DOI: https://doi.org/10.24297/jap.v20i.9160

The Great Power of Prediction from a Massive Photon Hypothesis

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Abstract

Mass, an inherent property of matter, is calculated directly for the photon particle from the very classical principles of the kinetic theory of gases. That concept of photon mass is nearly as old as physics itself and in fact nothing prevents this approach to be carried out for a so-called quantum particle, not even its minute size. It is not an end result with no perspective nor other outcome. Quite the opposite, a single ponderable tiny photon frees the mind of old ways of thinking and opens up new paths to a broad field of investigation where the very large can then be described and explained by the very small. This reality of a non-zero mass suddenly shows up in the interpretation of many experiments which become clear and simple to comprehend. Besides, that same key particle has the potential to unlock and solve some long lasting major observational issues or enigmas. All this converges upon its acknowledgement and acceptance.

Keywords: photon gas, photon mass, CMB radiation, speed of light, photon drag, viscosity

1. Introduction

Is there a contradiction regarding the photon particle or a special case as if nature would be exception-tolerant? Conventional physics has established that a photon has both energy and momentum *p*, but curiously does not have a real mass despite the well accepted Newton's second law of motion ($F = dp/dt = m\, dv/dt = ma$) yet no experiment has ever ruled out a real mass for it and very strong doubts remain about this hidden reality. This is to the point that many attempts have been made [1] mostly with cosmic observations to find a photon mass resulting in widely different upper limits ranging from less than 10^{-36} kg to less than 10^{-54} kg but nothing has been firmly established. This current state of affairs lacks clarity for physicists to say the least. These considerations put aside, this question will be settled by the search for a direct relationship between the wave associated with photons forming a medium of gas and the derived mass of the photon.

2. Theoretical Framework

It is a well established fact that the Cosmic Microwave Background (CMB) radiation has a spectrum of a black-body at a temperature near absolute zero. As it follows very closely to Planck's black-body spectrum, this very stable temperature in our local space has been accurately determined to be T=2.72548 K by direct observations with satellites (1989 — COBE and its followers) and comparison with the black-body distribution curve. With that temperature as the sole parameter, accurate calculations can be done to find the mass of a photon by just simply using the nineteen century kinetic theory of gases along with statistical mechanics originally developed for molecules and atoms and applied down to the ultra-small scale of photon particles which form a true ideal gas in space. That could well be the only existing (and no longer theoretical) perfect gas coupled to a perfect black-body in thermal equilibrium that results in smoothly distributed photon particles. They are presumably perennial due to their elementary status and in incessant random motion. All the requirements are fulfilled for that occurrence: perfectly elastic collisions, absence of interactions and very large inter-particle distance compared to their size.

3. Photon Mass

The theorem of equipartition of energy considers the total internal energy of a particle in a gas or a set of particles in a Maxwell-Boltzmann distribution. It gives the mean kinetic energy according to the temperature and the number of degrees of freedom where the internal kinetic energy is shared evenly among all the accessible modes of motion. Here we consider a quantum gas with the photon particle having three translational degrees, an intrinsic spin angular momentum (one degree) plus two more degrees to take into account circular left and right polarization states (helicities). These thus form three rotational degrees of freedom, a total of six degrees each having 1/2 kT of contributing kinetic energy. This equals 1/2 $m\,v^2$ or $m_0\,c_0^2$ in this case, c_0 being the speed of light, k the universal Boltzmann constant and m_0 the mass of a photon. We can then write $3kT = m_0\,c_0^2$ or

$$c_0 = \sqrt{\frac{3\,k\,T}{m_0}}. \tag{1}$$

Here is the equation derived for an ideal gas applied to photons and a strong reminder of the Newton-Laplace equation relative to the speed of sound in the form $c = (\gamma P / \rho)^{1/2} = (\gamma kT / m)^{1/2}$. This is normal, both equations have been built from the same concepts as kinetic theory with a wave carried by a gas at definite velocity depending on pressure, mass density and absolute temperature. On that account, it should be possible to calculate or predict the speed of light in the same manner as sound speed once the characteristics of photon gas are defined.

On a side note: if valid, that equation which implicitly has set up the speed of light value immediately raises an important question regarding the constancy of that speed which would be dependent on the square root of absolute temperature T of the gas. However there is no reason why T itself should remain constant throughout the universe. An example is the Boomerang Nebula, some 5000 light-years away where its gases get expelled with force creating literally a vacuum around it. A true vacuum, the photons filling space are evacuated. With a temperature of only 1 Kelvin, speed of light there should be reduced by 39% according to Eq. (1)! If it is so, c_0 and possibly other fundamental constants only apply to our galactic neighbourhood where they have been measured. We will come back to this topic.

We solve Eq. (1) for m_0 which represents the mass of a single photon. Thus the mass can be calculated directly. By $m_0 = 3kT / c_0^2$ it is found to be $m_0 = 1.25605 \times 10^{-39}$ kg or about 725 million times smaller than an electron (the mass is left in SI units for further calculations).

Evidence of photon mass is clearly displayed by observation of the deflection of light rays grazing the surface of the Sun correctly predicted by von Soldner in 1801 [2] (although his calculation appears to be done for half the path of the ray hence half deflection angle). The photon particle is attracted by the gravitational pull of the Sun due to its mass as any other object small or large. The 1960 Pound-Rebka experiment implying photons subjected to a fall in the gravitational field of the Earth (the gravitational red shift) is further evidence of photon mass and it is easily explained by Newtonian mechanics.

4. Six Degrees of Freedom for a Photon, a Justification

Two different calculation paths can be carried out to check the reality of six degrees of freedom regarding the photon particle. In that process the second one will show the main features of the gas. They will both lead to an identical result of photon gas pressure.

— The straight path from photons rebounding elastically in random motion in a cubical cavity model

Pressure P has been demonstrated [3] to be equal to 1/3 of the energy density U which only depends on the temperature or $P(T) = 1/3\ U(T)$. The Stefan-Boltzmann law describes the power radiated from a black-body

$$U = \frac{4\,\sigma}{c_0}\,T^4 \tag{2}$$

With $T = 2.72548$ K and the Stefan-Boltzmann constant being $\sigma = 5.670374 \times 10^{-8}$ W/m^2 K^4, we find

$U = 4.174\,68 \times 10^{-14}$ Pa (or J.m^{-3}) and $P = 1.39156 \times 10^{-14}$ Pa.

— The second path using the ideal gas law

We recall 6 degrees of freedom or 3kT of kinetic energy as theorized. We apply the ideal gas law where pressure P, temperature T and volume V are all related within a single equation $PV = NkT$, N being the number of particles or the number n per unit volume N/V (in m^3). By inserting the photon mass or factor $m_0/3$ into that equation yields the expression $P = (n\, m_0/3) \times (3kT/m_0)$. The product $n\, m_0$ represents the mass density ρ and $3kT/m_0$ is simply c_0^2 —Eq. (1)—, it comes to:

$$P = \frac{1}{3}\rho c_0^2 \tag{3}$$

This is the same as Newton-Laplace equation but with another adiabatic index γ . It can be paralleled to Eq. (1)

$$c_0 = \sqrt{\frac{3P}{\rho}} \tag{4}$$

We are then able to calculate in succession:

— the minimum averaged photon energy $E = 3kT$ at that temperature:

$E = 1.22888 \times 10^{-22}$ J

— the number n of photons per volume $n = U/E$:

$n = 3.69807 \times 10^{8}$ m^{-3} or 370 photons /cm^3 on average.

— the mass density $\rho = n\, m_0$ in the same volume with a known m_0 or literally the mass of space:

$\rho = 4.64495 \times 10^{-31}$ kg. m^{-3}

and finally:

— the pressure $P = 1/3\, \rho\, c_0^2$:

$P = 1.39156 \times 10^{-14}$ Pa.

We obtain the same result. That means the gas is quite ideal without any approximations as it would be if it were not. The photon particle has 6 degrees of freedom with a half integer 1/2 kT each or a total of 3kT. Any other factor but 6 will not fulfill that equality.

5. One Essential Link

Using this newly calculated elementary mass, it is of great interest to determine what is called the thermal de Broglie wavelength λ_{TH} as the average wavelength of a wave generated by massive particles in an ideal gas in thermal equilibrium at a specific temperature. This definition corresponds exactly to that particular situation, it is applicable to the massive gas of photons. What is the radiation wavelength emanating from such a gas? The de Broglie wavelength $\lambda = h/p$ where p the momentum is the real mass times velocity (mv) which becomes $m_0\, c_0$ leads to the equation:

$$\lambda_{TH} = \frac{h}{m_0 c_0} \tag{5}$$

or the more elaborate de Broglie equation originally derived from the kinetic energies in play $E = 1/2\, mv^2$ or $E = P^2/2m$ and $E = 3/2\, kT$ for particles moving at speed v. It can also now be regained directly for photons moving at speed c_0 from Eq. (1) and Eq. (5) put together and eliminating c_0:

$$\lambda_{TH} = \frac{h}{\sqrt{3 m_0 k T}} \tag{6}$$

With m_0 =1.25604 x 10^{-39} kg the mean wavelength is then:

λ_{TH} = 1.75967 x 10^{-3} m.

Conversely in the frequency domain (where f and λ are the mean values), by $f = c_0 / \lambda$ or by just equating the Planck's and Einstein's famous energy relations leads to:

$$h\,f = m_0\,c_0^2 \tag{7}$$

At this point it is often said that the photon "effective mass" varies with the frequency (of the photon) since h and c_0 are constants in principle, a weird statement. This is not the correct interpretation of this expression, instead the frequency depends on the photon mass but the frequency of what? To find out we solve it with that same invariant mass m_0 for the frequency f:

f = 1.70369 x 10^{11} Hz.

Quite remarkably the associated wave of 1.76 mm or the average frequency of 170.37 GHz can be favourably identified as the CMB radiation. It certainly cannot be said as it still is today that this radiation is a "signature" or a "thermal relic" following an extraordinary event and considered as supporting evidence. It would have disappeared a long time ago. Instead, being continuously generated by the pervading gas the radiation is coming from all parts of space with very little variation (1 part per 100,000) without any privileged direction. What has just been found is the average frequency or $3kT/h$. What has been detected by instruments is the spectral radiance peak frequency at 160.23 GHz which is equally obtained by the derivative of Planck's black body radiation law at that temperature of 2.72548K yielding a factor of 3 /2.82144 = 1.06329 between the two marker frequencies. The hypothesis of a massive photon actually meets the results of the CMB observations which in turn confirms, by Eq. (1), the quantified energy $3kT$ a photon possesses and above all, the reality of mass with the right amount.

6. Two not so Fundamental Constants

This new knowledge of a real mass regarding the photon obtained by Eq. (1) and substantiated by the de Broglie wavelength applied to that gas allows us to take a closer look at Eq. (6). Here we realize that wavelength and temperature and photon mass m_0 are all related, two of which can be retrieved from CMB observational data namely λ (or f) and T. By eliminating m_0 this time between the same Eqs. (5) and (1) yields another formula in the form of Eq. (8) only dependent on the wavelength and temperature that clearly reveals the way in which this radiation has set the speed of light and Planck's constant value:

$$c_0 = \frac{3kT}{h}\lambda_{TH} \tag{8}$$

Eq. (8) and Eq. (7) or its equivalent form $h = 3kT/f$ finally offer a concrete path to calculate from this framework both universal constants h and c_0, in contrast to those same constants determined experimentally. We first calculate h directly from temperature and peak frequency with the above factor as measured by the CMB radiation and then apply this result into Eq. (8) to get the speed of light. We notice that both h and c_0 stand on the same footing as shown by that last equation and this indicates that h is susceptible to variation due to temperature like c_0 although the magnitude of a possible increase or decrease of this constant value is not known at present. Thus, once the hypothesis of a massive photon is considered and this line of thought followed, these two so-called fundamental constants can then be predicted. So the question why do they take those values has a clear response: they originate from the photon gas radiation in the vicinity of the Earth where the measurements have been performed and not elsewhere. This is true at least for those two. As such they cannot be universal since temperature has been seen to be different in other parts of space. This property of photon gas filling the universe explains their existence. Therefore being derivable from a more universal truth (the CMB radiation) where physical parameters can change in space and time, they are not immutable even if the exactness of c_0 and h (which is now fixed and unchanging) is set by definition. This partially answers one of the most fundamental questions of physics or where fundamental constants originate. On the contrary, a mass-less photon as it is the tenet today would have made it impossible to establish the above proposed equations and to come up to this interpretation and these conclusions.

These two constants are calculable in principle from the CMB radiation data as described. Numerically it comes, unsurprisingly, given the round off numbers:

h = 6.62601 x 10^{-34} J.s , and

c_0 = 2.99797 x 10^8 m/s.

The realization that the radiation is intimately linked to the ubiquitous gas of photons where the electromagnetic waves are propagating through, leads to reconsidering the meaning of this omnipresent constant h with a new eye. This constant is defined as the amount of energy that a photon can carry according to the frequency of the associated wave in which it travels. This makes little sense. Now based on more solid grounds it then becomes derived from this theory as the ratio between the quantum of photon energy and the mean radiation frequency of the CMB spectrum, a bridge between the microscopic and macroscopic domains underlined by a huge scale 34 degrees of magnitude apart. This new interpretation based upon the properties of space explains its smallness. It is of historical interest to note that Max Planck spent a long time searching about the origin or physical nature of his own constant. Now we know why. The CMB radiation was only discovered about sixty years later. Surely this late interpretation would have contented him. It is also of interest to observe that it was not on time either for Louis de Broglie –a believer of massive photons– to lay down the above derivations as they would have to wait to be confronted and confirmed by the CMB satellite data of the 90's. They were not available during his lifetime. All the cards except one (a trump card) were in his hands!

7. Three more Features of Photon Gas

Once again the photon mass can make a contribution to finding out the viscosity and the mean free path of the photons composing the gas. These two are important features which dictate its behaviour. Two equations can be put forward to evaluate those variables:

$$l = \frac{k\,T}{\sqrt{2}\,\pi\,d^2\,P} \tag{9}$$

$$l = \frac{\mu}{P}\sqrt{\frac{\pi\,k\,T}{2\,m_0}} \tag{10}$$

The mean free path l, the dynamic viscosity μ and the diameter d of the photon particle are the three unknowns for those two equations. However d can be evaluated if we admit that the photons composing a light ray follow a helical path. This is what has been observed and confirmed by experiments with microwave guides [4] where the electromagnetic waves are no longer transmitted through the pipe at lower frequencies, a low cutoff frequency depending on the pipe size. According to this model very high frequency gamma rays should have an ultimate frequency limit where the adjacent spires of the electromagnetic ray are so close to each other that the wave suddenly collapses due to collisions between photons. This limit would then correspond to the photon particle of diameter d.

Astronomical observations of gamma ray bursts have been reported to be as high as 2.4 x 10^{23} Hz. We assume that a maximum is around 1 x 10^{24} Hz for a gamma ray. By λ = c /f, that makes a photon diameter d =3 x 10^{-16} m. With Eq. (9) a mean free path value of 6.763 x 10^{21} m is obtained. This is a huge distance partly because of pressure or a lack thereof. In light-years equivalent l = 704,486 ly, well beyond the visible edge of our Milky way. This should explain why distant astronomical objects like far away galaxies observed in deep field space are not blurred by photon-photon scattering. More surely photons have better chances to encounter hydrogen or helium molecules during their journey through space suggesting that scattering processes could be the cause of the red shift-distance relation or part of it. This also explains, although pressure is incomparably greater than calculated above, why two energetic laser rays aimed at each other do not collide as would do two water jets.

The second equation, Eq. (10), that contains m_0 can then be solved for the dynamic viscosity μ. The calculation gives μ = 0.434 Pa.s. Although close to unity it is a huge number also when compared to other gases which range from 7.5 x 10^{-6} to 2.2 x 10^{-4} Pa.s. It is thus several orders of magnitude larger and closer to a thick fluid like a heavy motor oil. Even with the uncertainty regarding the photon diameter all calculations lead to large numbers for both l and μ. Definitely the gearwheels of celestial mechanics got a permanent lube!

This outstanding feature of the photon gas shows itself at spiral galaxies where the arms display a filamentary aspect which is more pronounced at their periphery where photons tend to accumulate while the central core has the tendency to repel photon gas by the pressure of radiation. The other non-photon gases present would be subjected to being carried along and forced to follow the general movement of that sticky gas of photons, each of them in orbit within the structure.

8. Four Experiments Accounting for Photon Drag

With a dragging effect as a consequence of the gas viscosity, numerous experiments and observations can receive satisfying explanations. Most of these, still "pending", have not so far received any convincing explanation. They are old experiments and observations which deserve to be readdressed. In the first place, among them are the famous 1887 Michelson-Morley and 1925 Miller experiments [5]. A dragging effect of photon gas at the surface of the Earth and a lesser effect in altitude (Miller at Mt. Wilson Observatory) fully explain the reported null result and the disputed result of Miller without the need of mysterious arm contraction. This shrinkage has been viewed as an acceptable solution.

Also an even older observation is the starlight aberration observed by Bradley in 1827 [6] where the Earth moving around the Sun drags this highly viscous gas with it. A light ray coming from a star which stays in another ethereal medium, but moving relative to the one around the Earth, must encompass changes of direction during its journey toward the Earth. There is a gradual transition between the two media moving independently. The resulting measured angle supports that evidence.

This effect cannot be more explicit than with the recent experiments undertaken in the last decade by Marmet and Kelly [7] and also investigated by Gift [8] who have measured the one-way speed of light (and not the usual two-way) on two locations on the revolving Earth at the same latitude with ultra-precise synchronized clocks of the GPS positioning system. They reported a small difference of light speed in the two directions of $c - v$ eastward and $c + v$ westward relative to the surface of the Earth, v being the speed of rotation of the Earth's surface at that latitude, thus confirming an Earth-bound medium which is carried along resulting in light speed anisotropy in contradiction with the postulate of light speed invariance of special relativity. This illustrates once again that the Earth and other massive bodies bear a gaseous envelope of dragged photons in their vicinity while continuing their course through space.

9. Temperatures Rule all

We examine the evolution of the gas of photons through temperature variations. Some figure estimates are needed. Just like the Paris accord on climate change, a temperature increase of only 2K will make a huge difference for the climate on Earth and for the energy density in space. This is due to the fourth power in temperature set by the Stefan-Boltzmann law, an equation —Eq. (2)— that works for atmospheric sciences and warm-blooded organisms too. Here we consider a deep space filled with dark photons with T = 4.725K instead of T = 2.725K. With the same calculations as used previously, energy density and pressure increase then by 7 times. The mass density of space and the number of dark photons augment by 300% whereas the speed of light is augmented by 31% according to Eq. (1), with the condition that constant σ does not change which is unlikely since it is composed of several constants, among them the speed of light and Planck's constant. Nevertheless these calculations show that the concentration of photons augments very rapidly with temperature and an increase of T as low as 2K in intergalactic space is already sufficient to create a new order in these regions.

10. Fundamental Constants Need Adjustments

These calculations also show that there is no longer a good match in the results between the two paths described above as space temperature increases. The reason is that certain constants vary. To restore equilibrium c_0 must be augmented by the square root of the ratio of temperatures 4.725K to 2.725K as noted before and the speed of light will definitely be faster in some parts of space. In short: fundamental constants cannot be universal, their values would only apply to our neighbourhood at this present epoch only. This likely could solve another issue too. Observed brightness of Type 1a Supernovae in remote galaxies have been found significantly dimmer than expected inferring greater distances. With cosmic distances notoriously imprecise, an increase in light speed in deep space has the potential to make such a readjustment. This alternative explanation, if confirmed by other evidences, would render moot the existence of an accelerating universe and the presence of dark energy.

11. Dark Photons, do they Matter?

As outlined, the analogy with sound waves can be pushed much further. Just like in our atmospheric space where air molecules which are not participating in transmitting a passing sound wave stay quiet or “silent” except a remaining detectable faint noise due to their incessant motion, photons do exactly the same. Without a passing disturbing light wave, they stay “dark”, except a remaining detected faint background radiation, the CMB. As they carry the smallest amount of energy $3kT$, the term cold dark photons or simply dark photons is appropriate for them and preferable to the long banished word *ether* which was believed to be static or quasi immobile although supporting light waves and inducing a “wind” onto celestial bodies. By this study we now know that mass of space is a physical reality just like a mass of air we cannot see, even present in that very same mass of air and this mass is constituted of dark photons, the vast majority of them making up the bulk of the universe between galaxies and clusters. Dark photons are actually promising candidates for the hidden dark matter which is known to exist.

12. Bound Photons and Weighty Waves

With such a low mass density of 4.645×10^{-31} kg.m^{-3} it appears that dark photons will not contribute by any means to eight or nine times more than ordinary matter. This is what has been called the missing mass. However, a much more important ingredient has to be taken into account: the mass of electromagnetic waves of all kinds crisscrossing space. In view of the innumerable quantity of photons in play contained in a single ray, this could well be by far the dominant mass in the universe. Photon particles are excellent contenders and they suitably solve the perplexing question of the missing dark matter. Is there a need to search any longer? CMB photons have been detected as long ago as 1964-65 by Penzias and Wilson. All this has been simply dismissed because they were thought to be mass-less in the first place. What we know so far is that the calculated mass of space has been established along with certain fundamental constants in the vicinity of the solar system. What are the conditions in other parts of the galaxy and beyond? They could all be different. There are strong indications that dark photons which are gravitationally bound like the rest tend to concentrate at the edge of a spiral galaxy due to the intense radiation pressure exerted by the central bulge or core which contains a concentration of stars. They form a large halo of more condensed matter where pressure, temperature and friction with normal matter and photon concentration and also viscosity gradually increase toward the edge and well beyond (viscosity and temperature increases hand in hand). As a consequence, the rotation curve of the galactic disc is rendered rather flat as observed. A great picture then slowly appears to unveil: the galaxies themselves by their shapes could be seen as low pressure systems in respect with the surrounding space like the image of hurricanes in our atmosphere. This inverted view matches with this description. The future will tell whether this last prediction is realized.

Conclusions and Outlook

As seen, there is no incompatibility of any kind. The de Broglie wavelength applied to a calculated massive photon leads directly to the observational data of the CMB radiation without any adjustment. Thus the hypothesis of a photon mass is satisfied. Unquestionably the actual provenance of this radiation is revealed, it comes from the sole presence of a gas of photons pervading all space. Surprisingly this gas has been found to be unusually highly viscous and this explains its behaviour visible at large scale. Additionally the origin of two fundamental constants and their predictive evaluations as a result of the derived equations is demonstrated. Photons in both modes, dark or active, appear to be responsible for the missing mass in the universe. Because unsolved conceptual problems still exist, especially in astrophysics and cosmology, several interesting questions which have been raised in this writing should pave the way to more related discoveries. In addition many potentially long lasting issues resulting from experiments are likely to be resolved with that ponderable photon. Just a few of them have been described. Many others remain which deserve to be analyzed taking into account adapted local cosmological parameters subjected to the variability of natural constants. We must also keep this view of the presence of weighty electromagnetic waves and cold matter composed of non-interacting dark photons exerting gravitational force to hold stars in the inner side of the galaxy and meshing the rest of matter with it. This stable and dynamic web formed by never decaying photons would make up the vast majority of the universe's mass. It always existed.

Conflicts of Interest

This author declares no conflict of interest of any kind.

Acknowledgements

The author is deeply grateful to James Allison for his assistance in the final formulation of this text.

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