' Lewis, a chemist [7], named the light quanta as 'photon' in 1926. According to him photons were uncreatable and indestructible. He considered photons to be "atoms of light" which are conserved. But his notion of photon was a bit different from that used today.
Again, a photon is a spin-one particle. It has only helicity and energy which can not be localized at a point. It has, also, been shown that photons carry spin angular momentum which is independent of its frequency [8].

Also, we find in [9] that photon may be considered as a small mass ( ) concentrated in a ring of radius which rotates with velocity of light ( ) having a linear motion with velocity along the axis of rotation. So, photons may have two velocities which produces right and left rotations.

Again, Pine and others [10] have studied photons and concluded that photons would be absorbed by nuclei, atoms and molecules. In the works [11,12] we may obtain informations about some of the properties of photon. Now, electromagnetic photons may be emitted in many natural processes. Gauge theories could be applied to these photons [13]. So, photons are considered to be gauge bosons.

Also, from [1] it is learnt that photon is massless. Relativistic mass is just the energy scaled to unit of mass. For a photon with wavelength or energy the mass is or . Terrestrial experiments have shown that the rest mass of photon is less than . It is also mentioned that photons may , always, be travelling with in matter when their phase is shifted due to interaction with atomic scatterers. This modifies the momentum and wavelength but not the speed. Again, Eugene [14] has discussed about the well known dispersion effect of light.

Now, in the earlier times of the last century some questions about plane light waves have been raised by some authors. Of course, there appear some papers [15-17] where we, again, find their answers.

Again, we have found that photon has no electric charge and is stable [18]. It has been mentioned here that a photon has two possible polarization states and it is described by exactly three continuous parameters which are the components of its wave vector.

It is known that under low resolution the transport of energy, linear and angular momentum by electromagnetic radiation is often continuous but under sufficient resolution it breaks down forming discrete quanta. The authors of [19] is of opinion that a photon is the result of an elementary excitation of the quantized electromagnetic field. It can be treated as a quasi-particle which is approximately similar to an electron. Its unique properties arise from its zero rest mass and its spin-one nature. Photons could not be localized to a point and are inherently relativistic. For a photon, it was assumed that the magnitude of spin is , the helicity is which corresponds to right handed and left handed circular polarizations [20] as mentioned earlier.

Now, photons, in the form of rays, loose energy while passing through matter and upper limit of photon mass is [21]. Again, it is learnt that light travels through transparent medium at a speed lower than . In addition light can undergo scattering and absorption in the process. Also, circumstances show that energy transfer through a material is mostly radiative involving emission and absorption of photons within it [1].

In super conductors photons develop a non-zero effective rest mass resulting in electromagnetic forces to become short range inside it [22]. In [23] the authors showed why photons, the regeneration of Newton's corpuscles, was proposed by Einstein again (with slight modification in the characteristic) and why photon concept is governing the scientific world uptil now.

Now, according to [24] light is an electromagnetic wave consisting of photons having kinetic energy , mass ,spin angular momentum about an axis (which is the direction of propagation). According to them photon is not only a particle or wave but it is a system which may be called Super System of Photon (SSP). The system carries kinetic energy and has no rest mass. In SSP electromagnetic and gravitational fields are unified and the system transforms one field to the other.

Several workers [25—31] observed that photon contains electromagnetic field accompanying the gravitational field. It can interact with gravitational field when the source of relativistic mass of photon is gravitational interaction. Also, photon may decay into one or more graviton. We collect from [1] the following informations about photon [32].

Composition	Elementary Particle
Staristics	Bosonic
Interactions	Electromagnetic
Symbol	or
Theorised by	Albert Einstein
Mass	
Mean life time	Stable
Electric charge	
Spin	
Parity	
C Parity	
Condensed	

III. SOME IMPORTANT CHARACTERISTICS OF PHOTON

Following are some important characteristics of photon as considered by several workers.

a) Photon is a particle having kinetic energy , mass (inertial and electromagnetic) [33]; b) Photons may be of two types – right rotating and left rotating which imply the two types of S-L interactions in it and that two types of energy--momentum exist in photon [8,9.34,35]; c) Photon charge, related to a type of energy-momentum, exists which is very small having an upper limit ( ) [18,21,36-39]; d) Photon has no traces of rest mass but a moving mass. The source of relativistic mass of photon is gravitational interaction within it [20,25,30,40]. Photon can decay into one or more graviton; e) Photon is not only a particle or wave but a super system in which gravitational interaction is happening resulting in electromagnetic field with respect to an observer [24,41,42].

IV. CHARGE OF PHOTON

The answer to the question whether a photon is charged is a debatable issue in the field of physical science. Several authors are of opinion that photon is charged, of course, with a very small amount having an upper limit while others say that photon is neutral. It is to note that different limits to the photon charge have been imposed by different authors in different times, considering photons to have equal magnitude of charge but of different signs. In this section we shall present some works related to photon charge.

Some authors [43] have studied the massless particles which, according to them, are nothing but photons. They studied about the conservation law and the photon. The charge of photon was, also, studied by Cocconi [44]. He discussed a constraint on photon charge, which is comparatively weaker, with an approach based on angular spread of photons propagating from distant extra-galactic sources. He explained this hypothetic small change in magnetic field and has tried to propose a limit on this charge [45]. Another constraint has been obtained recently by a study of the properties of cosmic micro-wave background (CMB). It is noticed that there is existence of a small photon charge in charge symmetry of the universe which would contribute to the observed CMB anisotropy.

To have an idea about photon charge Raffelt [46] studied about the trajectory of photons coming from a distant source having a packet of different frequencies. Again, the charge of photon was studied in [47]. In [48] a measurement of the deflection of a laser beam in a modulated magnetic field with a prototype apparatus was made. It has produced an upper limit of on the charge of photon. Using modern high resolution instruments and extra-galactic compact radio sources Kobychev and others [18] obtained an estimate of the upper limit of the charge of photon which is (assuming the photon charge to be energy independent).

Okun [38] has made it clear that if photon is charged and principles of quantum field theory are not violated then there should exist at least two kinds of photons with opposite charges . Again, charge neutrality of photons has been assumed in [49]. Okun [39] has mentioned that there exist several papers on photon, specially the neutrality of photons which, also, set an upper limit on the charge of photon. Now, trial has been made to put an upper limit on photon charge [50]. Again, the spin, charge and fine structure constant of photon have been delt with in [51,52] while in [41] the authors have discussed about Lorentz transformation applicable to Super System of Photon.

Again, we may cite some works which are mainly related to charge of photon [18,45,53-57]. In all these , the upper limit of the charge of photon follows from non-observation of any action of external static electric or magnetic fields of photon's charge while the fact that these fields themselves are "built from photons" is ignored. In fact, the above authors implicitly assumed that all photons are either neutral as in ordinary electrodynamics or all are charged. But, this assumption is not proper.

V. MASS OF PHOTON

In literature we find a number of works on the mass of photon. It should be mentioned that the existence of the mass of a photon is one of the most debatable issues in physics. Special Theory of Relativity assumes photons without rest mass but having a relativistic mass which travels with the speed of light. But, some scientists are of opinion that photon has a non-zero rest mass however small it may be. It should be mentioned that there is no conclusive evidence regarding the above matter. This section will contain some works on the mass of photon and its related matters.

de Broglie [58] noticed that mass of photon would lead to a faster speed of violet light than that of red light. After a few years some workers [59] have studied the localized states for the systems like that of photon. A general study of the photon mass was, also, done by Bass and others [60] who briefly discussed whether photon mass is zero or has a value however small. Some workers tried to attach a limit to the mass of photon [61].

Now, Kole [62] used the relations … (1) and … (2) where and are respectively the energy and momentum of photon (which is the quantum of any form of wave energy), phase velocity, rest mass, velocity of light. Here (1) contains information about the medium while (2) refers to a particle without reference to other matter. Equivalence of (1) and (2) means that a photon in a medium may be considered as a particle in vacuum. This particle has a "rest mass". It is clear from this work that photon-photon interaction may take place if . This work, also, contains the study about rest mass of the radio-frequency photons.

Some studies on rest mass and mass of photon were made as it appears in [63-66]. Studies have been made about the movement of wave quanta in mechanical force fields under different characteristics of the media (i.e. static and variable) and also for different kinds of fields [67]. Here, an experiment has been designed to study the rest mass of photon. Also, studies have been made about the rest mass of photon in [68] while an upper limit to the photon's rest mass was proposed in [69]. An experiment to determine the photon mass was also conducted [70] with, to some extent, reliable results. Again, the masses of photon and graviton were studied [71]. Now, Goldstone theorem was discussed [72] and according to it the masslessness of photons was assumed.

Ryntov noticed that the limit of photon mass i.e. considered by Particle Data Group (PDG) [73] is the best one. He [74] developed the idea of Ginsburg [75] and first derived a self-consistent and complete set of MHD equations accounting for finite mass of photon. He did not put a new limit on the photon mass but mentioned a possible way of improving it by the analysis of some properties of Solar Wind. Of course, Lakes [76] considered some limits on the photon mass through an experiment.

The work of Sivaram [36] reveals that - ray bursts GRB990123 were detected 22 second after the burst and in the radio-frequency range about a day later. It puts some more stringent constraints on the photon's rest mass and charge. The delay in detection was thought to be due to the presence of finite mass and charge of the photon. On this basis an expression for the delay time was put forward. It should be mentioned that the best acceptable photon mass was given by PDG [77].

It is well known that any massive quantum particle undergoes dispersive deflection in external gravitational fields. So, with the help of such deflection of the quantized massive electromagnetic radiation by the gravitational field of the Sun, an upper bound for the photon mass has been found out (with the assumption that photons are massive particles) [78]. Now, some tests of Coulomb's law and the rest mass of photon have been performed by Tu and others [79]. Again, Okun [39] has vividly studied photon's history, mass and charge like other workers. Here, the processes of the creation of charge and mass have been examined. The symmetry behind charge parity has been clearly shown as well.

Studies on the photon mass was, also, made in [80,81]. Again, in the paper [52] mass, charge and the fine structure constant were studied. The interaction of two plane waves moving at the speed of light has, also, been examined.

VI. SOME AVAILABLE REVIEWS ON PHOTON MASS

From the beginning of 1968 a special issue of Uspekhi Fizicheskikh Nauk was under preparation to mark fifty years of this review journal. Kobzarev and Okun [82] corrected the estimates of de Broglie and

Schrodinger. Goldhaber and Nietto published an extensive review [83]. There is the review on rest mass by Byrne [84] published in 1977. The latest review by Tu, Luo and Gillis [85] published in 2005 includes a large number of works.

VII. SPIN OF PHOTON

Photons are having spins. Different workers have studied photon's spin both theoretically and experimentally. Let us try to present some works on photon-spin in this setion.

It is well known that Nicols and others [86] have studied preliminarily the presence of heat and light radiations which may be looked upon as a study of motion of photons. Following Dirac [87] one may consider plane polarized light to be a quantum with spin. Similar are the cases with other types of polarized light.

Raman and Bhagavantam [8] have studied experimentally the spin of the photon and have mentioned, in the line of Prof. S.N.Bose, that the photons have energy , linear momentum and also an intrinsic spin or angular momentum around an axis parallel to its direction of motion. The change in spin of the photon is either 0 or Bohr Unit. The measurements made by them are clearly decisive in favour of the spin theory. Spin structure of the photon has been studied by Bass and others [88,89]. Bauke and others [90] have discussed the electron spin dynamics induced by photons. Now, opto-mechanical photon shuttling between photonic cavities may occur as in [91]. Again, the study of the natural process of spin-spin interaction of light has, also, been made [92]. In [93] the authors have tried to measure the photon's spin angular momentum and optical torque in integrated photonic devices by opto-mechanical methods.

VIII. ANGULAR MOMENTUM OF PHOTON

Like spin, photons may possess angular momentum. Both are of particular interest to research workers in current days. Several works appear in literature which deal with angular momentum theoretically as well as experimentally. Trial would be made to include, in this section, some works on photon angular momentum.

Poynting [94] and Abraham [95] showed that a beam of light may possess angular momentum. In a work by Beth [96] circularly polarized light was transformed into linear polarization, removing spin angular momentum from the light beam. This results in a measureable torque. The angular momentum of light has been mechanically detected and also measured giving results as predicted by the theory. The fact that angular momentum is associated with polarized light, especially to circularly polarized one, was studied in [97].

Again, we found in Allen and others [98] well defined orbital angular momentum for laser light with a Laguerre-Gaussian amplitude distribution. To measure the mechanical torque induced by the transfer of orbital angular momentum associated with the above transformation an experiment has been proposed by Van Enk and others [99]. It was, also, shown that the electron light carries angular momentum [100]. Again, Allen and others [101] have studied the orbital angular momentum related to light. It is to note that spin and angular momentum of light are of importance to present day study as pointed out in [102]. Orbital angular momentum of photons has, also, been delt with in [34,103].

On the other hand discussion on the electromagnetic energy momentum was made in [104]. Brief study of radiation pressure and the linear momentum of electromagnetic field was made by Mansuripur [105]. Radiation pressure and the linear momentum of light in dispersive di-electric media was, also, observed by Mansuripur [106]. He studied the behavior of circularly polarized light, specially the angular momentum in di-electric media and derived an expression for the angular momentum density of a single plane wave in a limiting case [107].

Now, using Helmholtz theorem on the decomposition of vector fields the angular momentum of the classical electromagnetic field is decomposed into a spin component and an orbital component. The method has been applied to linearly and circularly polarized plane waves in their classical and quantum forms [108]. The authors of [109] have delt with the momentum of electromagnetic wave when it propagates through a di-electric medium.

It is well known that optical forces may be produced in integrated photonic circuits [110]. Again, general treatment of optical forces and potentials in mechanically variable photonic systems has been done in [111]. Also, discussions on photonic quantum technologies have been given in [112]. Taking into account the concept in [9] the linear and rotational velocities add according to Lorentz transformation thus limiting the maximum velocity to [113]. In [114] it is seen that natural separation of the generators of Lorentz Boosts into spin and orbital parts fails, as the spin part is identically zero. In [115] the case of twisted photons and also the orbital angular momentum of it have been reviewed. Also, the angular momentum of light was delt with in [116]. It could be seen that the work [117] received much attention from different spheres of physics. They have proposed a theoretical and experimental frame-work for the study of light-matter interactions and the angular momentum of light.

A new concept of photonic wheels has been given in [118]. However, finite sections of circularly polarized plane waves are found experimentally to carry angular momentum. A mathematical model is described here that gives a quantitative account of this effect to resolve the paradox mentioned in [119].

IX. WAVE PARTICLE DUALITY OF PHOTON

It was Luis de Broglie who considered a photon to have duality i.e. wae and particle nature. This is an important conjecture which was successfully applied to optical phenomena. In this section we shall briefly discuss some phenomena related to wave and particle nature of light or photon.

Zu [35] establishes a classical geometric model of a single photon based on field matter. He deduces the formula for the size of a photon assuming only two kinds of photons viz. right handed and left handed circularly polarized. He also suggest the frequency of photon polarization to be its spin frequency. Here wave like nature of photon is ascribed to its spin and the particle like nature to its translational motion.

This work is based on following hypotheses--
A) The photon consists of electric field vector and magnetic field vector overlapping in a plane. A photon has no rest mass but motional mass. The mass is due to and . B) Spin angular momentum of photon suggests that there is neither unpolarized nor plane polarized photons but they are circularly polarized being either right handed or left handed corresponding to the helicity or . C) In quantum electrodynamics [120,121] is the photon oscillation frequency. But here it is supposed that photon never oscillates though the electromagnetic fields do and is the polarization rotation angular frequency of photon i.e. spin frequency. D) When two photons of same frequency interfere, the resultant field vector may be either (or) or zero. E) The bending of light in a field of gravity indicates that photon follows mechanical laws.

Mreover, [122] clarifies the single photon interference effect in a simple manner with experimental evidence.

X. STRUCTURE OF MOTION OF PHOTON

A brief discussion on the structure of motion related to the integral of motion has been inserted in this section.

In [123] the Hamiltonian of free photon has been linearized by using Pauli's metric. Some characteristics of photon which follows from this linearization have been examined. This paper showed that the integral of motion is the total angular momentum which is the sum of orbital and spin momentum for a half-one spin.

XI. PAIR PRODUCTION BY PHOTON

This section contains the resultant effect after collision of photons leading to pair production.

[124] discusses the situation that would happen after collision between a high energy and a low energy photon. They have calculated the absorption probabilities and also considered the absorption by a black body photon gas and absorption by a power-law photon spectrum with a low energy and high energy cut off as also the photon spectrum with two cut offs.

XII. PHOTON-GRAVITON MIXING

Photon graviton mixing in an electromagnetic field is a process of potential interest for cosmology and astrophysics. In this section we shall discuss about it in brief.

It is known that Einstein-Maxwell theory implies the mixing of photons with gravitons in an external electromagnetic field. This process and its consequences have been studied for many years by many workers [125]. They have deduced the photon-graviton polarization tensor in a constant field, the properties of which are similar to those of photon-photon polarization tensor. The mixing was also studied in [126].

XII. Radius of the Photon Orbit

Photons rotate in a particular orbit with respect to a rotating black hole. Discussions on the radius of the photon orbit has been included in this section.

A photon sphere is a spherical region of space. The photons travelling near the horizon of a black hole are pulled by it. Radius of a photon orbit around the rotating black hole could be looked upon as a function of intense gravitational field intensity of the rotating black hole [127].

XIII. INTERACTION BETWEEN LIGHT AND MATTER

The phenomenon of interaction between light and matter leading to scattering of photons is one of the important objects of study in optics. In this section this interaction would be discussed in brief.

The authors in [128] extended the Bialynicki-Birula-Sipe formalism to include the interaction of photons with non-absorptive continuous media. They have, briefly, discussed the photon wave equations in vacuum and, also, some of the properties of photon wave functions. Again, they have applied the second quantization procedure to the photon wave function formalism in a linear non-dispersive and non-absorptive medium.

XIV. INTERACTION BETWEEN PHOTON AND GRAVITATIONAL FIELD

Interaction of photons with gravitational field is one of the major problems in the theory of gravitation. In this section we shall present some works on the topic.

Scott [129] proposed a new theory of gravitation where space-time is always flat and gravitational field is described by equations of Maxwell's form. The interaction of photons with gravitational field follows from the basic quantum theory which predicts that photon frequency is proportional to the energy while wavelength is inversely proportional to momentum.

Again, photon velocity depends on gravitational potential and deflection of light ray (depending on mass) is due to gravitational refraction. Gould and others [130] have studied the opacity of the universe. Also, interaction of photons with gravitational field was delt with in [131]. Crawford [25] has analysed the behavior of photons in gravitational field considering the photons to be point particles that travel along geodesics. It was shown that photons could interact with the transverse gradient of the gravitational field to give a deflection in addition to the well known gravitational deflection of general relativity. Again, an equation describing the motion of a photon in a gravitational field exterior to a stationary homogeneous body was established in [132]. In this paper the author showed that a photon is not only accelerated angularly by a gravitational field but linearly also, although to a small extent.

Faraon and others [133] have studied the interaction of light and gravitational field when the field varies from weak to a strong one. Some authors have delt with the interaction of photons with a low amplitude gravitational wave propagating in a flat space-time. In section II of this paper the authors present the ray trajectories of photon in Hamiltonian form for photons moving in a generic gravitational field. The authors examine the case of motion of photon in a flat space-time perturbed by a low amplitude gravitational wave in section III of this paper. Lastly, in section IV the authors consider the photon motion along the direction of propagation of the gravitational wave and illustrate their formalism with numerical examples. It has been shown here that photons can strongly interact in a flat space-time with low amplitude gravitational waves. Mendonca [135] has considered widely the production of acceleration of the photon. Again, interaction of photon with gravitational field has been studied by several workers [28, 136-138]. The relation between electromagnetic field and gravitational field was studied, in brief, in [139].

XV. WAVE FUNCTION PHOTON

It is well known that electromagnetic waves are generated during spontaneous emission of photons. The waves could be described by wave functions appropriate to the case. In this section the wave functions and their related matters are presented in a lucid way.

Several authors like de Broglie [140] has studied the mechanics of photon waves. Again, the mechanical structure of photon has been discussed in [141]. Philippidis and others [142] describe the photon propagation through a di-electric using quantum mechanics on the basis of the effect of photon penetration through a potential barrier. The authors have discussed the link between the photon wave function and the electromagnetic fields of the wave. It is to be mentioned that the photon wave function introduced here differs from that in non-relativistic quantum mechanics. They have, also, deduced Fresnel equations using quantum mechanical methods.

A localized one-photon state has been experimentally realized in [143] and a good approximation to the ideal localized one-photon state has been achieved. Huang and others [144] have, also, studied the single photon wave function, of course, in free space.

In [145-147] we find the studies of wave function of photon. It was noted that photon, a relativistic particle, fits within the frame work of elementary non-relativistic quantum mechanics. With no rest mass it cannot be stopped except by an absorption process. Thus, spin and angular momentum of photon are not separate. Also, due to the absence of rest mass there is lack of photon localizability. Sipe has deduced an expression of photon wave function generated in spontaneous emission of single photon with the idea that photon is a particle. Now, experimental observations have been made in [148] about the localization of photons. Keller [149] has studied the photon emission from atom.

Again, the two photon wave mechanics has been discussed in [150]. Also the quantum structure of continuous entanglement has been examined in [151]. From this, the authors derive a set of two photon mode functions that provide an exact, discrete and effectively finite basis for characterizing pair wise entanglement. Similar matters have been delt with in [152] while Keller [153] discussed some crucial points related to localizability of photon. Entanglement of the two photons emitted in spontaneous parametric down conversion has been examined in [154]. In this connection the characteristics of light have been reconsidered in [155].

We have two papers [156,157] where there are discussions on the nature and characteristics of light which are related to the light particles i.e. photons. Mach [158] reviewed the properties of photon from a different point of view. [159,160] discussed the nature of photons. Again, [161] considers the wave function of photon from a different aspect. The quantum aspects of propagation of photon in transparent infinite media was delt with in [162].

Studies have been made about the interaction of photon and a homogeneous medium during the propagation of light through it. An expression for propagation of the photon through a non-dispersive medium was found out. It was argued that the wave function of the interacting photon is a Q-vector. The photon wave function was, also, studied and Fresnel formulae were deduced by Popesku and others [163].

XVI. PHOTONS AND GRAVITATIONAL FIELD.

The idea that photons may produce gravitational field is a long standing one. This field could be observed in the form of waves. Studies of this field (or the wave) and their effect on photons have been done by several authors . The gist of some of these studies have been presented in this section.

It is seen that Riemannian spaces conformal to Einstein spaces have been considered for study [164] while a general discussion on gravitational waves has been done by Peres [165]. The mathematical theory of plane gravitational waves in general relativity was proposed by Takeno [166].

In a work [167] the phenomenon of gravitation and its application to current research was considered. The work of Edelen [168] presents the discussion on the gravitational field of light. Bonnor [169] gave exact solution of Einstein's equations representing the gravitational field of a steady beam of light. From a study of null geodesics the author concluded that a uniform beam of light is gravitationally stable. The outcome of Bonor's work is—

I. The gravitational field of light is twice that of a material source having the same energy density.
II. The gravitational field of pulses and beams of light consists of plane fronted gravitational waves.
III. A uniform beam of light is gravitationally stable.
IV. Parallel beams (or pulses) of light shinning in the same sense do not interact.

The problem of gravitational fields of massless particles has been discussed by several authors [170,171]. Again, the concept in [172] is that photon existing at is an idealization. In reality one should consider a photon produced at a finite instant of time . Now, according to general theory of relativity photons as well as electromagnetic waves contribute to the stress-energy tensor which exerts a gravitational attraction on other objects [26].

XVII. GRAVITATIONAL FIELD OF PHOTON

Photon itself creates no gravitational field. But the source of photon emission creates a gravitational field which emits a gravitational wave. This phenomenon was studied by different workers in different times. We shall try to include some such works in this section.

It is seen that the gravitational properties of photon have been illustrated in [173,174]. Also, some studies of gravitational fields were made by Kramer [175]. In the work [176] the gravitational field due to the circulating flow of electromagnetic radiation of a uni-directional ring laser is found by solving the linearized Einstein's field equations at an interior point of the laser ring. In the work [177] the stationary gravitational field of two identical counter-moving beams of pure radiation is found in full generality. Bonnor [29] considered the field of a photon on an infinite straight path. His conclusion is that at the moment of generation of photon the source of the photon determines its gravitational field by emitting a gravitational wave. The photon itself appears to create no gravitational field.

There are some works related to the gravitational field of light which were classified as follows—

I. On the basis of very early approach [178],
II. On the field of interacting particles and beams [133,175,177,179,180].
III. On the gravitational shock waves of massless particles and beams [181-183] where consideration is that light can be source of non-linear gravitational waves and lastly,
IV. On a different approach to the field of a photon [184].

Some workers have determined [30] gravitational field created by a single photon by taking into account the relativistic mass of the photon as source of gravitational interaction. Here, discussions have been made about some aspects related to the photon as an ultra-relativistic particle.

In [185] space- time geometry of electromagnetic field in the system of photon has been introduced to unify electromagnetic field and gravitational field in flat and curved space-time.

XVIII. APPLICATIONS

Some simple applications of photon have been mentioned in this section. As an application, the energy balance of nuclear reactions involving photons is commonly written in terms of the masses of the nuclei involved, where the terms are related to - photons [186].

It is to be mentioned that there are some other common applications as in the cases of optical instruments and those related to design purposes.

XIX. CONCLUDING REMARKS

The authors have discussed several works related to photon available in literature. Some possible areas where future improvements might occur have been considered.

The overall discussions presented here show that it is difficult to attribute a fixed value of any of the properties of photon. For this reason, it could be mentioned that photon is important for study in fundamental physics as well as in electrodynamics.

The purpose of this review has been to introduce the readers of this subject to the present theoretical and experimental situation in a nut shell.

This review is neither exhaustive nor completely detailed. Trial has been made to present a useful section of the literature on the topic to the readers. This would be a helpful starting point for workers continuing further study.

XX.REFERENCES

[1]. Photon, Wikipedia, The free encyclopedia.

[2]. Villard P., Comptes Rendus des Scances de l'Academie des Sciences, 130, 1010-1012 and 1178-1179,(1900) .

[3]. Planck Max, Energy and mass in relativity theory, Ann. Phys., 9, 561, (1901).

[4]. Lenard P., Energy and mass in relativity theory, Ann. Phys., 8, 169, (1902).

[5]. Compton A. H., About energy and mass in relativistic theory, Phys. Rev., 22, 409,(1923).

[6]. Einstein A., Quanten theorie des einatomigen idealen gases, Sitzungs berichte der Preussischen Akademic der Wissenschaften (Berlin), Physicalisch-Mathematische Klasse,261-267, (1924); 3-14, (1925).

[7]. Lewis G. N. Conservation of photon, Nature, No. 2981, 118, 874, (1926).

[8]. Raman C. V. and S. Bhavantam S., Experimental proof of the spin of the photon, Ind. J. Phys., 6, 353-366, (1931).

[9]. Rocard Y., Thermodynamique, Masson, Paris, 250 p, (1957).

[10]. Pine S. A., Hendrickson J. B., Cram D. J., Hammond G. S., The Molecular Basis of Visual Excitation, Organic Chemistry (4thEd.), McGraw Hill, Section 11-5c, G. Wald, Nobel Lecture, Dec.12, (1967).

[11]. Simmons J. W., Guttman M. J., States, Waves and Photons: A Modern Introduction to Light (Reading, M A : Addison-Wesley), (1970).

[12]. Jauch J. M., Rohrlich F., The Theory of Photons and Electrons (New York, Springer-Verlag), 34 p, (1976).

[13]. Aitchison I. J. R., Hey A. J. G., Gauge Theories in Particle Physics, IOP Publishing, (1993).

[14]. Eugene H., Optics, Pearson Addison Wesley, Errata, (2001).

[15]. Khrapko R. I., Question #79, Does plane wave not carry a spin? Am. J. Phys.,69, 405, (2001).

[16]. Allen L, Padgett M. J., Response to question #79, Does plane wave not carry spin angular momentum?, Am. J. Phys., 70, 567-568, (2002).

[17]. Yurchenko V. B., Answer to question # 79, Does the plane wave not carry a spin? Am. J. Phys., 70, 568-569, (2002) .

[18]. Kobychev V. V. and Popov S. B., Constraints on the photon charge based on observations of extragalactic sources, arXiv: hep-ph/0411398 V1 30 Nov (2004).

[19]. Raymer M. G. and Smith B. J., The Maxwell wave function of the photon, SPIE Conference Optics and Photonics, Conference Number 5866, San Diego, Aug. (2005).

[20]. Burgess C. P., Moore G. D., The Standard Model A Primer, Cambridge Univ. Press, (2007).

[21]. Amsler C., Doser M., Asner D., Babu K., Baer H., Band H., Barnell R., et al, Reviews of Particle Physics, Phys. Lett. B, 667, 1, (2008).

[22]. Frank W., The Lightness of Being: Mass, Ether and the Unification of forces, Basic Books, 212 p, (2010).

[23]. He-Zhou, He He-Xiang, Feng Jie, Chen Xio Dong,The actual nature of light from Newton, Einstein to the recent mistakes, Journal of Quantum Information Science, 1(02):54-56, (2011).

[24]. Das M. C., Misra R., A Classical Approach of Unified Field, International Letters of Chemistry, Physics and Astronomy, 7(2), 73-84,(2013).

[25]. Crawford D. F., Interaction of a photon with a gravitational field, Nature, 254, 313-314, (1975).

[26]. Stephani H., Stewart J., General Relativity: An Introduction to the theory of Gravitational Field, Cambridge University Press, 86-108 p, (1990).

[27]. Mendonka J. T., Drury L. O'C, Resonant Interaction of Photons with Gravitational Waves, Phys. Rev. D, 65, 024026-1-5, (2001).

[28]. Accioly A,, Paszko R., Photon Mass and Gravitational Deflection, Phys. Rev. D, 69, 107501, (2004).

[29]. Bonnor W. B., The Gravitational Field of Photon, Gen. Relativ. Gravit., 41, 77-85, (2009).

[30]. Grado-Caffaro M. A., Grado-Caffaro M., Gravitational Field from Photon, Optik—International Journal of Light and Electron Optics, 123(9), 814-815, (2012).

[31]. nan S. C., Direct Graviton Production via photon-photon fusion at the CERN-LHC , Chin. Phys. Lett., 29 (3), 031301- 1-4 (2012).

[32]. Particle Data Group, Amsler et al, Rev. particle Phys.: Gauge and Higgs Bosons, Phys. Lett. B, 667,1, (2008+ 2009 partial update).

[33]. Roy S., Lorentz Electromagnetic Mass : A Clue for Unification? Apeiron, 14(3), 155, (2007).

[34]. Harwit M., Photon Orbital Angular Momentum in Astrophysics, The Astrophysical Journal, 597, 1266-1270, (2003).

[35]. Zu D., The Classical Structure Model of Single Photon and Classical point of view with regard to Wave –Particle Duality of Photon, Progress in Electromagnetics Research Letters, 1, 109-118, (2008).

[36]. Sivaram C., Constraints on the photon mass and charge and test of equivalence principle from GRB 990123, Bull. Astr. Soc. India, 27, 627-630, (1999).

[37]. Kobychev V. V., Popov S. B., Constraints on the photon charge from observations of extra-galactic sources, Astronomy Letters, 31(3), 147-151, (2005).

[38]. Okun L. B., On the charge of the photon, arXiv : hep-ph/ 0505250V1 30 May (2005).

[39]. Okun L. B., Photon: history, mass and charge, arXiv :hep-ph/0602036V2 13 Feb (2006).

[40]. Sahoo S., Roy A. D., Mandal S., Photon: Massless or Massive, ARPN Journal of Science and Tecnology, 4 (7), 413-417, (2014).

[41]. Das M. C., Misra R., Lorentz Transformation in Super System and in Super System of Photon, International Letters of Chemistry, Physics and Astronomy, 19 (1), 8-14, (2014).

[42]. Misra R., Das M. C., Electromagnetic Energy-momentum Tensor of Photon, Paper Communicated for publication, (2018).

[43]. Guralni G. S., Hagen C. R., Kibble T. W. B.,Global Conservation Law and Massless Particles, Phys. Rev. Lett., 13 (20), 585-587, (1964).

[44]. Cocconi G., Proceedings of the International Seminar Quarks, '90, Nature, 329, 8, (1987).

[45]. Cocconi G., Upper limits on the electric charge of the photon, Am. J. Phys., 60, 750, (1992).

[46]. Raffelt G., Pulsar Bound on the Photon Electric Charge Re-examined, Phys. Rev. D, 50, 7729: hep-ph / 0411398, (1994).

[47]. Hankins A., Rackson C., Kim W. J., Photon Charge Experiment, Am. J. Phys., 81, 436, (2013).

[48]. Semertzidis Y. K., Danby G. A., Lazarus D. M., New Laboratory Technique for measuring the Photon Charge, Phys. Rev. D, 67, 017701, (2003).

[49]. Caprin C., Ferreira P. G., Constraints on the Electrical Charge Asymmetry of the Universe, JCAP 0502, 006: hep-ph / 0310066, (2005).

[50]. Sivaram C., Arun K., Bounds on Photon Charge from Evaporation of Massive Black Holes, arXiv: 0802. 1562V1 [astro-ph.co], (2008).

[51]. Laster C., Spin, Charge and Fine Structure Constant, The General Science Journal, June 6, (2011), http://www.wbabin.net/files/4479_laster1.pdf .

[52]. Laster C. A., Pair Production: The Origin of Charge, Mass and CP Symmetry, The General Science Journal, July 7, (2011).

[53]. Grodzins L., Engelberg D,, Bertozzo W., Photon Charge Experiment, Bull. Am. Phys. Soc., 6, 63, (1961).

[54]. Stover R. W., Moran T. I., Trischka J. W., Energy and Mass in Relativity Theory, Phys. Rev., 164, 1599, (1967).

[55]. Cocconi G., Upper limit for the electric charge of the photons from the millisecond pulsar 1937, Phys. Lett. B, 206, 705, (1988).

[56]. Sivaram C.,Upper Limit on the Photon Electric Charge from Cosmic Micro-wave background, Am. J. Phys., 63, 1473, (1994).

[57]. Particle Data Group, Review of Particle Physics, Phys. Lett. B, 592, 31.335, (2004).

[58]. Broglie L. de, La Mechanique Ondulatoire du Photon, Une Nouvelle Theorie de la Lumicre, tome premier, Paris,39-40, (1940).

[59]. Newton T. D., Wigmer E. P., Localized states of elementary systems, Rev. Mod. Phys., 21, 400, (1949).

[60]. Bass L., E., Must the photon mass be zero? Proc. Roy. Soc. London A, 232, 1-6, (1955).

[61]. Goldhaber A. S., Nieto M. M., New Geomagnetic Limit on the Mass of the Photon, Phys. Rev. Lett., 21, 567-569, (1968).

[62]. Kole K. D., Finite rest masses of Wave Quanta in Material Media, Austr. J. Phys., 24, 871-880, (1971).

[63]. Goldhaber A. S., Nieto M. M.,(1971), How to catch a photon and measure its mass? Phys. Rev. Lett., 26, 1390-1392, (1971).

[64]. Park D, Williams E. R., Comment on a proposal for determining the photon mass, Phys. Rev. Lett., 26, 1393-1394, (1971).

[65]. Krou N. M., Theoretical Interpretation of a Recent Experimental Investigation of the Photon Rest Mass, Phys. Rev. Lett., 26, 1395-1398, (1971).

[66]. Williams E. R., Park D., Photon Mass and the Galactic Magnetic Field, Phys. Rev. Lett., 26, 1651-1652, (1971).

[67]. Kole K. D., Finite rest masses of Wave Quanta in Inhomogeneous Material Media, Austr. J. Phys., 62, 359-367, (1973).

[68]. Goldhaber A. S., Nieto M. M., The Photon Rest Mass, Sci. Am., 234(5), 86-96, (1976).

[69]. Chibisov G. V., Astrophysical Upper Limits on the Photon Rest Mass, Sov. Phys. USP, 19, 624-626, (1976).

[70]. Crandall R. E., Photon Mass Experiment, Am. J. Phys., 51, 698-702, (1983).

[71]. Kostelecky V. A., Samuel S., Photon and Graviton Masses in String Theory, Phys. Rev. Lett., 66, 1811-1814, (1991).

[72]. Rosentime B., Kovner A., Masslessness of the Photon and Goldstone Theorem, Int. J. Mod. Phys. A, 6, 3559-3569, (1991).

[73]. Particle Data Group, Phys. Rev. D, 50, 351 (1994).

[74]. Ryntov D. D., The Role of Finite Photon Mass in Magnetohydrodynamics of Space Plasma, Plasma Physics Control Fusion, 39, A73-A82, (1997).

[75]. Particle Data Group, Eur. Phys. J., 3, 223, (1998).

[76]. Lakes R., Experimental Limits on the Photon Mass and Cosmic Vector Potential, Phys. Rev. Lett., 80, 1826-1829, (1998).

[77]. Particle Data Group, Phys. Lett. B, 592, 335, (2004).

[78]. Accioly A., Paszko R., Photon Mass and Gravitational Deflection, Phys. Rev. D, 69, 69-71, (2004).

[79]. Tu L. C., Luo J., Experimental Tests of Coulomb's Law and the Photon Rest Mass, Metrologia, 41, S 136-S 146 (2004).

[80]. Edelberger E, Dvali G., Gruzinov A., Photon Mass Bound Destroyed by Vortices, Phys. Rev. Lett., 98, 010462 / 1-4 (2007), arXiv: hep-ph / 0306245, (2007).

[81]. Goldhaber A. S., Nieto M. M., Photon and Graviton Mass Limits, arXiv : 0809.1003 V5 [hep-ph] 5 October (2010).

[82]. Kobzarev I. Yu, Okun L. B., Astronomical Upper Limits on the Photon Rest Mass, Uspekhi Fiz. Nauk, 95, 131-137, (1968).

[83]. Goldhaber A. S., Nieto M. M.,Terrestrial and Extra-terrestrial Limits on the photon Mass, Rev. Mod. Phys., 43, 277, (1971).

[84]. Byrne J. C., Cosmic Tests of Maxwell's Equations, Astrophys.&Spae Sc.46, 115-132, (1977).

[85]. Tu L. C., Luo J., Gillies G. T.,The mass of the photon, Rep. Prog. Phys., 68, 77-130, (2005).

[86]. Nichols E. F., Hull G. F., A preliminary communication on the pressure of heat and light radiation, Phys. Rev., 13, 307-320, (1901).

[87]. Dirac P. A. M., Quantum Mechanics, Cambridge University Press,131 P, (1930).
[88]. Kramers Hendrik Anthony, Quantum Mechanics, North Holland Pub. Co., Amsterdam, (1957).
[89]. Bass S. D., The spin structure of the photon, World Scientific, 14, 212, (2007),
[90]. Bauke Heiko, Ahrens Sven, Keitel C. H., Grobe Rainer, Electron-spin dynamics induced by photon spins, New Journal of Physics, 16, 103028, (2014).
[91]. Li H., Li M., Optomechanical Photon Shuttling between Photonic Cavities, Nat. Nanotechnol., 9, 913-919, (2014).
[92]. Bliokh K. Y., Rodriguez-Fortuno F. J., Nori F., Zayats A. V., Spin-orbit interaction of light, Nat. Photonics, 9, 796-808, (2015).
[93]. Li He, Li Huan, Li Mo, Optomechanical Measurement of Photon Spin Angular Momentum and Optical Torque in Integrated Photonic Devices, Applied Physics, Sci. Adv. 2016:2: e 1600485 9 September (2016).
[94]. Poyting H., The Orbital Angular Momentum of Light, Proc. Roy. Soc. London Ser A, 82, 560-567, (1909).
[95]. Abraham M., Atomic Structure of Spectral Lines,Physikal Zs., 15, 914, (1914).
[96]. Beth R. A., Mechanical Detection and Measurement of the Angular Momentum of Light, Phys. Rev., 50, 115-125, (1936).
[97]. Holbourn A. H. S., Angular Momentum of Circularly Polarized Light, Nature,137, 31,(1936).
[98]. Allen L., Beijersbergen M. W., Spreeuw R. J, C., Waerdman J. P.,Orbital Angular Momentum of Light and the Transformation of Laguerre-Gaussian Laser Modes, Phys. Rev. A, 45(11), 8185, (1992).
[99]. Enk S. J. Van,, Nienhuis G., Spin and Orbital Angular Momentum of Photons, Europhysics Letters, 25 (7), 47,(1994).
[100]. Jackson J. D., Classical Electrodynamics, Wiley, New York, (1998).
[101]. Allen L., Padgett M., Babikar M., The Orbital Angular Momentum of Light, Progress in Optics, 39, 291-372, (1999).
[102]. Padgett M., Allen L.,Light with Twist in its Tail, Contemp. Phys., 41, 275-285, (2000).
[103]. Allen L., Barnett S., Padgett M., Optical Angular Momentum, Institute of Physics Publishing, (2003).
[104]. Obukhanov Y. N., Hehl F. W., Electromagnetic Energy- Momentum and Forces in Matter, Phys. Lett. A, 311, 277-283, (2003).
[105]. Mansuripur M., Radiation Pressure and the Linear Momentum of the Electromagnetic Field, Optic Express, 12 (22), 5375, (2004).
[106]. Mansuripur M., Radiation Pressure and Linear Momentum of Light in Dispersive Di-electric Media, Opic Express, 13 (6), p- 2245,(2005).
[107]. Mansuripur M., Angular Momentum of Circularly Polarized Light in Di-electric Media, Optic Express, 13 (14), p- 5315-5324, (2005).
[108]. Stewart A. M., Angular Momentum Of Light, J. Mod. Opt., 52, 1145-1154, (2005).
[109]. Pfeifer R. N. C., Nieminen T. A., Heckenberg N. R., Rubinsztein-Dunlop H., Momenta of an Electromagnetic Wave in Di-electric Media, Rev. Mod. Phys., 79 (4), 1197-1216, (2007).
[110]. Li M., Pernice W. H. P., Xiong C., Baehr-Jones T., Hochberg M., Tang H. X., Harnessing Optical Forces in Integrated Photonic Circuits, Nature, 456, 480-484, (2008).
[111]. Rakich P. T., Popovic M. A., Wang Z., General Treatment of Optical Forces and Potentials in Mechanically Variable Photonic Systems, Optic Express, 17, 18116-18135, (2009).
[112]. O'Brien J. L., Furusawa A., J., Photonic Quantum Technologies, Nat. Photonics, 3, 687-695, (2009).
[113]. Quantic De, Spin of the Photon, Deonto-ethics, 22 October,(2009).
[114]. Barnett S. M., On the six components of optical angular momentum, J. Opt., 13(6), 064010, (2011).

[115]. Torres J. P., Torner L(ed), Twisted Photons: Application of Light with Orbital Angular Momentum, Weinheim: Wiley-VCH, (2011).

[116]. Andrews O. L., Babiker M(ed)., The Angular Momentum of Light, Cambridge University Press, (2012).

[117]. Fernandez-Corbaton I., Zambrana-Puyalto X., Molina-Terriza G., Helicity and Angular Momentum : a Symmetry-based Frame Work for the study of Light Matter Interactions, Phys. Rev. A, 86, 042103, (2012).

[118]. Aiello A., Banzer P., Newgebauer M., Leuchs G., From Transverse Angular Momentum to Photonic Wheels, Nat. Photonics, 9, 789-795, (2015).

[119]. Stewart A. M., Angular Momentum of the Electromagnetic Field : The Plane Wave Paradox Resolved, arXiv https//arXiv org/pdf/physics/0504082.

[120]. S. N. Gupta S. N., Quantum Electrodynamics, Gordon and Breach Science Publishers, (1977).

[121]. BerestetskiiV. B., Lifshitz E. M., Pitaevskii L. P., Quantum Electrodynamics (2nd Ed.), Pergamon Press Ltd., (1982).

[122]. Grangier P., Roger G., Aspect A., Experimental Evidence for a photon anti co-relation effect on a beam splitter : A new light on single photon interferences, Europhysics Letters, 1, 173-179, (1986).

[123]. N. V., B. S., J. P., Markoshi B., S. S., Sajfert V. D., V. M., Photon's Structure of motion, Acta Physica Polonica A, 116 (4), 471, (2009).

[124]. Gould R. J., Schreder G. P., Pair production in Photon-photon collisions, Physical Review, 55 (5), 1 1404, (1967).

[125]. Bastianelli F., Schubert C., One loop photon-graviton mixing in an electromagnetic field : Part !. JHEP 0502 (2005), 069 gr-qc / 0412095 AEI- 2004-047.

[126]. Bastianelli F., Nucamendi U., Schubert C., Villanueva V. M., Photon-graviton mixing in an Electromagnetic Field, arXiv : 0711.0992 V2 [hep-ph] 9 Apr (2008).

[127]. Manjunath R., Radius of photon orbit of rotating Black Hole, Reports and Opinion, 2 (1), 78-81, (2010).

[128]. Saldanha P. L., Monken C. H., Interaction between light and matter : a photon wave function approach, New Journal of Physics, 13, 073015 : 1-12, (2011).

[129]. Scott J. C. W., Photons in the gravitational field, Canadian Journal Of Physics, 44 (7), 1639-1648, 10.1139 / 66-137, (1966).

[130]. Gould R. J., Schreder G. P., Opacity of the Universe to high energy photons, Phys. Rev. Lett., 16, 252, (1966).

[131]. Weinberg S., Gravitation and Cosmology, Wiley, New York, (1972).

[132]. Howusu S. X. K., General mechanics of a photon in the Gravitational Field of a Stationary Homogeneous Spherical Body, Apeiron, 3, No. 17, 9, (1993).

[133]. Faraon V., Dunse R. M., The gravitational interaction of light from weak to strong fields, Gen. Relativ. Gravit., 31, 91, (1999).

[134]. Mendonca J. T., Drury L. O'C, Resonant interaction of photons with gravitational waves, Phys. Rev. D, 5, 024026-1-5, (2001).

[135]. Mendonca J. T.,Theory of Photon Acceleration (Institute of Physics, Bristol), (2001).

[136]. Hajra S., A study on the interaction of gravitating field with electromagnetic entities, Journal of Gravitational Physics, 2 (2), 7-22, (2008).

[137]. Wagener P. C., A unified theory of interaction : gravitation and electromagnetics, Progress in Physics, 4, 3-9, (2008).

[138]. Wagener P. C., A unified theory of interaction : gravitation and electromagnetics and the strong force, Progress in Physics, 1, 33, (2009).

[139]. Das M. C., Misra R., Fundamental way of charge formation and relation between electromagnetic field and gravitational field, International Journal of Astronomy and Astrophysics, 2 (2), 99, (2012).

[140]. Broglie L. de, The reinterpretation of wave mechanics, Found. Phys., 1:5, https:// doi.org/10.1007/ BF 00708650 1(1) 5-15, (1970).

[141]. Ionesco-Pallas N., Sofonea L., Mechanical Structure of photon, Revue Romaine de Physique, 22(2), 405-425, (1977).

[142]. Philippidis C., Dewdney C., Hiley B. J., Quantum Interference and Quantum Potential, Nuovo, Cim. B, 52, 11, (1979).

[143]. Hong C, K., Mandel L., Experimental realization of a localized one-photon state, Phys. Rev. Lett. 56, 58, (1986).

[144]. Huang H., Eberly J. H., Localized single-photon wave functions in free space, J. Mod. Opt., 40, 915, (1993).

[145]. Bialynicki-Birula, On the wave function of the photon, Acta. Phys. Pol. A, 86, 97, (1994).

[146]. Sipe J. E., Photon wave functions, Phys. Rev. A, 52 (3), 1875, (!995).

[147]. Bialynicki-Birula, Photon wave function, Progress in Optics, XXXV1 ed. E. Wolf (Amsterdam: Elsevier), (1996).

[148]. Bialynicki- Birula, Experimental Localization of Photons, Phys. Rev. Lett., 80, 5247, (1998).

[149]. Keller O. Space-time description of photon emission from an atom, Phys. Rev. A, 62, 022111, (2000).

[150]. Smith B. J., Rymer M. G., Two photon wave mechanics, Phys. Rev. A, 74,062404, (2000).

[151]. Law C. K., Walmsley I. A., Eberly J. H., Continuous Frequency Entanglement : Effective Finite Hilbert Space and Entropy Control, 84 (23), 5304, (2000).

[152]. Arnaut H. H., Barbosa G., Orbital and Intrinsic Angular Momentum of Single Photon and Entangled Pairs of Photons Generated by Parametric Down-conversion, Phys. Rev. Lett., 85, 286, (2000).

[153]. Keller O., Optical Tunneling – a finger print of the lack of photon localizability, J. Opt. Soc. Am. B, 18, 206, (2001).

[154]. Eberly J. H., Chan K. W., Law C. K., Spontaneous-noise entanglement and photon wave functions, Chaos, Solitons and Fractals, 16, 399-402, (2003).

[155]. A., Light Reconsidered, Optics and Photonics News, OPN Trends, 14, S2-S5,(2003).

[156]. London R., What is a photon? Optics and Photonics News, OPN Trends, 14, S6-S11, (2003).

[157]. Finkelstein D., What is a photon? Optics and Photonics News, OPN trends, 14, S12-S17, (2003).

[158]. Mack H., Schleich W. P., A photon viewed from Wigner Space, Optics and Photonics News, OPN Trends, 14, S28-S35,(2003).

[159]. Roychowdhury C., Suppliment to Optics and Photonics News, OPN trends, 14(10), (2003).

[160]. Roychowdhury C., Roy R. The Nature of Light : What is a Photon? OPN trends, 14 (10), S1, (2003).

[161]. Smith B. J., Raymer M. G., Photon wave function, Wave packet quantization of light and coherence theory, New J. Phys., 9, 414, (2007).

[162]. Nistor R. E., Quantum Aspects of Photon Propagation in Transparent Infinite Media, Romanian Reports in Physics, 60 (3), 471-491, (2008).

[163]. Popescu I-Iovitz, Sterian P., Dobre M., The photon wave function and the Fresnel formulas, Romanian Reports in Physics, 62 (2), 360-368, (2010).

[164]. Brinkmann H. W., On Riemann Spaces conformal to Einstein spaces, Proc. Natl. Acad. Sci. U. S., 9, 1, (1923).

[165]. Peres A., Some Gravitational Waves, Phys. Rev. Lett., 9, 571, (1959).

[166]. Takeno H., The Mathematical theory of plane gravitational waves in general relativity, Scientific Reports of the Research Institute for Theoretical Physics, Hirosima University, Hirosima No. 1, Ken, Japan, (1961).

[167]. Ehlers J., Kundt W., Article in : Gravitation and introduction to current research, ed. L. Witten, John Wiley, New York, 85p, (1962).

[168]. Edelen D. G. B., A Gravitational Field of Light, J. Math. Mech., 16, 453, (1966).

[169]. Bonnor W. B., The Gravitational Field of Light, Commun. Math. Phys., 13, 63-174, (1969).

[170]. Aichelburg, P. C., Sexl R. U., On the gravitational field of massless particle, Gen. Relativ. Gravit., 2, 303, (1971).

[171]. R. W. Nachony, The Gravitational Influence of the Beam of Light, J. Math. Phys., 14, 1239, (1973).

[172]. Voronov N. A., Kobzarev I. Yu., On the gravitational field of a massless particle, Sov. Phys.- JETP, 39 (4), 575-578, (1974).

[173]. Nachony R. W., Gravitational Solutions, including radiation, for a perturbed light beam, J. Math. Phys., 27, 2362, (1986).

[174]. Mitskievic N. V., Kumaradtya K. K.,The Gravitational field of a spinning pencil of light, J. Math. Phys., 30, 1095, (1989).

[175]. Kramer D., The gravitational field of two counter-propagating beams of light, Class. Quantum Grav., 15, 173, (1998).

[176]. Mallet R. L., Weak gravitational field of the electromagnetic radiation in a ring laser, Physics Letters A, 269, 214-217, (2000).

[177]. Ivanov B. V., Colliding beams of light, Class. Quantum Gravit., 20, 397, (2003).

[178]. Peres A., Some gravitational waves, Phys. Rev., 118, 1105, (1960).

[179]. Hegarty J. C., Gravitational effect of electromagnetic radiation, Nuovo. Cim. 61, 47, (1969).

[180]. Dray T., Hooft G't, The gravitational shock wave of a massless particle, Nucl. Phys. B, 253, 173, (1985).

[181]. Ferrari V., Pndenza P., Veneziano G., Beam like gravitational waves and their geodesics, Gen. Relativ. Gravit., 20, 1185, (1988).

[182]. Muthukrishnan A., Scully M. O., Zubairy, The concept of the photon revisited, Optics and Photonics News, 14, S18-S27, (2003).

[183]. Sparano G., Vilasi G.,Vilasi S.,The gravity of light, Class. Quantum Gravit., 28 (19),(2010), arXiv : 1009.3849 V5[gr-qc] 25 Jan 2011.

[184]. Hogan P. A., Equation of motion in linearized gravity, Ind. J. Tho. Phys., 11, 419, (1974).

[185]. Das M. C., Misra R., Space-time geometry of electromagnetic field in the system of photon, International Letters of Chemistry, Physics and Atronomy 9 (1), 13-14, (2013).

[186]. Dunlop A. A., An introduction to the Physics of Nuclei and Particles, Books/cole, (Section-10.1), (2004).