EFFECTIVE PHOTON HYPOTHESIS, SELF FOCUSING OF LASER BEAMS AND SUPER FLUID

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Abstract

The effective photon hypothesis of Panarella and Raychaudhuri shows that the self focusing of photon in the laser beam is inherent and it also shows that the cause of phenomena of self focusing of intense laser radiation in solids is not actually the nonlinear intensity dependent refractive index. In the effective photon hypothesis the laser photon have much better chance than ordinary photon to undergo a phase transition to a superfluid state.

If a super fluid photon in the laser beam can be realized then in the effective photon hypothesis gives interesting results. The effective photon hypothesis shows that if the average energy X-ray laser beams is $h\nu = 10^3 \text{ eV} \sim 10^4 \text{ eV}$, we find that mass of the quasiparticles in the X-ray laser beams is in the range $10^5 \text{ eV} \sim 10^{12} \text{ eV}$. Thus the mass of the quasiparticle in the X-ray laser beams can be $Z$-boson of the electroweak theory of weak interactions. It is possible that $W^+$ and $W^-$ can be originated from another vector boson whose mass is more than 200 GeV.

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1 Introduction

The celebrated formula of physics $E = h\nu$ is independent of the light intensity and this formula was verified in the low light intensity experiment before the optical laser invented. Now a days it is a routine affair to get photon intensity as high as $10^{30}$ to $10^{33} \text{ cm}^{-2}\text{sec}^{-1}$. These corresponds to photon number densities $N \sim 3 \times 10^{19}$ to $3 \times 10^{22}\text{ cm}^{-3}$, which are about $10^7$ to $10^{10}$ times higher than the ordinary light phenomena. A new phenomenon appears when the laser beams interact with metals or gases, such as ionization of gases, photoemission from metal surfaces and supercontinuum generation in gases. The phenomena are not expected, because the photon energy of the laser beams used is at least an order of magnitude lower than the ionization potential of the gases or the work function of the materials irradiated. The difficulties faced by the classical theories in an attempt to explain the above characteristic phenomena. Multiphoton processes are generally described within the context of the lower order perturbation theory. If we think multiphoton theory is the correct answer to explain the above-mentioned characteristics then why multiphoton theory cannot applicable to lower intensity photon. Moreover, multiphoton theory predicts that the photoelectric current $i$ is a function of light intensity $I$, namely, $i \propto I^n$, where $n$ is the integral part of $(W/h\nu) + 1$, $W$ being the work function of the irradiated material. The experimental results, shows the electron emission from a metal to be directly proportional to light intensity rather than being the $n$th power the light intensity. On the otherhand, the power threshold observed for multiphoton processes is a natural consequence of the intensity dependence of the effective photon energy. Again, since the electron emission is a single photon process, the electron current must be linear with intensity according to effective photon hypothesis, which is in agreement with experimental results.

Panarella (1972, 1974,1986) has shown from elementary analysis that a photon cannot approach another one closer than characteristic distance $\lambda$, which can be assumed to be the equivalent of the wave length $\lambda$ in the classical theory of light. This implies that a photon occupies a volume of space equal to or greater than $\sim \lambda^3$. In terms of photon number density $N$, photon flux $F$, and the intensity $I$, the maximum allowed values for $\lambda = 5 \times 10^{-5} \text{ cm}$, we therefore have $N = 1.62 \times 10^{13}\text{ cm}^{-3}$, $F = Nc = 4.56 \times 10^{23} \text{ cm}^{-2}\text{sec}^{-1}$ and $I = 1.81 \times 10^5 \text{ W/cm}^2$. It is well known that at the focus of high intensity laser beams, these values are exceeded if we take the fundamental value that two photon photons cannot come any closer than 1 unless a specific mechanism allow this to occur (perhaps a photon-photon inelastic scattering or basic neutrino-antineutrino interaction), then this implies that the photons, in
the course of focusing, have their wave length reduced or frequency raised thus giving energy at the expense of energy from surrounding photons. This hypothesis seems to have already retained experimental confirmation. In fact, some experiments of ionization of gases by focused laser beams to indicate a photon energy increase at the experimental light intensity and never less than this intensity. The gases, in fact, begin to be ionized at this intensity, although their ionization potential is well above the original energy of the photon when emitted by the laser source. Hence the photon seems to have gained energy in the course of focusing. The cause of phenomena of self-focusing of intense laser radiation in solids the nonlinear intensity dependent refractive index \( n = n_1 + n_2 E^2 \), where \( n_1 \) is the normal refractive index and \( E \) the time averaged of the effective field of the laser beam radiation. The coefficient of \( n_2 \) determine the magnitude of the nonlinear behaviour of refractive index, self focusing happens provided that the laser power exceeds a critical value \( P_c \) which is in CGS units \( \omega^2 \), for \( n_2 = 10^{-11} \) in CGS unit, \( \lambda = 10^{-4} \) cm, \( \omega = 2 \times 10^{15} \) sec\(^{-1} \), \( P_c = 2 \times 10^4 \) watt which is equivalent to \( I_c \sim 10^{12} \) W/cm\(^2 \). It is suggested that if \( I > I_c \) the beam begins to undergo self focusing. The critical temperature below which this is going to happen is a function of temperature dependence of \( n_2 \). Most likely \( n_2 \) is a decreasing function of temperature and vanish for certain temperature where the critical bond is broken. The temperature is playing the role of a critical temperature and is therefore of the order of \( 10^3 \) K. The nonlinear optical property results in self focusing can be interpreted as an attractive force acting between the photons. If the photon gas is dense enough it can undergo Bose-Einstein condensation and if the attractive force is strong enough, it is conceivable that it becomes superfluid, by undergoing a second order transition.

In this paper we will show here that the cause of phenomena of self-focusing of intense laser radiation in solids is not actually the nonlinear intensity dependent refractive index \( n = n_1 + n_2 E^2 \), where \( n_1 \) is the normal refractive index and \( E \) the time averaged of the effective field of the laser beam radiation. The coefficient of \( n_2 \) determine the magnitude of the nonlinear behaviour of refractive index, self focusing happens provided that the laser power exceeds a critical value \( P_c \) which is in CGS units \( \omega^2 \), for \( n_2 = 10^{-11} \) in CGS unit, \( \lambda = 10^{-4} \) cm, \( \omega = 2 \times 10^{15} \) sec\(^{-1} \), \( P_c = 2 \times 10^4 \) watt which is equivalent to \( I_c \sim 10^{12} \) W/cm\(^2 \). In section-2 we will describe the effective photon hypothesis and its consequence in the formation of superfluid state. After that we will show that in the superfluid state the effective photon can be the vector boson of the electroweak theory of particle physics.
2 Effective Photon Hypothesis and Superfluid State

During 1964 to 1970 Panarella was engaged in experimental research of ionization gas by laser beams and he relates that the available classical-theories namely multiphoton and cascade theory -were unable to explain the experimental results. He then postulated the possibility of exchange of energy among photons at the focus of high intensity laser beams and designated this photon that had acquired energy from the exchange as effective photon. Effective photon suggests that since electron emission is a single photon process, the electron current must be linear with intensity in agreement with the observation (Panarella 1986). The failure of multiphoton theory to explain the ionization of gases by laser beams which led to postulate of a single photon process of ionization and to the effective photon photon model, in which the photon energy is now a function of intensity

\[ E = h\nu f(I, \nu) = h\nu \exp[\beta\nu f(I)] = \frac{h\nu}{1 - \beta\nu f(I)} \]

Enhance photon energy is occurs if \( \beta\nu f(I) \) sufficiently differ from zero at the focal point of the laser beam etc., \( h\nu \) is the normal photon energy, \( \beta\nu \) and \( f(I) \) is a function of light intensity has not been contradicted so far either by the experiment on laser induced gas ionization or by photoemission from laser irradiated metals. Because of the positive aspects of the hypothesis Raychaudhuri (1986, 1989) was lead to give a theoretical basis. If one starts with a composite nature of photons, one may end up with coupling constant \( g^2 = 5 \times 10^{-12} e^2 \), the energy of photon results in

\[ E = \frac{h\nu}{\varepsilon} \]  (1)

and

\[ \varepsilon = 1 - \frac{3.9 \times 10^3 N_\gamma}{m_\nu (eV)(\omega^2 - \omega_0^2)} \]

Where \( N_\gamma \) is the number density of photon, \( \omega \) average frequency of the photons in the laser beams, \( \omega_0 \) is the characteristic frequency of the laser medium can be taken as

\[ \omega_0^2 = 3.9 \times \frac{10^3 N_\gamma}{m_\gamma (eV)} \]

The above formulas (1) can be similar to Panarella’s effective photon formula. Now it can be said that

\[ 0 < \frac{3.9 \times 10^3 N_\gamma}{m_\nu (eV)(\omega^2 - \omega_0^2)} < 1 \]  (2)

is the condition for ordinary photon energy to be enhanced and ordinary photon to be to be maser, laser, X-Ray lasers etc. The above formula has been applied to (i) Cosmic masers,
(ii) ionization of highly excited hydrogen atom in a strong microwave field, (iii) Auroral Kilometric radiation, (iv) multiphoton absorption in chemical reactions etc. (Raychaudhuri, 1993, 1996). The detection of effective photons (i.e., energy enhanced of photon) has to be made at angles very near to forward scattering of photon-photon scattering by laser beams with very high intensity (Raychaudhuri, 2002, 2005). In this connection it may be mentioned that there was an attempt to search for stimulated photon-photon scattering in vacuum at a center of mass photon energy 0.8 MeV (Bernard et al. 2000). Brodin et al. (2001) have proposed trapping of photons inside a so-called high power resonant cavities. This cavity concentrates photons of particular energies. After producing photons of different energies (or equal energies) could smash into each other, then goes away with two energies that were not among the original frequency.

In the case of effective photon hypothesis it is shown by Raychaudhuri (1986, 1996) that self focusing of photon is possible when $I \geq 10^{12} \text{ W/cm}^2$. We will show here that the cause of phenomena of self-focusing of intense laser radiation in solids is not actually the nonlinear intensity dependent refractive index $n = n_1 + n_2 \mathbb{E}^2$, where $n_1$ is the normal refractive index and $\mathbb{E}^2$ the time averaged of the effective field of the laser beam radiation. The coefficient of $n_2$ determine the magnitude of the nonlinear behaviour of refractive index, self focusing happens provided that the laser power exceeds a critical value $P_c$ which is in CGS units $P_c \approx \frac{c^4}{4n_2 \omega^2}$, for $n_2 = 10^{-11}$ in CGS unit, $\lambda = 10^{-4} \text{ cm}$, $\omega = 2 \times 10^{15} \text{ sec}^{-1}$, $P_c = 2 \times 10^4 \text{ watt}$ which is equivalent to $I_c \sim 10^{12} \text{ W/cm}^2$. It is suggested that if $I > I_c$ the beam begins to undergo self focusing. The critical temperature below which this is going to happen is a function of temperature dependence of $n_2$. Most likely $n_2$ is a decreasing function of temperature and vanish for certain temperature where the critical bond is broken. The temperature is playing the role of a critical temperature and is therefore of the order of $10^3 \text{ K}$. The nonlinear optical property results in self focusing can be interpreted as an attractive force acting between the photons. From the effective photon hypothesis concept self focusing of photon is possible approximately at the same intensity of photons. The effective photon formula is suggested by Panarella and Raychaudhuri due to interaction of photons themselves in the laser photons. Thus the effective photon hypothesis is the alternative way to explain the many of the phenomena associated with the laser. If the photon gas is dense enough, it can undergo Bose-Einstein condensation, and if the attractive force is strong enough it is conceivable that it becomes superfluid by undergoing a second order transition. An ordinary photon gas obeying a Planck's blackbody radiation law is already a degenerate Bose-Einstein
gas. The same must be true even for the low temperature photon gas of laser beam. In the laser beam the photon can be understood as quasiparticles as the photon passes through the laser beam every photon experience a force from the surrounding photons. In the laser beam the quasiparticle of \( m^* \) are moving with velocity \( v = c\varepsilon \). The wave length in the medium is \( \lambda^* = \lambda\varepsilon \) and we have

\[
\lambda^* = \frac{h}{m^*v}
\]

with \( \lambda = \frac{h}{mv} \) and \( v = c\varepsilon \), we obtain from (1)

\[
m^* = \frac{m}{\varepsilon^2}
\]

For \( m^* \) we can compute the rest mass \( m_0^* \) of the quasiparticle

\[
m_0^* = m^* \sqrt{1 - \frac{v^2}{c^2}} = \frac{m}{\varepsilon^2} \sqrt{1 - \varepsilon^2} \]

which shows that

\( m_0^* = 0 \) for \( \varepsilon = 1 \) and we have

\( m_0^* = m^* \) around \( \varepsilon < 1 \) and the Bose gas of the quasiparticle of \( m^* \) is NR, under this condition Bose-Einstein condensation occurs if \( T < T_B \) (critical temperature) (Winterberg,1989) given as follows:

\[
KT < KT_B \approx \frac{\pi h^2}{m^* N^{2/3}}
\]

Where \( N \) is the number of quasiparticles. Where \( N \) is the number of quasiparticles. Now writing \( 3/2KT = 1/2m^*v^2 \)

We find

\[
1/3m^*v^2 < \frac{\pi h^2}{m^* N^{2/3}}
\]

gives \( N > \left[ \frac{(m^*)^2v^2}{3\pi h^2} \right]^{3/2} \approx 8(1/\lambda\varepsilon)^3 \)

For \( \lambda = 10^{-4} \) gives \( N > 10^{16} \sim 10^{22}/cm^3 \) where \( \varepsilon \) ranges from \( 10^{-1} \) to \( 10^{-3} \). For Bose-Einstein condensation to occur the beam intensity \( I > I_c \) (critical),

\[
I_c = 8(1/\lambda\varepsilon)^3(\varepsilon)(h\nu) = (8hc^3/\lambda^4\varepsilon^2)
\]

If \( I = \frac{P}{\pi r^2} \geq I_c \), where \( r \) is the beam radius.

A transportation with superfluid state may occur. From the above for \( I = I_c \), a critical beam with radius \( r_c \) below the transition would take place

\[
r < r_c = (\frac{P}{\pi I_c})^{1/2} = (\frac{\lambda^4\varepsilon^2}{8\pi hc^2P})^{1/2}
\]
If $P > P_c$ less focusing is needed and we therefore find

$$r < r_c \sqrt{\frac{P}{P_c}}$$

require to make

$$\frac{P}{P_c} = \left( \frac{r}{r_c} \right)^2 = \left( \frac{0.5}{0.6} \right)^2 \frac{1}{\varepsilon^2} = \frac{0.75}{\varepsilon^2}$$

Thus $\frac{P}{P_c}$ can range from 75 to $7.5 \times 10^7$

If $\varepsilon$ ranges from $10^{-1}$ to $10^{-4}$

i.e., $P = 7.5 \times 10^5$ to $7.5 \times 10^{11}$ watt.

We will now show that laser photons have much better chance than ordinary photon to undergo phase transition to a superfluid state. For an ordinary photon the uncertainty principle is

$$mrc \geq h$$

whereas for laser photon it is

$$m^*r^*v \geq h$$

gives $mrc \geq h\varepsilon$ which shows that the laser photon can be much more density packed than ordinary photons and greatly enhances the chance for a second phase transition. In a superfluid laser beam all the photons will be highly correlated, a property which would find its establishment in the formation of energy gap. In fact the energy gap is

$$\Delta(h\nu) = h\nu' - h\nu$$

$$h\left(\frac{\nu}{\varepsilon} - \nu\right) = \frac{h\nu(1 - \varepsilon)}{\varepsilon}$$

as a result, individual photons of superfluid condensate would not be scattered out of the beam.

Now taking average photon energy in the laser beam $h\nu = 1$ eV we find that

$$m^* = \frac{m}{\varepsilon^2} \sim 10^{-33} \text{ gm/} \varepsilon^2 \longrightarrow 10^{-31} \text{ gm to } 10^{-25} \text{ gm}$$

for $\varepsilon$ ranges from $10^{-1}$ to $10^{-4}$.

Thus the mass of the quasiparticles in the laser beam is therefore of the order of $100$ eV $\sim 100$ MeV. The mass of the quasiparticles is therefore in the range of the various mass of the vector particles.

In the case of X-ray laser beams $h\nu = 10^3$ eV $\sim 10^4$ eV, in that case mass of the quasiparticles in the X-ray laser beams is in the range $10^5$ eV $\sim 10^{12}$ eV. Thus the mass of the quasiparticle in the X-ray laser beams can be one which may be the Z-boson of the electroweak theory.
of weak interactions. It is possible that $W^+$ and $W^-$ can be originated from another vector boson whose mass is more than 200 GeV. The finite rest mass of the particle leads to a range of interactions and which is given by the Compton wavelength

$$\Lambda_c = \frac{h}{m_0 c} = \frac{(h/mc)^2}{\sqrt{1-\varepsilon^2}} = \frac{\lambda^2}{\sqrt{1-\varepsilon^2}} = 10^{-2} \lambda \text{ to } 10^{-8} \lambda.$$  

3 Discussion

The effective photon hypothesis suggests that from laser beam with very high intensity a superfluid photon beam can be realized. If a superfluid photon in the laser beam can be realized then the effective photon hypothesis gives interesting results. The effective photon hypothesis shows that if the average energy X-ray laser beams is $h\nu = 10^3 \text{ eV} \sim 10^4 \text{ eV}$, we find that mass of the quasiparticles in the X-ray laser beams is in the range $10^5 \text{ eV} \sim 10^{12} \text{ eV}$. Thus the mass of the quasiparticle in the X-ray laser beams can be produced as $Z$-boson of the electroweak theory of weak interactions. It is possible that $W^+$ and $W^-$ can be originated from another vector boson from the quasiparticle in the X-ray laser beams whose mass is more than 200 GeV.

References:

1. E.Panarella(1972) Lett. Nuovo Cimento 3, 417.

2. E.Panarella(1974) Found. Phys. 4, 227 and Phys.Rev A16, 677.

3. E.Panarella (1986) in Quantum uncertainties, NATO ASI series B162 Physics, edited by W.M.Honig, D.W.Kraft and E.Panarella,237, Plenum press.

4. P.Raychaudhuri (1986) in Quantum uncertainties, NATO ASI series B162 Physics, edited by W.M.Honig, D.W.Kraft and E.Panarella,271, Plenum press.

5. P.Raychaudhuri(1989) Physics Essays 2, 339.

6. P.Raychaudhuri (1993) Ind.J.Theo.Phys. 41, 54.

7. P.Raychaudhuri (1996) Review Bull. Cal.Math.Soc. 4 (1 and 2)47.

8. P.Raychaudhuri (2002) Physics Essays 15, 457.
9. P. Raychaudhuri (2005) Review Bull. Cal. Math. Soc. 12, 11.

10. F. Winterberg (1989) Z. Naturforchung 44a, 243.

11. D. Bernard et al (2000) Eur. Phys. J. D 10, 141.

12. G. Brodin, M Marklund and L. Stenflo (2001) Phys. Rev. Lett. 87, 171801.