the general science journal

Are photons really massless?

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Dec. 6. 2017

Abstact:

At the beginning of the 20th century, by proposing of the relativity and limit speed of light c, the Newton's second law was corrected considering the limit of speed c and the relativistic mass. After 1906 Einstein have derived the second postulate of special relativity the constancy of the speed of light by assuming that the light quanta that he proposed in 1905 were massless particles.

In standard model the photon is the basic unit of electromagnetism, the quantum of the electromagnetic field and the basic "unit" of all forms of electromagnetic radiation. Having zero rest mass, and traveling always at the speed of light c. In addition, in standard model, fundamental particles are point-like particles.

But in recent years, numerous articles have been published based on empirical evidence which shows the photon has the shape, the upper limit of mass, and the minimum of electric charge which challenges the old approach to the photon. In this paper old and new approches has reviewed and a new definition of particles relative to their speed has propounded.

A look at history of photon

At the beginning of 19th century, Michael Faraday found that electricity and magnetics have close relation. Faraday introduced the concept of field for the first time and in the time of Maxwell, it was widely used in which according to it forces transform through fields; for example, gravitational force is transformed trough gravitational field. In 1864, Maxwell formulated

electromagnetic equations and codified how to produce a magnetic field by a variable electric field and vice versa. Maxwell equations in electromagnetics have the same importance in which Newton laws of motion have in classic mechanics.

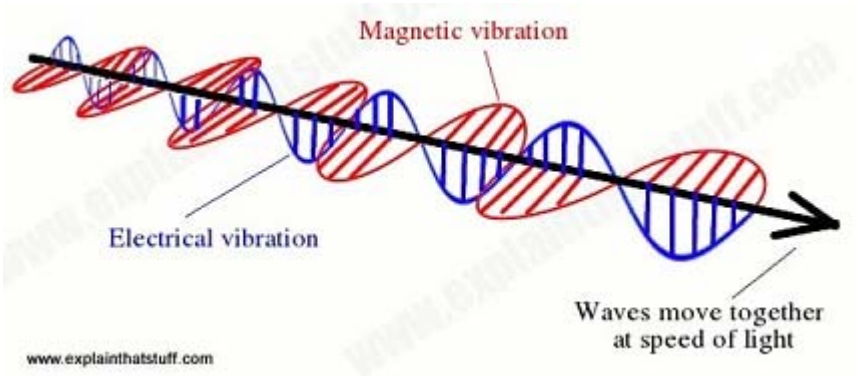

Fig1: electromagnetic wave propagation

In classical mechanics, Electromagnetic radiation is created when a charged particle is accelerated[1] by an electric field, causing it to move. The movement produces oscillating electric and magnetic fields, which travel at right angles to each other (figure1).

Electromagnetic wave equation

The homogeneous form of the electromagnetic equation is written in terms of either the electric field **E** or the magnetic field **B**, takes the form of the electromagnetic wave equation derives from[2] Maxwell's equations as follw:

$$\left(v_{ph}^2\nabla^2 - \frac{\partial^2}{\partial t^2}\right)\mathbf{E} = 0 \qquad (1)$$

$$\left(v_{ph}^2\nabla^2 - \frac{\partial^2}{\partial t^2}\right)\mathbf{B} = 0 \qquad (2)$$

In a medium with permeability μ , and permittivity ϵ

$v_{ph} = \frac{1}{\sqrt{\mu\epsilon}}$, v_{ph} is phase velocity in medium

In vacuum with μ_0 and ϵ_0 $v_{ph} = c$, where c is speed of light.

And ∇^2 is the Laplace operator

In a medium with permeability μ , and permittivity ϵ

The electromagnetic wave equation derives from Maxwell's equations. In general, any wave is just a way of shifting energy from one place to another.

[1] - http://www.livescience.com/38169-electromagnetism.html
[2] - https://en.wikipedia.org/wiki/Electromagnetic_wave_equation

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"Maxwell's theory of electrodynamics, based[1] on forces acting over insensible distances, proved to be tremendously successful. The elaborate and complicated material mechanisms that Maxwell originally conceived to embody the mathematical relations of the field eventually receded in his thinking, as he came to focus more and more on purely abstract energy-based considerations."

"After tracing to the action of the surrounding medium both the magnetic and the electric attractions and repulsions, and finding them to depend on the inverse square of the distance, we are naturally led to inquire whether the attraction of gravitation, which follows the same law of the distance, is not also traceable to the action of a surrounding medium. However Maxwell notes that there is a paradox caused by the attraction of like bodies. The energy of the medium must be decreased by the presence of the bodies and Maxwell said" As I am unable to understand in what way a medium can possess such properties, I cannot go further in this direction in searching for the cause of gravitation"[2].

"More precisely he required that the law governing propagation[3] of gravitational action be Lorentz covariant and that the gravitational forces transform in the same way as electromagnetic forces." Poincaré, in a paper in July 1905[4], suggested that all forces should transform according the Lorentz transformations.

Attempts to calculate the energy distribution for[5] the radiation from a blackbody using classical ideas were unsuccessful. In 1900, Max Planck made a bold suggestion. He assumed that the radiation energy is emitted, not continuously, but rather in discrete packets called quanta. The energy E of the quantum is related[6] to the frequency as follow:

$$E = h\nu \qquad (3)$$

$$\mathrm{h} = 6.62607 \times 10 - 34$$

Where h is universal Planck's constant.

"In 1902 Lenard discovered that energy of electrons[7] in photoeffect does not depend on the intensity of light, while it depends on the wavelength of the latter.

In 1905 Einstein extended Planck's hypothesis to explain the[8] photoelectric effect, which is the the emission of electrons by a metal surface when it is irradiated by light or more-energetic photons.

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[1] - http://www.mathpages.com/home/kmath613/kmath613.htm
[2] - http://www-groups.dcs.st-and.ac.uk/history/HistTopics/General_relativity.html
[3] - http://www.pitt.edu/~jdnorton/papers/Nordstroem.pdf
[4] - http://www-groups.dcs.st-and.ac.uk/history/HistTopics/General_relativity.html
[5] - https://www.britannica.com/science/quantum-mechanics-physics#ref611804
[6] - http://ffn.ub.es/luisnavarro/nuevo_maletin/Planck%20(1901),%20Energy%20distribution.pdf
[7] - https://arxiv.org/pdf/hep-ph/0602036.pdf
[8] - https://www.britannica.com/science/quantum-mechanics-physics#ref611804

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Planck radiation formula was only a new scientific interpretation of classical electromagnetic theory. Because classical electromagnetic theory could not explain some of the new experiences such as photoelectric effect[1], Planck's radiation relation was accepted.

In special relativity, the speed of light is the upper limit for the speeds of objects with positive rest mass, and individual photons cannot travel faster than the speed of light. "Einstein once called the speed of light The Universe's speed limit[2], he claimed that traveling faster than the speed of light would violate the causality principle." in 1926, G. N. Lewis introduced the concept[3] of "atom of light" that called "Photon".

Consider that photon is not a solid spherical, even a point – like particle. Because "There are still many puzzling aspects of the nature of light[4]". Einstein wrote in 1951[5]: "All these fifty years of pondering have not brought me any closer to answering the question, what are light quanta?"

However, "A photon-like wave-packet based on novel solutions of Maxwell's equations is proposed. It is believed to be the first 'classical' model that contains so many of the accepted quantum features"[6].

Finally, physicists accepted the dual nature of light[7] that they have defined light as a collection of one or more photons propagating through space as electromagnetic waves.

"Through the work of Albert Einstein, Louis de Broglie and many others, it is now established that all objects have both wave and particle nature (though this phenomenon is only detectable on small scales, such as with atoms), and that a suitable interpretation of quantum mechanics provides the over-arching theory resolving this ostensible paradox"[8]. Within a few years, de Broglie's hypothesis was tested by scientists shooting electrons and rays of lights through slits. What scientists discovered was the electron stream acted the same was as light proving de Broglie correct.[9]

$$\lambda = \frac{h}{p}\ , \lambda\ is\ de\ Broglie\ wavelength \qquad (4)$$

$$Where, h\ is\ Plank's constant\ and\ p\ is\ momentum\ of\ a\ particle$$

De Broglie wavelength broke the boundary between particle and wave. Einstein said[10]: "We are faced with a new kind of difficulty. We have two contradictory pictures of reality; separately

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1 - http://www.physlink.com/education/askexperts/ae24.cfm

2 - http://zidbits.com/2011/05/why-cant-anything-go-faster-than-the-speed-of-light/

3 - http://physics.stackexchange.com/questions/273032/what-exactly-is-a-photon

4 - http://iopscience.iop.org/article/10.1088/1367-2630/9/11/414/pdf

5 - https://arxiv.org/pdf/hep-ph/0602036.pdf

6 - https://arxiv.org/ftp/quant-ph/papers/0609/0609156.pdf

7 - http://science.howstuffworks.com/light6.htm

8 - https://www.sciencedaily.com/terms/wave-particle_duality.htm

9 - Wave Nature of Electron, DeBroglie Wavelengths, Hyperphysics, http://hyperphysics.phy-astr.gsu.edu/hbase/debrog.html

10 - http://www.zmescience.com/science/physics/light-particle-wave-03032015/

neither of them fully explains the phenomena of light, but together they do "[1]. "The history of theoretical efforts to define photon wave functions dates back to the early days of quantum mechanics and is still unfolding. Overviews have been given in. However, there is not yet a consensus on the form a photon wave function should take or the properties it should have."[2]

Mysteries zero rest mass of the photon

Let's focus on energy and momentum of photon. After 1906 Einstein have derived the second postulate of special relativity the constancy of the speed of light by assuming that the light quanta that he proposed in 1905 were massless particles[3]. Relativistic energy and momentum is given by;

$$E = \frac{m_0 c^2}{\sqrt{1-\frac{v^2}{c^2}}} \quad and \quad P = \frac{m_0 v}{\sqrt{1-\frac{v^2}{c^2}}} \qquad (4)$$

It is just possible that we could allow $m_0 = 0$ provided the particle always travels at the speed of light[4] c. In this case above equations will not serve to define and so that for massless particle given by;

$$E = |P|c \qquad (5)$$

As it follows from the Einstein relativistic mass formula:

$$E^2 = m_0^2 c^4 + p^2 c^2 \qquad (6)$$

What does determine the momentum and energy of a massless particle? Not the mass (that is zero by assumption) not the speed (that is always c). Relativity offers no answer to this question, but curiously enough, quantum mechanics does, in the form of Plank's formula:

$$E = mc^2 = hv \Rightarrow m = \frac{hv}{c^2} \qquad (7)$$

Only moving[5] photon has mass as follows from the Einstein formula $E = mc^2$. These arguments and equations are based on the assumption of the photon is massless that is just a mathematical interpretation of photon-like wave-packet[6]. There are good theoretical reasons to believe that the

[1] - The world's first image of light as both a particle and a wave, ZME Science, 2015, http://www.zmescience.com/science/physics/light-particle-wave-03032015/

[2] - https://www.nist.gov/sites/default/files/documents/pml/div684/fcdc/photon-wave.pdf

[3] - Field, J. Einstein and Planck on mass-energy equivalence in 1905-06: a modern perspective. 2014 arXiv preprint arXiv:1407.8507

[4] - Griffiths, D. Introduction to elementary particles: John Wiley & Sons, 2008, page 89

[5] - Miroslav Pardy, Massive photons in particle and laser physics, 2003, https://arxiv.org/pdf/hep-ph/0308190.pdf

[6] - https://arxiv.org/ftp/quant-ph/papers/0609/0609156.pdf

photon mass should be exactly zero, but there is no experimental proof of this belief[1]. Physicists have not stopped on assumption of massless. These efforts show there is an upper bound on the photon mass, although the amount is very small, but not zero. The tight experimental upper bound of the photon mass restricts the kinematically allowed final states of photon decay to the lightest neutrino and/or particles beyond the Standard Model[2]. Theories and experiments have not limited to photons and graviton will also be included. For gravity, there have been vigorous debates about even the concept of graviton rest mass[3].

Experimental evidence of photon's mass, shape, and electric charge

The issue of light mass (even from the earliest days of the presentation of relativity) has been discussed. "Since it is now clear that among the founding texts of Special Relativity are the two works of Henri Poincaré "Sur la dynamique de l'électron", it is interesting to look for their differences with the work of Einstein. The "Palermo Memoir" contains a mine of relativistic results ignored by the Einstein text, but this Einstein text has also some additions: three small applications of the Lorentz transformation (the aberration of stars, the Doppler-Fizeau effect and the radiation pressure on moving mirrors) and a main difference: the "second principle": the constancy of the velocity of light. As a consequence, for Einstein, the photons must have a zero rest mass. For Poincaré the constancy of the velocity of light is only a physical ascertaining and his "Lorentz transformation" is only a direct consequence of his Relativity Principle without the necessity of the constancy of the velocity of light. Hence, the possibility remains that the photons have a very small, but non-zero, rest mass[4]".

About the pressure and distortion of photon, it is notable that "The deviation of the photons of polarized laser light on reflection is due to the force created by the mass of the photon at the contact point of reflection. Force can only be created if photon has mass. A photon of zero mass cannot create any force at the contact point of reflection and will not deviate. The mass of spinning photon creates the force to turn at the contact point of reflection resulting in the deviation of photon and change the direction of photon[5]". Another example of a massless problem is the neutrino. "Neutrinos appear very strongly to travel at the speed of light and according to the afore-stated, they must be massless. Experiments appear to strongly suggest that indeed, neutrinos most certainly are massive particles. While this solves the problem of neutrino oscillation, it directly leads to another problem, namely that of "How can a massive particle travel at the speed of light[6]"?

"The Nobel Prize in Physics 2015 recognises for their key contributions to the experiments which demonstrated that neutrinos change identities. This metamorphosis requires that neutrinos have mass. Its Standard Model of the innermost workings of matter had been incredibly successful,

[1] - Hojman, S. A., & Koch, B. (2013). Closing a window for massive photons. *Advances in High Energy Physics, 2013*

[2] - Heeck, J. How stable is the photon? *Physical review letters, 111*(2), 021801, (2013).

[3] - Goldhaber, A. S., & Nieto, M. M. Photon and graviton mass limits. *Reviews of Modern Physics, 82*(1), 939. (2010)

[4] - C. Marchal, "PHYSICS WITH PHOTONS OF NON-ZERO REST MASS"
http://web.ihep.su/library/pubs/tconf05/ps/c4-2.pdf

[5] - Narendra Swarup Agarwal, "Experimental Proof of Mass in Photon" Journal of Modern Physics, 2015
https://file.scirp.org/pdf/JMP_2015042114060745.pdf

[6] - Golden Gadzirayi Nyambuya, "Are Photons Massless or Massive?" Journal of Modern Physics, 2014,
http://file.scirp.org/pdf/JMP_2014122515125440.pdf

having resisted all experimental challenges for more than twenty years. However, as it requires neutrinos to be massless, the new observations had clearly showed that the Standard Model cannot be the complete theory of the fundamental constituents of the universe[1]".

There are many articles that show, photon has upper limit mass[2] and electric charge[3], which are consistent with experimental observations. Theories and experiments have not limited to photons and graviton will also be included. For gravity there have been vigorous debates about even the concept of graviton rest mass[4].

In recent decades, the structure of photon[5] is discussed and physicists are studying the photon structure[6]. Some evidence shows the photon consists of a positive and a negative charges. In addition, new experiment shows that the probability of absorption at each moment depends on the photon's shape, also photons are some 4 meters long which is incompatible with unstructured concept. "Scattering of light by matter has been studied extensively in the past. Yet, the most fundamental process, the scattering of a single photon by a single atom, is largely unexplored. One prominent prediction of quantum optics is the deterministic absorption of a travelling photon by a single atom, provided the photon waveform matches spatially and temporally the time-reversed version of a spontaneously emitted photon[7]" (figures 2).

"Here we experimentally address this prediction and investigate the influence of the photon's temporal profile on the scattering dynamics using a single trapped atom and heralded single photons. We don't often think of photons as being spread out in time and space and thus having a

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[1] - The Nobel Prize in Physics 2015, Takaaki Kajita, Arthur B. McDonald

https://www./nobel_prizes/physics/laureates/2015/press.html

[2] - Heeck, J. (2013). How stable is the photon? Physical review letters, 111(2), 021801

Liang-Cheng Tu, Jun Luo and George T Gillies, "The mass of the photon" Rep. Prog. Phys. 68 (2005) 77–130 , doi:10.1088/0034-4885/68/1/R02

Antonio Accioly, Jos´e Helay¨el-Neto, and Eslley Scatena, "Upper bounds on the photon mass", Phys.Rev.D82:065026,2010, DOI: 10.1103/PhysRevD.82.065026

[3] - Giuseppe Cocconi, "Upper limit for the electric charge of the photons from the millisecond pulsar 1937+21 observations" Physics Letters B Volume 206, Issue 4, 2 June 1988, Pages 705–706

http://www.sciencedirect.com/science/article/pii/037026938890723X

V. V. Kobychev and S. B. Popov, "Constraints on the Photon Charge from Observations of Extragalactic Sources" Astronomy Letters, Vol. 31, No. 3, 2005, pp. 147–151.

http://xray.sai.msu.ru/~polar/html/publications/charge/AL147.pdf

C Sivaram and Kenath Arun "Some Additional Bounds on the Photon Charge"

http://arxiv.org/ftp/arxiv/papers/0802/0802.1562.pdf

L.B. Okun, "PHOTON: HISTORY, MASS, CHARGE", ACTA PHYSICA POLONICA B Vol. 37 (2006) http://www.actaphys.uj.edu.pl/fulltext?series=Reg&vol=37&page=565

[4] - https://arxiv.org/pdf/0809.1003.pdf

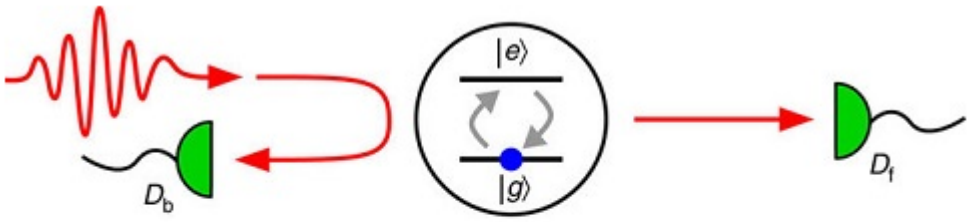
[5] - http://www.slac.stanford.edu/econf/C990809/docs/butterworth.pdf

[6] - http://cerncourier.com/cws/article/cern/28060

[7] - Victor Leong, et. al., "Time-resolved scattering of a single photon by a single atom",

Nature Communications (2016). DOI: 10.1038/ncomms13716. Preprint available at: https://arxiv.org/abs/1604.08020

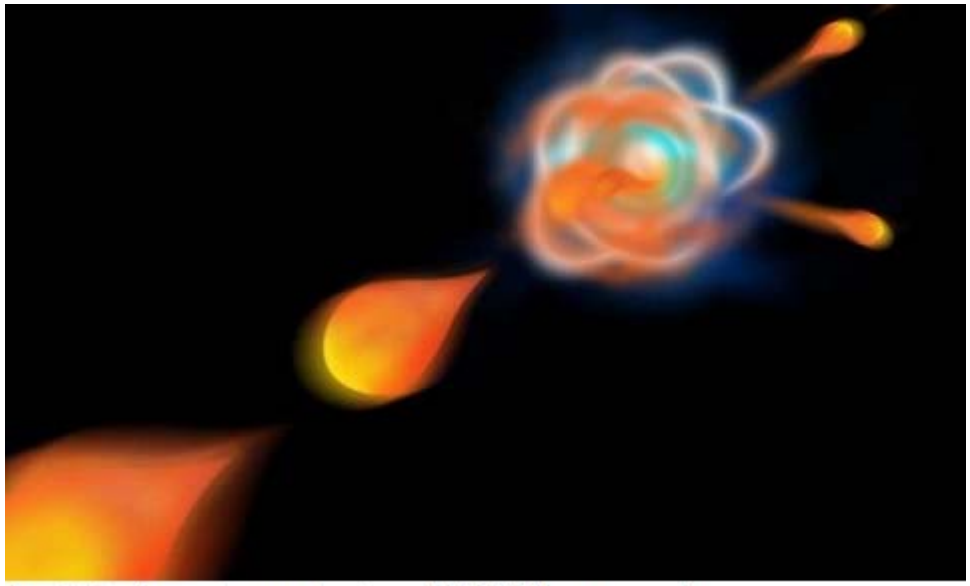
shape, but the ones in this experiment were some four meters long. Christian Kurtsiefer, Principal Investigator at CQT, and his team have learned to shape these photons with extreme precision[1]". (Figure 3)



D_f and D_b: forward and backward detectors, $|g\rangle$ and $|e\rangle$: ground and excited levels of the atom.

http://www.nature.com/article-assets/npg/ncomms/2016/161129/ncomms13716/images/m685/ncomms13716-f1.jpg

Fig2: Single photon scattering by a two-level atom in free space. The time evolution of the atomic excited state population is inferred by measuring photons in the forward or backward direction.



http://cdn.phys.org/newman/csz/news/800/2016/shapematters.jpg

Fig 3: Scientists at the Centre for Quantum Technologies at the National University of Singapore have shown that a photon's shape affects how it is absorbed by a single atom. This artist's illustration is not to scale: in the experiment the photons are some 4 meters long, while the atom is less than a nanometer wide. Credit: Timothy Yeo / Centre for Quantum Technologies, National University of Singapore.

According to the quantum mechanics that photon is an unstructured particle. How the concept of unstructured photon is able to describe the different shapes and four meter long of photon?

[1] - Mapping the interaction of a single atom with a single photon may inform design of quantum devices, Phys.org, December 2, 2016, available at: http://phys.org/news/2016-12-interaction-atom-photon-quantum-devices.html

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In addition to four meters long and shapes of photons, how two opposites' charged particles such as electron and positron absorb and emit neutral and unstructured photons?

"Quantum foundations are still unsettled, with mixed effects on science and society. By now it should be possible to obtain consensus on at least one issue: Are the fundamental constituents fields or particles? As this paper shows, experiment and theory imply unbounded fields, not bounded particles, are fundamental. This is especially clear for relativistic systems, implying it's also true of non-relativistic systems. Particles are epiphenomena arising from fields. Thus the Schroedinger field is a space-filling physical field whose value at any spatial point is the probability amplitude for an interaction to occur at that point"[1].

If there are no particles and there are only fields, what are fields made up of? To answer this question we should focus on the base of particles physics concepts. The Standard Model of particle physics describes the universe in terms of matter (fermions) and force (bosons). Particles of matter transfer discrete amounts of energy by exchanging bosons with each other. There exists an antiparticle for every fermion in nature. The simplest example which illustrates the involved principle is that of the electron and positron[2].

To understand and describe structure of all fundamental particles, especially photon and its rest mass, we need to reconsider the electromagnetic energy or photon-like wave-packet. For study and understanding the photon structure we need to describe relation between frequency and energy of photon. The change of frequency of the photon in the gravitational field has been demonstrated by the Pound-Rebka experiment[3].

The Pound–Rebka experiment

A photon with mass $m = \frac{hv}{c^2}$ has weight as $mg = \frac{hv}{c^2} g$, in gravitational field. When photon falls a distance equal y toward the earth, according to conservation law of energy we have:

$$hv' = hv + mgy = hv + \left(\frac{hv}{c^2}\right) gy \qquad (8)$$

$$v' = \left(1 + \frac{gy}{c^2}\right) v \qquad (9)$$

If we consider this phenomenon as another evidence to verify the general relativity, we will be stopped in the same old theories. Therefore, if we want to get a different result, we have to change our thoughts. The work that gravitational force does on the photon does not mean a simple concept of increasing in kinetic energy, but some deeper and more profound concepts are hidden beyond it. If we want to look at this phenomenon from the point of view of quantum field theory, we must accept that gravitons penetrate to the structure of the photon and in addition to the increasing its energy cause increasing electric and magnetic field intensity. Nevertheless, by considering the

[1] -Art Hobson, There are no particles, there are only fields, 2013, https://arxiv.org/ftp/arxiv/papers/1204/1204.4616.pdf

[2] - https://home.cern/about/physics/standard-model

[3] - http://milesmathis.com/pound.html

accepted concepts of quantum mechanics for gravitons, this phenomenon is not justifiable. Therefore, we need to reconsider the concepts of quantum mechanics about graviton and investigate about this phenomenon beyond quantum mechanics.

So to generalize the relation between bosons and energy, we should start with gravity which is the weakest fundamental forces.

The discrete amount energy of graviton

Consider a photon with energy $E = h\nu$ is escaping from a strong gravitational field. By reducing the frequency of photon (photon energy reduction), intensity of electric and magnetic fields are reduced too and finally, intensity of both the fields reaches to zero and the photon loses all its energy. Final limit for energy of photon before that reaches or tends to zero and still has spin, is equal to the smallest discrete amounts of energy that is given by:

$$\text{Smallest discrete amount of energy} < h\nu, \forall\, \nu\ detectable \qquad (10)$$

Regarding to gravity is the weakest fundamental forces which is transferring by graviton, relation(10) is defining the energy of graviton E_G that is given by:

$$E_G < h\nu, \forall\, \nu\ detectable \qquad (11)$$

Where G is symbol of graviton. And the mass of the graviton m_G is given by:

$$m_G < \frac{h\nu}{c^2}\ , \forall\, \nu\ detectable \qquad (12)$$

This definition (relation 12) is acceptable. Because gravitational potential energy (graviton energy) converts to electromagnetic energy (photon energy). Therefore, the increase in photon mass is due to the addition of graviton mass, ie, the graviton has also a mass that is defined by the relation (12).

However, both of the above equations (11 and 12) do not show some intuitive value and assessable. In addition, the above equations do not have any specific information about electric and magnetic fields associated with photon. Therefore, we should be looking for an intuitive experience to be able to achieve tangible values and find out that how to produce electric and magnetic fields associated with the photon. Our approach for such this selection is changing the photon energy in a gravitational field that is associated with the intensity of electric and magnetic fields of photon. It means that gravity works on the photon and gravitons enter to the structure of the photon in which it is justified according to the following equation:

$$F = -\frac{dU}{dx} \qquad (13)$$

Where dU changing potential energy at small distance dx and F is the force. Now we should explain the process of changing energy (equation 8) by using equation (13). Photon falls at

specified distance dy in gravitational field and its potential energy is reduced to dU (its kinetic energy increases). Reduction in potential energy of photon means that its frequency and kinetic energy increase that is given by $d\nu$ and $dE = hd\nu$ respectively. From the perspective of quantum mechanics, that photon unstructured, it is impossible to explain this phenomenon. Therefore, if we want to analyze the structure of photon, we must pass the quantum space and enter into sub quantum space. From the perspective of sub quantum space, a number of gravitons enter into photon structure that is justified by equation (13), and the energies of gravitons is added to the energy of photon. Now the question is how many gravitons enter into the structure of photon that generates the smallest possible change of energy that is given by $dE = hd\nu$? Also changing in energy of photon is associated with changing in intensity of electric and magnetic fields. Therefore, the work done on the photon by gravity must be discussed in such a way that justifies changing in intensity of electric and magnetic fields. Due to this reason in the CPH Theory, gravitons have properties that when gravity works on photon, can alter the intensity of electric and magnetic fields of the photon. This attitude led to the terms color-charge and magnetic-color in which they have used to define gravitons. In other words, identity of graviton changes without any change in its energy.

Color-charges and magnetic-color

Now we are in a position that are able to take a new look at the structure of photon and define the features and properties of graviton in a way that is compatible with the feature of photon, and it is in accordance with experimental conditions very well. A photon with the lowest possible energy also carries electric and magnetic fields. Therefore, the features of gravitons entered into the structure of the photon must behave in a way that along with explaining the energy of photon, describes increasing in intensity of electric and magnetic fields. In other words, some of these gravitons cause increasing the electric field of photon and some other gravitons increase the intensity of magnetic field. Also, not only a photon at lowest level of its energy is formed by some of the gravitons, but also its formed members have electric and magnetic properties that is called color-charge and magnetic-color in CPH theory. The next step is to specify color-charges and magnetic-colors in which it is obtained by paying attention to at least change in energy of photon in a gravitational field (in a gravitational blueshift).

Formed elements of photon

For finding properties of gravitons and analyzing this process, we must observe these following conditions:

Condition1: photon is carrying two perpendicular electric field and magnetic field.

Condition2: The photon is electrically neutral and particles forming the electric field must neutralize each other.

Condition3: There are two groups, positive and negative color-charges in structure of photon that form photon's electric field and neutralize each other.

Condition4: Because these electric fields are moving, they create magnetic fields around themselves.

Condition5: simultaneously by producing positive and negative electric fields, two magnetic fields are produced around the electric fields do form. Therefore, it will be made two groups of magnetic-colors.

The above features necessitate that we consider each photon including four groups, two groups carry positive and negative electric effects and two groups carry magnetic effects. Suppose a photon with frequency ν and energy $h\nu$ is formed of n_1 elements, so that:

$$n_1 = n_{11} + n_{12} + n_{13} + n_{14}$$

Moreover, this photon with frequency ν' and energy $h\nu'$ is formed of n_2 elements, so that:

$$n_2 = n_{21} + n_{22} + n_{23} + n_{24}$$

For two levels of energy $h\nu'$, $h\nu$, we form the below matrices:

$$h\nu = \begin{bmatrix} n_{11} & n_{12} \\ n_{13} & n_{14} \end{bmatrix} \qquad (14)$$

$$h\nu' = \begin{bmatrix} n_{21} & n_{22} \\ n_{23} & n_{24} \end{bmatrix} \qquad (15)$$

Now, we consider the matrix of changing energy of photon $\Delta E = h\nu' - h\nu$ as follow:

$$\Delta E = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \qquad (16)$$

Matrices (14, 15 and 16) must satisfy the following equation:

$$h\nu' = \begin{bmatrix} A & B \\ C & D \end{bmatrix} + \begin{bmatrix} n_{11} & n_{12} \\ n_{13} & n_{14} \end{bmatrix} = \begin{bmatrix} n_{21} & n_{22} \\ n_{23} & n_{24} \end{bmatrix} \qquad (17)$$

According to conditions (9), it will be determined elements A, B, C, D. We consider the first row of the matrix (16), the elements of A, B for negative and positive colors charges. Element A represents positive color-charges and element B represents negative color-charges. In interaction between gravitons and photons, photon falls at specified distance dy and its energy increases (equation 9) that due to equation (13) the identity of a number of gravitons change by carrying gravitational force towards color-charges and enter to the structure of photon. We use the symbol of graviton G, for the both negative color-charge as G^- and positive color-charge as G^+, so that:

$$A = \kappa\, G^+ , \qquad B = \kappa\, G^-$$

Where κ is a natural number. In other words, when gravity works on photon, a number of gravitons enter into the structure of photon and photon's intensity of electric field increases,

without any electrically effect and it is not created electric charge, because the photon is electrically neutral. So A, B must carry electric effect and their numbers must be equal (conditions2 and 3).

Also according to the relative intensity electric fields and magnetic of electromagnetic waves $\boldsymbol{E} = c\boldsymbol{B}$, since color-charges and magnetic-colors are carrying electric and magnetic fields that they are NR-particles and countable, therefore, this relative can be replacement by a natural number such as κ, so we have $\boldsymbol{E} = \kappa\, \boldsymbol{B}$. When a number G^+ enter into photon structure, intensity of positive electric field of photon increases. Therefore, according to Maxwell's electromagnetic equations, the intensity of magnetic field increases, too. Therefore, the element C (equation16) must increases the intensity of magnetic effect around the positive color-charges. Similarly, the element D must increases the intensity of magnetic field around the negative color-charges. The effect of these two elements are the same, but in terms of direction (which is proportional to the electric field) are different. Thus, according to the electric and magnetic field intensity we can be written:

$$\boldsymbol{C} = \boldsymbol{G}_m^+ , \qquad \boldsymbol{D} = \boldsymbol{G}_m^-$$

The negative sign in relation $D = \boldsymbol{G}_m^-$, only determines the direction of magnetic colors around the negative color-charges. So matrix (16) that is called the CPH matrix, will be as follows:

$$CPH = \begin{bmatrix} \kappa\, G^+ & \kappa\, G^- \\ G_m^+ & G_m^- \end{bmatrix} \qquad (18)$$

According to the above expression, we are now able to define the least magnitude of a photon. A photon of minute energy contains some positive color-charges $\boldsymbol{G}^+$, negative color-charges G^- , right rotation color-magnetic G_m^+ and left rotation color-magnetic $\boldsymbol{G}_m^-$ as shown in the CPH matrix (equation 18). This very small energy can be express as the following;

$$\text{Minute electromagnetic energy: } E_{Minute} = (2\kappa + 2)E_G \qquad (19)$$

Thus, each photon is formed of a natural number E_{Minute}, so we have;

$$E = n(2\kappa + 2)E_G \text{ , or } \qquad E = n\begin{bmatrix} \kappa\, G^+ & \kappa\, G^- \\ G_m^+ & G_m^- \end{bmatrix} \qquad (20)$$

Equations (11 and 12) have previously defined the mass and energy of graviton. The longest wavelengths of radio production and broadcasting by radio stations is the world's longest wavelength which is more than 100 km[1]. Using the equation $m = h\nu/c^2$, the mass such photon is less than $10^{-40}\, kg$. By comparing this value with the electron mass that is equal to

[1] - Jim Lucas, What Are Radio Waves? Live Science, 2015, https://www.livescience.com/50399-radio-waves.html

$9.1 \times 10^{-31}\ kg$, and in the pair production a high-energy photon converts to an electron and a positron, each photon is containing billions and billions of gravitons.

Positive and negative sub quantum energies

When density of color-charges changes in the structure of a photon, then the density of magnetic-color changes, too. Therefore, the electric fields do not decay in the structure of photon. In general, we are able to describe the sub quantum energy (SQE), virtual photons and real photon as follows:

1- **Positive Sub Quantum Energy ($\boldsymbol{SQE^{+}}$):** The positive sub quantum energy is a set of positive color-charges with its affiliates magnetic-color that is shown by right wedge $\rhd$ (the first column of the CPH matrix, equation 18), which is defined as follows:

$$\text{Positive Sub Quantum Energy } \boldsymbol{SQE^{+}} : \rhd = \begin{bmatrix} \kappa \boldsymbol{G^{+}} \\ \boldsymbol{G_m^{+}} \end{bmatrix} \qquad (21)$$

2- Negative Sub Quantum Energy ($\boldsymbol{SQE^{-}}$): The negative sub quantum energy is a set of negative color-charges with its affiliates magnetic-color that is shown by left wedge $\lhd$ (the second column of the CPH matrix, equation 18), which is defined as follows:

$$\text{Negative Sub Quantum Energy } \boldsymbol{SQE^{-}} : \lhd = \begin{bmatrix} \kappa \boldsymbol{G^{-}} \\ \boldsymbol{G_m^{-}} \end{bmatrix} \qquad (22)$$

Photon and virtual photons

Virtual photons: There are two types of virtual photons, positive virtual photon γ^{+} and negative virtual photon γ^{-} that each of them is formed of number same-sign sub quantum energies, which is defined as follows:

$$\text{Positive virtual photon; } k \rhd = \gamma^{+} \qquad (23)$$

$$\text{Negative virtual photon; } k \lhd = \gamma^{-} \qquad (24)$$

Photon: A real photon is formed of a positive virtual photon and a negative virtual photon:

$$\gamma^{+} + \gamma^{-} = \gamma \qquad (25)$$

$$(n \rhd + n \lhd) = n(\rhd + \lhd)\ or\ n|\rhd\rangle + n|\lhd\rangle = \gamma \qquad (26)$$

Where, $n\ and\ k$ are natural numbers. So far, the production of electromagnetic energy (photons) was described by using gravitational blueshift, in reverse phenomena photons decay to negative and positive virtual photons. In gravitational redshift, virtual photons also decay to positive and negative sub quantum energies (SQEs), and sub quantum energies (SQEs) decay to

color-charges and magnetic-colors, too. Color-charges and magnetic-colors away from each other, lose their effect on each other and become gravitons (figure 4).

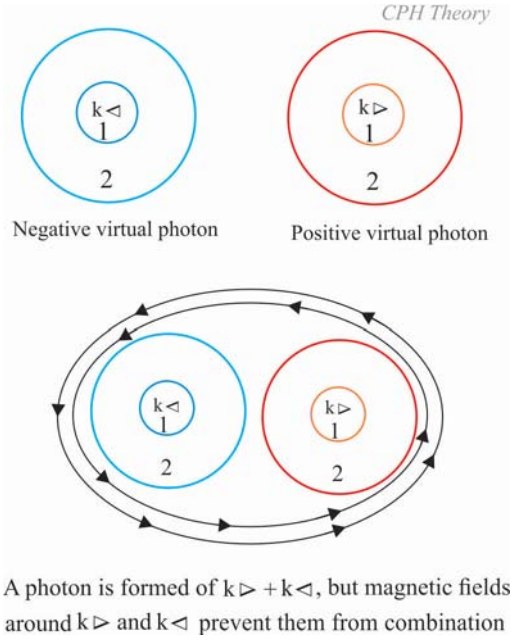

Fig4; structure of photon

So, photons are combination of positive and negative virtual photons. Photon is a very weak electric dipole that is consistent with the experience. In addition, this property of photon (very weak electric dipole) can describe the absorption and emission energy by charged particles.

Considerable notes

Momentum of graviton: Graviton carries a discrete amount of energy and has momentum. The momentum equals mass times velocity, and velocity is a vector quantity while mass is a scalar quantity. A scalar multiplied by a vector is a vector. That is, graviton carries the force of gravity and it turns into energy. All forces (fundamental and non-fundamental) are such, that is, force is converted into energy, and vice versa.

Particles and NR-particles: There are two kinds of particles in physics:

1- Some particles like the photon moves only with the speed of light, in all inertial reference frames. Let's call these kinds of particles as Never at Rest condition particles (NR-particle).

2- Other particles like the electron always move with the speed $v < c$ in all inertial reference frames, they could be called particles.

According to the above definitions, photon and graviton are NR-particle, while electron and proton are particles.

Are photons really massless?

Concept of particle: Generally, we have almost the same understanding and imagination of large objects (at the level of molecules and larger). However, in the case of subatomic particles, there is no clearly defined and visualized concept, and there are many uncertainties, especially in the case of photon and graviton. Therefore, any theory offers certain understanding (such as loop and string theories) of these particles. So, in CPH Theory the particle is used, without any particular imagine of it.

Therefore, photons gain mass of gravitons (color charges and magnetic colors). And photons (electromagnetic energy) convert to matter – antimatter and vice versa. The photon carries energy and energy has mass. When a photon is absobed by matter, its energy (mass) is added to kinetic energy (mass) of matter. It means light and heat have mass.

This is reasonable that photon and graviton are not massless particles. For more see following book:

Beyond the Standard Model : Modern physics problems and solutions

https://www.amazon.com/gp/offer-listing/1939123623