The Problem of the Photon

by

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Abstract

The problem of the photon is how to resolve that light exhibits behavior only explainable as it being a wave phenomenon yet light also exhibits behavior only explainable as it being of particle nature. It is shown that the natural photon-particle is impossible so that light is a pure simple wave effect of propagating half-cycle sinusoidal bursts of electro magnetic (E-M) field.

However, at its generation, such as from an atomic orbital electron, a particle photon momentarily exists as the total created E-M field at the first instant of its existence, which field then propagates outward in many directions as E-M wave. Sections of the periphery of that expanding front are inverse-square reduced portions of the "starting particle".

And, however, at the point of photon interaction with an electron or other particle a large number of inverse-square reduced small portions of expanding such wave front peripheries combine there to produce the momentary effect of a single particle, an "ending particle" photon.

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1 - The Problem

The problem of the photon is how to resolve that light exhibits behavior only explainable as it being an electro magnetic (E-M) wave phenomenon yet light also exhibits behavior that would appear to be only explainable as it being of particle nature. The evidence for the wave nature of light is extensive including the wave behaviors of: reflection, interference, refraction, diffraction, frequency, wavelength, polarization, and so forth and the highly successful Maxwell's Equations[1]

Then phenomena appeared that seem to require a particle nature of light hence its particle name, "Photon". Those phenomena were the failure at short wavelengths of the theoretical Rayleigh-Jeans law of black body radiation, the photoelectric effect, and the line spectra of gases. This evidential wave-particle duality led to the concept of the photon as a particle in the form of a "wave packet". But, the particle nature of the photon still has a number of problems.

A wave in free space spreads out as it propagates, but the particle photon wave packets must be considered as staying together like a particle. The E-M wave front is continuous, but a front of propagating particles involves the particles' moving radially from the source with the distance between particles increasing with distance from the source and nothing in the spaces between.

E-M radiation is produced by acceleration of charge and must produce E-M propagation that is spatially symmetrical to the charge's motion, but the particle theory requires that the radiation travel away from the accelerated charge as a specific particle in some specific direction without symmetry . The next particle may be in another direction, the next in a third, and so on, so that a large number of radiated particles exhibit a dispersion pattern somewhat like that of the wave field, but that still is behavior that is inconsistent with the wave aspect.

2 - Analysis of the Photon from Its Generating Source

To resolve this problem it is necessary to go first to the constraints on what a photon is as they are imposed by its source, the transition of an atomic orbital electron from an outer to an inner orbit which transition must fit and match to, the following requirements.

- The transition is a change from the initial state to the final state as in part of a single cycle of an oscillation. It is not a changing to a different state and then returning back to the original state as in a full cycle of an oscillation.

- To avoid an infinite rate of change, which is impossible, the transition must be a smooth variation, without any sudden "jump".

- The resulting radiation exhibits all of the characteristics of Maxwellian electro magnetic wave and is at one simple frequency, the photon frequency. It therefore must be in the form of a simple sinusoid.

- The theory of information in communications shows that at least a sample every half-cycle of an oscillation is required to specify it sufficiently. Therefore, at least a half cycle of the photon oscillation is required to specify it.

Therefore, for all of the above reasons, the photon must be in the form of a half-cycle of a sinusoidal function of time.

- In general, magnetic field is directly proportional to the velocity of the moving electric charge producing that field. Therefore the magnetic field of the photon is directly proportional to the transitioning electron's velocity. Since the photon magnetic field must be a half-cycle sinusoid the transitioning electron's velocity variation must be of a half-cycle sinusoid form.

- The electron velocity must vary in accordance with the above from the stable velocity of the initial orbit through a period of increase and ending in the stable velocity of the final orbit. (The potential energy lost in the move to a lower orbit appears half in the emitted E-M radiation, the photon, and half in the increase in electron kinetic energy due to its greater velocity in the inner orbit).

The combination of these factors results in the specification that the photon must be a half cycle of a pure sinusoidal type variation behaving as in the following figure.

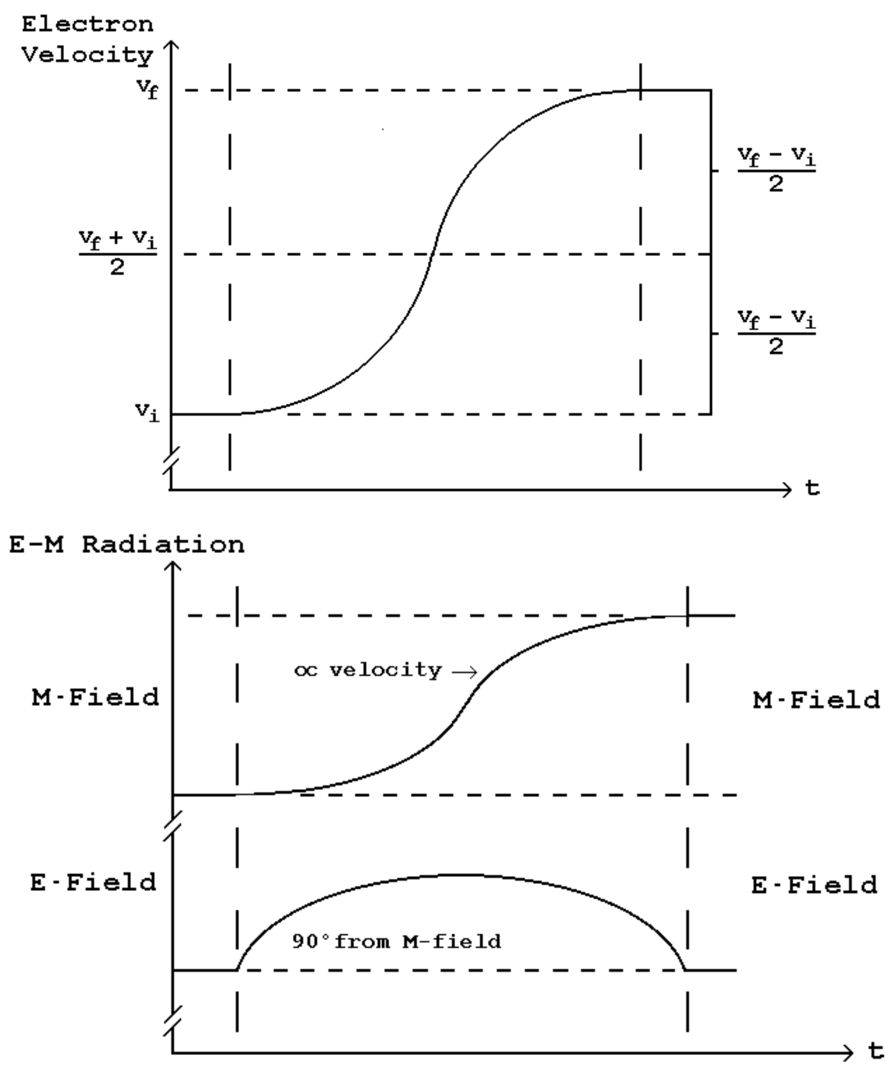

Figure 1 – The Orbit Transitioning Photon Generating Electron Behavior

The electron, traveling from its initial outer orbit to its final inner orbit with its velocity gradually increasing in a sinusoidal manner as in Figure 1, follows a path as illustrated in Figure 2, below, and emits an E-M wave field in “doughnut form” as in Figure 3, below, relative to its instant-by-instant varying vector velocity direction at each instant of the transition.

The peculiar shape of that field because of the directional orientation of the “doughnut” swinging through a substantial portion of a full circle according to the path of the electron’s orbital descent causes the propagated E-M wave to contain the requisite form, angular momentum and energy for causing an encountered orbital electron elsewhere to be elevated to a higher orbit equivalent to the higher orbit that the electron previously descended from. The propagated E-M burst contains and transmits both energy and angular momentum.

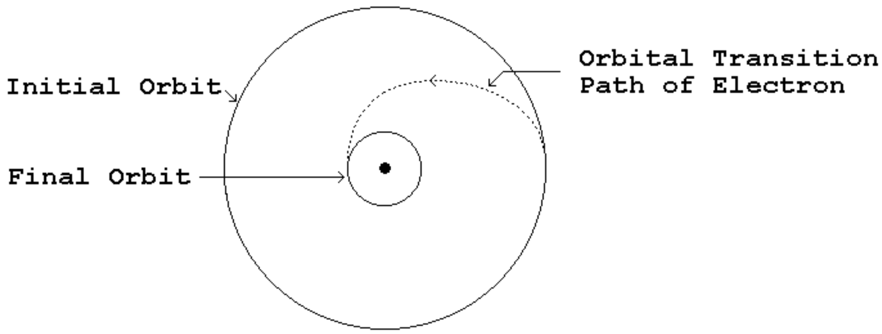

Figure 2 – Typical Electron Outer-to-Inner orbit Change Path

[In terms of the final orbital period the transition takes place in $1^1/_3$ orbital periods at most and in approximately ½ or less such orbital periods for most cases.][3]

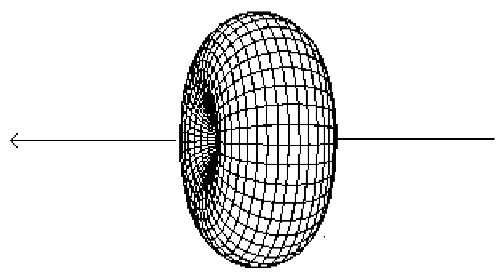

Figure 3 – Instantaneous Electro-Magnetic Radiation Pattern [doughnut shape] of a Single Electron Traveling Horizontally.

It is clear from the above that for the radiation emitted in this circumstance, which radiation is the photon, it is impossible that it travel outward away in a single specific direction as required for the photon-particle hypothesis. Furthermore, there are other problems with that hypothesis.

Perhaps the greatest other problem with the photon-particle theory is as follows . The wavelength of light is in the range of 10^{-7} meters . Atomic dimensions are on the order of 10^{-10} meters so that if a photon is to contain wavelength data relevant to the light that it represents, it must then have dimensions that are on the order of $10^3 = 1000$ times the size of an entire atom let alone than the size of a much smaller orbital electron. Clearly this is completely at variance with the photon-particle explanation of the photoelectric effect and line spectra of atoms.

For example, in the instance of absorption of a photon-particle causing the raising of an orbital electron to a higher orbit there would be, relatively speaking, a *football size photon* interacting with a *sand grain size atom*, the football-photon managing to focus its action solely on one *germ size electron* in the *sand grain size atom* without disturbing any of the rest of the atom.

Conversely, in the instance of an orbital electron falling to a lower orbit and emitting a photon-particle to carry off half the lost energy, there would be a *germ size electron* giving birth to a *football sized photon*.

The photoelectric effect has the same problem. For a photon-particle to eject an electron from an encountered metal material means a *football size photon* interacting with a *germ size electron* in the material composed of *sand grain size atoms* without disturbing anything other than the particular *germ size electron*.

3 - Resolution of the Photon's Seeming Particle-Like Behavior

The description of the earlier above scenarios, there illustrated in terms of relative metaphorical particles [*football photon, sand grain atom, germ size electron*], however now treated as the interaction of E-M wave radiation and the atomic orbital electron, is as follows.

The entire atomic orbital electron behavior is constrained, of course, by the condition that only certain specific orbits are stable, all others being unstable, and a criterion of stability is that the orbital path length be exactly an integer multiple of the electron's matter wavelength.[2] The frequency of the E-M wave radiation, which radiation is the photon produced by a change from an outer stable orbit to an inner one, is a function of the energy difference between the orbits, $W = h \cdot f$, h being the Planck constant.

The atomic orbital electron falling from an outer orbit to an inner orbit follows a curved path somewhat less than a full orbital pass[2]. Throughout the duration of that curved descent path the electron gradually loses energy and emits E-M wave radiation outward at right angles to its path in a pattern symmetrical to the instantaneous vector direction of the electron at any moment. That brief burst of a half cycle of E-M radiation carrying and transmitting orbital change energy and angular momentum, propagates on outward decreasing in amplitude as the inverse square of distance from its point of origination.

Such radiation bursts encounter atomic orbital electrons, other than their source one, at various small parts of their overall outward propagating wave front periphery, at various distances from each burst's source. Sometimes at such an encounter, out of the arriving plethora of such bursts, a subset arrives coordinated enough to match the energy, frequency and angular momentum requisite to elevate the encountered electron from its current stable orbit exactly to a higher stable orbit through an increase in its energy and angular momentum by the amount in the combined bursts in the subset of the incident E-M waves.

The process is not unlike that in an antenna's reception of a radio signal in which the part of the arriving / passing E-M wave that actually encounters free electrons in the antenna material induces motion in those free electrons, motion corresponding to that which generated the radio waves. Of the total of all wave bursts encountering an atom, only those that directly encounter a particular orbital electron affect that electron's motion. Most of the time that effect is not to elevate the electron to a higher stable orbit. Rather, the effect is to elevate the electron to a higher energy level where it is in an unstable position and it immediately re-radiates the E-M wave that acted on it and returns to its lower stable orbit. To an external observer it is as if nothing happened.

But, a correctly coordinated subset of incoming wave bursts will occasionally elevate an encountered electron to a higher stable orbit producing an absorption spectrum line and an electron in a position from which, if it is disturbed from its new stable orbit, it will radiate a radiation spectrum line.

Similar action takes place in the photoelectric effect, the difference being that in the photoelectric case photon burst subsets of sufficient energy elevate electrons to an electric current free of the metal atom on which the incoming photon was incident. That "incoming photon" is actually a coordinated subset of the plethora of half-cycle E-M wave bursts. All arriving natural "photons" are such.

In all of the radiative cases, whether from orbital electrons or vibrating molecules' Black Body Radiation or other charged particle sudden accelerations, the energy is <u>exchanged</u> in a quantized amount $W = h \cdot f$ as proven by Planck in his resolution of the Rayleigh-Jeans law of black body radiation. But that quantum of energy travels off away from the location at which the initial energy exchange took place as an E-M wave propagating outward in many directions. The concentration of the $W = h{\cdot}f$ overall total rapidly diffuses in space as the surface of the outward propagating wave front increases,

In all of the absorptive cases, orbital electrons or photoelectrons, or Black Body radiated heat E-M waves, the arriving and acting "photons" are timing, phase and vector coordinated subsets out of the plethora of half-cycle E-M wave bursts, the appropriateness of the subset's composition depending on the particular environment on which it is incident: a particular electron in a particular atomic orbit, a loosely bound electron in a metal surface, an encountered molecule.

But, why is the "photon" energy, the energy in the exchange, dependent only on the frequency as in $W = h{\cdot}f$? how does wave amplitude enter into the process ?

As they propagate outward the waves disperse so that the amplitude at points on the periphery of each individual burst decreases steadily in inverse square manner from its value at the moment of the interaction that created it. The farther that an absorptive interaction is from the source of incoming radiation the greater the number of individual bursts, each contributing a small portion of the "requisite amplitude", that are required for an absorptive interaction to be able to take place.

If a "brand new" half-cycle burst at full amplitude as just created and before propagation outward were to encounter an electron in the identical energy-momentum-orbit situation as that of the electron that just finished generating the new burst, the new burst would elevate that "just finished" electron back to where it started from. That new burst's before propagation amplitude is the "requisite amplitude" that the actual numerous bursts of the subset must add up to.

The amount of energy naturally depends on frequency. The higher the frequency the more rapidly the E-M radiation oscillates. The E-M radiation carries the ability to cause corresponding change in motion in encountered charged particles. It requires more energy per time to make a rapid change than to make a gradual one. A shorter period (higher frequency) half-cycle sinusoid must contain directly proportional greater energy to produce the proportionally more rapid change.

4 – Special Cases - Laboratory Photons

The discussion and treatment of photons to this point has been of only natural world photons behaving in their natural fashion without any interference or action by humans. As to be expected the situation is somewhat modified when dealing with the effects of humans; however, there is no change in the fundamentals that photons are a purely E-M field effect not that of a discrete particle.

Radiating photons as above, whose E-M field disperses widely in nature, are focused, collimated into a monodirectional beam in the laboratory. That beam, in its effect upon encountering matter, is effectively a stream of photon particles, each still a half cycle burst of E-M field but having a particle's one specific direction.

The Compton Effect

The Compton Effect is considered the *sine qua non* of the particle theory of the photon. When x-rays of known wavelength impact atoms the x-rays are scattered through an angle Φ and emerge at a greater wavelength, meaning reduced frequency, related to Φ. That reduced frequency means reduced energy $W = h{\cdot}f$.

In the study of the Compton Effect the incoming x-ray radiation is considered to consist of particles and the study analyses a collision of a photon with an electron just as if two billiard balls were to collide in a glancing manner (Figure 4, below). The classical particle physics of the situation require that energy be conserved and that momentum be conserved independently in all directions.

The incoming incident x-rays are, of course, a collimated monodirectional beam of natural photons.

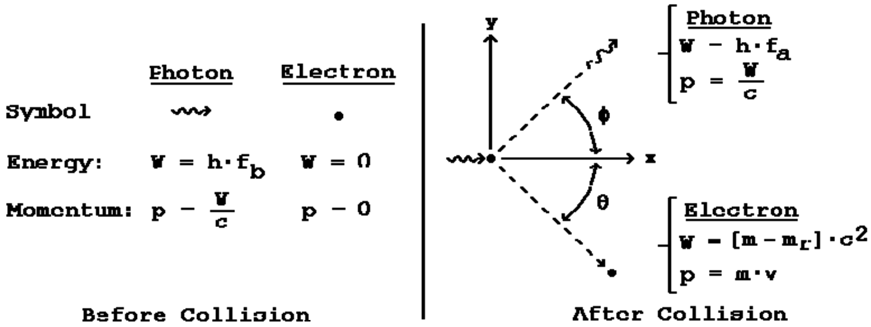

Figure 4 – The Compton Effect

Experiment has verified that in fact the scattered radiation is at reduced frequency and in agreement with the Compton developed formula. That has been taken as confirmation of the particle nature of the photon but it is not. It is only confirmation that, of course, energy and momentum must be conserved in such interactions. A particle form of radiation is not necessary to accomplish that.

In the "scattering" in the Compton Effect incoming E-M waves are absorbed by the electrons which then radiate new E-M radiation. The incoming photons are not particles but the half-cycle E-M wave bursts already developed.

Lasers

Lasers are another example of the use of single frequency focused beams of the half cycle sinusoidal bursts of E-M waves that would otherwise widely disperse. In the case of the laser the result is an optical "current" of those bursts, which in its single frequency and E-M oscillation is essentially equivalent to the electrically generated carrier waves which carry radio and broadcast transmitted information in modulation applied to the carrier.

Other Experiments

In general all experiments on the nature and behavior of light depend on using artificial light, that is single frequency light that is focused or collimated into a narrow monodirectional beam, which gives it some of the appearances of a particle while still retaining its E-M nature. Thus, in a sense, the problem of the wave-particle duality of light is the issue of "which light" – light as in free nature or specialized laboratory light.

References

[1] R. Ellman, *The Origin and Its Meaning*, The-Origin Foundation, Inc., http://www.The-Origin.org, 1997. [The book may be downloaded in .pdf files from http://www.The-Origin.org/download.htm].
- Section 15, opening portion

[2] R. Ellman, *The Origin and Its Meaning*, The-Origin Foundation, Inc., http://www.The-Origin.org, 1997. [The book may be downloaded in .pdf files from http://www.The-Origin.org/download.htm].
- Section 15, beginning page 174

[3] Knowing the time duration of the electron's orbital transition relative to the electron orbital period is helpful in visualizing the process. The orbital transition takes place in the time of one-half cycle of the photon's frequency. Letting "D xx" symbolize "the duration of xx" then

$$D\ \text{orbital transition} = D\ \text{photon} = \frac{1}{2\cdot\text{photon frequency}}$$

Let n be the orbit number, an integer representing the number of matter wavelengths in the orbit. The electron orbital velocity is proportional to $1/n$. Its matter wave frequency is proportional to $1/n^2$. The photon frequency is equal to one-half the difference between the initial and final orbits matter wave frequencies. From those, the duration of the orbital transition in terms of the duration per orbit in the final orbit is

$$\frac{D\ \text{orbital transition}}{D\ \text{final orbit}} = \frac{n_{initial}^2}{n_{final}\left[n_{initial}^2 - n_{final}^2\right]}$$

n_i	n_f	Transition/ final orbit	n_i	n_f	Transition/ final orbit
2	1	4/3	4	3	16/21
3	1	9/8	5	3	25/48
3	2	9/10	6	3	36/81
4	2	4/6	7	3	49/120
5	2	25/42			

The transition takes place in $1\text{-}^1/_3$ final orbit periods at most [$n_i = 2,\ n_f = 1$], and in less than 1 final orbit period for most cases [$n_f > 1$]. The orbit transition and photon emission take place with the electron traveling a significant portion of an orbit around the atomic nucleus in all cases.

Looked at another way, the transitioning electron travels in the range of on the order of 180^o to 360^o of a circular orbit. Its path being curved its direction at instants during the transition changes by on the order of 180^o to 360^o. Such a path is completely incompatible with a particulate photon being emitted in some one specific direction by that transition.