Phat Photons and Phat Lasers

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ABSTRACT

The initial theoretical finding that eventually led to laser development was Einstein's prediction, based upon statistical considerations, that the energy of quanta of light be given by Planck's constant times the frequency of the light. A new theoretical development based upon Weyl's gauge field theory predicts that photon energies are quantized with the energy given by $N^2h\nu$. Such quantization of photon energy changes the character of the photon from the Einstein photon that does not have a quantum number. Photon energy that includes a quantum number means that for a given energy the frequency may have more than one value. Conversely, photons of a given frequency may be found that have more energy than the Einstein photon. Further, the phat photons, all at a given frequency will have energy proportional to the number of phat photons and N^2. For these phat photons the electric field strength, which causes breakdown in optical fibers or air, depends linearly on N. Thus, more energy may be transmitted using phat photons of higher quantum numbers than increasing the number of photons of lesser quantum numbers while still keeping the electric field below the breakdown level. Further, while the stimulated and spontaneous emission probabilities are proportional to $1/N^2$ the Rayleigh scattering cross section diminishes by $1/N^8$. This reduction in the scattering cross section means that a laser emitting phat photons with N>1 will lose less energy traveling through the Earth's atmosphere than lasers using N=1. This reduction in energy losses through the atmosphere means increased efficiency for Earth based beamed applications. This presentation discusses the fundamental theory, emission probabilities, and cross section calculations.

Keywords: Photon, Compton effect, Photoelectric effect, Weyl's gauge field theory, scattering cross section

1. INTRODUCTION

The concept of a photon started with Einstein's light quanta[1]. The concept has been the subject of many articles since 1905. The name "photon" was first introduced by Lewis 21 years later[2]. However, both Planck's[3] and Einstein's derivations of the famous relation between energy and frequency, $\varepsilon=h\nu$, came from studies of radiation in thermal equilibrium with a system described by statistical thermodynamics. Planck quantized the equilibrium energy U of an oscillator while Einstein quantized the entropy density per unit volume. In 1917 Einstein wrote, "The properties of elementary processes required by [his momentum fluctuation relation] make it seem almost inevitable to formulate a truly quantized theory of radiation[4]." Einstein was not, and never would be, satisfied with his, and others, inability to obtain such a theory. In 1924, after the experimental evidence of the Compton Effect provided proof of the quantization of light, he wrote, "There are therefore now two theories of light, both indispensable, and-as one must admit today despite twenty years of tremendous effort on the part of theoretical physicists-without any logical connection"[5].

A whole range of practical applications for quanta of light has been developed. Not the least of these applications is the laser; whose applications range from medical lasers, military lasers to the shopping market checkout scanner. Now new predictions about the relationship between the energy and the frequency of a photon provide insight into new properties of photons that may be of benefit in many laser applications.

1.1 Old Physics

Weyl first introduced his geometric scale factor as a means of allowing a more general geometry by which he sought to unify the electromagnetism of Maxwell with the then new theory of gravity presented in Einstein's General Theory of Relativity[6]. In 1922 Schrödinger noticed that all the quantum orbits of a single electron atom produced a unity scale factor[7]. Shortly after Schrödinger published his fundamental work in quantum mechanics, London published a connection between electron orbits and Weyl's scale factor. London first set Weyl's scale factor to unity then showed that, given an electrostatic gauge potential, the only paths possible where those predicted by Schrödinger's quantum mechanical equations[8]. Though the scientific community may have noticed London's work, it was left to Weyl to make

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the next step. Weyl seized upon London's result to elevate his scale factor to the level of a gauge principle[9]. Many researchers have used the gauge principle since 1929. However, the fact that the gauge principle may be used to derive; first, Maxwell's electromagnetism and, secondly, with the additional restriction of a unity scale factor, Schrödinger's wave mechanics has been largely ignored. Perhaps, it may have been comforting to the community that the work of Weyl and London reproduced that of Maxwell and Schrödinger. However, they may have thought it easier just to use the original work.

1.2 A New Look at Old Physics

Weyl's gauge principle may be used to derive Maxwell's electromagnetic field equations[9]. These, in turn, may be used to derive the electromagnetic wave equations. At the same time the gauge principle, when the scale factor is set to unity, requires that the gauge potentials be quantized[10]. To see this conclusion consider that the requirement of a unity Weyl scale factor is given by

$$\frac{\ell}{\ell_0} = \exp\left[\int \phi_j dx^j\right] \equiv 1.$$

The unity scale factor then requires that

$$\int \phi_j dx^j = 2\pi i N \tag{1}$$

where $i = \sqrt{-1}$, N is an integer, and there is no summation over the j's. The ϕ_0 is the electrostatic potential and the ϕ_j, for j=1,2,3 are the components of the gauge vector potential.

London simplified Equation (1) by assuming that only the electrostatic potential be non-zero. London undoubtedly recognized Equation (1) as a line integral and that there would be a different path for every value of *N*. He then showed that the only paths possible for the unity scale factor to be satisfied were those paths given by the solutions to Schrödinger's wave equation.

The exponent of the scale factor may be thought of as having three parts: an integrand (one or more of the respective gauge potentials), a path (which is given by the differentials) and an integral value (the result of integrating the integrand over the path.) Thus, while London showed that the equations of quantum mechanics gave the paths allowed by a quantized exponent, provided the gauge potentials were known, another question might be asked of the exponent with equal expectations with regard to the descriptions of physical phenomena.

As may be recalled, Einstein's objection to Weyl's proposal of using his gauge geometry as a unifying theory of electromagnetism and gravity was primarily based upon the fact that the Weyl manifold was non-integrable. Einstein argued that such a path dependent manifold could not hope to describe such phenomena as atomic states that experimentally were determined to be independent of their history. What Schrödinger recognized and London proved was that the Weyl Quantum Principle, by setting the scale calibration to unity, filtered out gauges that were not integrable in order to leave only those that were integrable. Therefore, those paths, or states, that London showed resulted from imposing Weyl's Quantum Principle, that is, the paths determined by quantum mechanics, were not subjected to the history dependence contained in Einstein's objection. It is important to note that imposing Weyl's Quantum Principle did not select a single path independent state; rather, it stated that an infinite number of states were equally path independent. The states are separated from each other because each one has a different quantum number. Where Einstein may have expected to find a single integrable manifold, Weyl's Quantum Principle produces an infinite number of them.

For a new look at this old line integral, suppose we desire to consider light itself. Light has no electric charge so we must set the electrostatic potential to zero. This leaves us to choose at least one of the vector potential components to be non-vanishing. From a practical point of view it makes no difference which component we choose to be non-zero since we know that light may be polarized to have only one component. Consider the first vector potential component to be non-zero. This requires that Equation (1) become

$$\int \phi_1 dx^1 = 2\pi i N \ . \tag{2}$$

London assumed the gauge potentials were known. We, on the other hand, do not yet know what the first vector potential component may be. However, if we desire to study light we know the path is traveled at the speed of light. Now reconsider Equation (2), while keeping in mind there is only one path for a polarized light wave to travel, and notice that

Equation (2) requires that the vector potential component be quantized by the integer value *N*. We might then write $\phi_1 \equiv N\phi_1'$.

Weyl's gauge principle requires that Maxwell's equations must be satisfied. Maxwell's equations lead to wave equations that must be satisfied for the light we are studying. The wave description allows the discussion of polarization such that an electromagnetic wave traveling along the z-axis may have its electric field directed along the x-axis. Therefore, consider $\phi_0 = \phi_2 = \phi_3 = 0$. The quantization required of the non-zero component of the gauge (vector) potential leads us to write it as

$$\phi_1 = NB\cos 2\pi\left(\frac{z}{\lambda} - \nu t\right) \tag{3}$$

where the dependence upon *z* and *t* were chosen to be sure that the electric field, or

$$E_1(z,t) = \frac{\partial\phi_1(z,t)}{\partial(ct)} = \frac{NB\nu}{c^2}\sin 2\pi\left(\frac{z}{\lambda} - \nu t\right) \tag{4}$$

is a solution of the wave equations. This electric field expression may be used to find the average value of the Poynting vector, since

$$I = \left(\frac{1}{\mu_o}\right)\left\langle E^2\right\rangle. \tag{5}$$

The average value of the square of electric field is given by

$$\left\langle E^2(z,t)\right\rangle = \frac{N^2B^2\nu^2}{c^3}\int_{t=0}^{t=\frac{1}{\nu}}\sin^2\left(\frac{z}{\lambda} - \nu t\right)dt = \frac{N^2B^2\nu}{2c^2}. \tag{6}$$

Therefore,

$$I = \left(\frac{N^2B^2}{2\mu_o hc^3}\right)\nu. \tag{7}$$

Now a quantum of light for which *N=1* would have an energy flow of $I = h\nu$ when

$$B = \sqrt{2\mu_o hc^3}. \tag{8}$$

Einstein's energy relation, for a single light quantum passing through a unit area, is then given by $\varepsilon = h\nu$ when *N=1*. Consider, though, that Equation (7) specifies that the energy of all the quanta of light be given by the basic expression

$$\varepsilon = N^2 h\nu. \tag{9}$$

2. EXPERIMETNAL VERIFICATION

2.1 Hydrogen frequencies

The prediction of quantized photon energy in Equation (9) argues that the frequencies associated with quantum numbers above unity may have already been measured. A look at the National Institute of Standards and Technology web site shows C.E. Moore[11] reported the fundamental frequency for hydrogen was listed with a magnitude of 1,000, the *N=2* frequency showed a magnitude of 80 and the *N=3* frequency magnitude was 12. J. D. Garcia & J. E. Mack[12] reported similar numbers for the helium atom. Further, these frequencies do not have a source noted for them as do the other frequencies reported as these frequencies do not correspond to any known transitions. The predictions of Equation (9) then find verification in data already reported.

2.2 Phat Photoelectric Effect

Einstein offered an explanation of the experimentally determined photoelectric effect by offering his equation that gives the maximum kinetic energy of photo electrons freed by photons of energy $h\nu$ should be given by

$$K_{\max} = h\nu - \phi_o. \tag{10}$$

where ϕ_o is the minimum energy required to free the electron[13].

If we replace Einstein's relation for the energy of the photon with the expression for the phat photon we see that the maximum kinetic energy of the freed electron is given by

$$K_{\max} = N^2 h\nu - \phi_o . \tag{11}$$

In Equation (11) the phat photon quantum number shows that if there are phat photons present the maximum kinetic energy would be very different from that predicted by Einstein.

2.3 Phat Compton Effect

Compton explained the shifted component of the scattered light when x-rays interact with matter by applying Einstein's energy of the photon to the conservation of momentum and energy relations[14]. He assumed that the scattering process could be treated as an elastic collision between a photon and an electron, governed by the two laws of mechanics, the conservation of energy and the conservation of momentum. We shall do the same here except we will use the phat photon energy expression. Let an incident phat photon of energy $N^2h\nu$ collide with an electron initially at rest. The photon is scattered through a angle θ, while the electron recoils in a direction φ. The kinetic energy K given to the electron is $(m-m_o)c^2$ by Einstein's special theory of relativity. If $M^2h\nu_o$ is the frequency of the scattered phat photon, the conservation of energy requires that the sum of the kinetic energy of the electron and the energy of the scattered photon be equal to the energy of the incident photon, or

$$N^2 h\nu = M^2 h\nu_\theta + \left(m - m_o\right)c^2 . \tag{12}$$

Each photon carries momentum equal to its energy $N^2h\nu$ divided by the speed of light c, or h/λ. Since momentum is a vector quantity and is conserved, the x and y components must obey the equations

$$\frac{N^2 h\nu}{c} = \frac{M^2 h\nu_o}{c}\cos\theta + p\cos\varphi \tag{13}$$

and

$$0 = \frac{M^2 h\nu_o}{c}\sin\theta + p\sin\varphi \tag{14}$$

where p is the momentum of the recoil electron. (The plus sign appears with the $\sin\varphi$ because it is assumed all angles are positive when measured counterclockwise form the x axis.)

By using the same analysis as is done in the classical solution of the conservation relations we arrive at the expression for the wavelength shift to be

$$\Delta\lambda = \lambda_\theta - \lambda = \lambda_\theta\left(1 - \frac{N^2}{M^2}\right) + \frac{h}{m_o c}N^2\left(1 - \cos\theta\right) = \lambda_\theta\left(1 - \frac{N^2}{M^2}\right) + 0.02426N^2\left(1 - \cos\theta\right) . \tag{15}$$

Obviously, Equation (15) predicts the wavelength shift of the classical Compton theory when $N=M=1$. Also, it may be seen that when the scattered photon has the same quantum number as the incident photon Equation (15) reduces to

$$\Delta\lambda = +0.02426N^2\left(1 - \cos\theta\right) \tag{16}$$

which argues that for phat photons the wavelength shift differs from the $N=1$ shift by the factor of N^2. Further, since the energy of phat photons depends upon both the frequency and the quantum number, Equation (15) reflects the fact that while the wavelength shift is still independent of the incident frequency it is not independent of the quantum number.

3. BASIS OF A PHAT LASER

The relative number of particles per quantum state at two different energies for a system in thermal equilibrium at temperature T is given, in certain circumstances, by the Boltzmann factor, $e^{-(E_2-E_1)/kT}$. We use this result now to study the behavior of a possibly very important device we will call a *Phat laser* .

Consider transitions between two energy states of an atom in the presence of an electromagnetic field. In the spontaneous emission process, the atom is initially in the upper state of energy E_2 and decays to the lower state of energy E_1 by the emission of a photon of frequency $\nu = \left(E_2 - E_1\right)\big/ N^2 h$.

Let the spectral energy density of the electromagnetic radiation applied to the atoms be $\rho(\nu)$. Consider that there are n_1 atoms in energy state E_1 and n_2 in state E_2 where $E_2 > E_1$. The probability per atom per unit time, or transition rate per atom, that an atom in state *1* will undergo a transition to state *2* (stimulated absorption) clearly will be proportional to the energy density ρ(ν) of the applied radiation at frequency $\nu = {(E_2 - E_1)} \big/ {N^2 h}$. The transition rate for stimulated emission is also proportional to *ρ(ν)*. However, the transition rate for spontaneous emission does not contain *ρ(ν)* because that process does not involve the applied electromagnetic field.

The transition rates also depend on the detailed properties of the atomic states *1* and *2* through the electric dipole moment matrix element. It has been shown, classically, that an oscillating electric dipole will radiate electromagnetic energy at the average rate, $\bar{R}$ where

$$\bar{R} = \frac{4\pi^3 \nu^4}{3\varepsilon_o c^3} p^2$$

with *p* the amplitude of its oscillating electric dipole moment and *ν* the frequency of oscillation. Since we seek to determine the energy carried off by phat photons we must consider the photon energy as $n^2 h\nu$. The rate of emission of phat photons, *R*, is

$$R = \frac{\bar{R}}{N^2 h\nu} = \frac{1}{N^2} \frac{4\pi^3 \nu^3}{3\varepsilon_o h c^3} p^2 .$$

Therefore, we expect that the quantum mechanical rate of spontaneous emission of phat photons to be

$$R_{phat} = \frac{R}{N^2} = \frac{16\pi^3 \nu^3 p_{fi}^2}{\left(N^2 3\varepsilon_o h c^3\right)} \tag{17}$$

where p_{fi} is the matrix element of the electric dipole moment taken between the initial and final states[8].

Hence, the probability per unit time for a transition from state *1* to state *2* can be written as $R_{1\to 2} = {B_{12}\rho(\nu)} \big/ {N^2}$ in which B_{12} is a coefficient, calculated by classical quantum mechanics, that includes the dependence on properties of the states *1* and *2*. The total probability per unit time that an atom in state *2* will undergo a transition to state *1* is the sum of two terms, the probability per unit time A_{21}/N^2 of spontaneous emission and the probability per unit time B_{21} ***ρ(ν)/N²*** of stimulated emission. Again, A_{21} and B_{21} are coefficients whose values depend on the properties of states *1* and *2*, through the appropriate matrix elements. Hence $R_{2\to 1} = \left[A_{21} + B_{21}\rho(\nu)\right]/N^2$.

If now we consider that the n_1 atoms in state 1 and the n_2 atoms in state 2 of the system are in thermal equilibrium at temperature T with the radiation field of energy density ρ(ν), then the total absorption rate for the system $n_1 R_{1\to 2}$ and the total emission rate $n_2 R_{2\to 1}$ must be equal. That is $n_1 R_{1\to 2} = n_2 R_{2\to 1}$. Thus we have $n_1 \frac{B_{12}\rho(\nu)}{N^2} = n_2 \frac{\left[A_{21} + B_{21}\rho(\nu)\right]}{N^2}$.

If we solve this equation for ρ(ν) we obtain

$$\rho(\nu) = \frac{\dfrac{A_{21}}{B_{21}}}{\dfrac{n_1}{n_2}\dfrac{B_{12}}{B_{21}} - 1} .$$

We now assume we can use the Boltzmann factor, with $N^2 h\nu = E_2 - E_1$ to obtain $\frac{n_1}{n_2} = e^{(E_2 - E_1)/kT} = e^{N^2 h\nu/kT}$ so that we may write

$$\rho(\nu) = \frac{\dfrac{A_{21}}{B_{21}}}{\dfrac{B_{12}}{B_{21}} e^{N^2 h\nu/kT} - 1} . \tag{18}$$

This equation, giving the spectral energy density of radiation of frequency ν that is in thermal equilibrium at temperature *T* with atoms of energies E_1 and E_2 must be consistent with the phat photon blackbody spectrum. Hence, we conclude that

$$\frac{B_{12}}{B_{21}} = e^{\left(1-N^2\right)h\nu/kT} \tag{19}$$

and

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3} . \tag{20}$$

These results are similar to the results first obtained by Einstein in 1917, and therefore the coefficients, for $N=1$ and $\delta=0$ are called the *Einstein A and B coefficients.* Note that the argument does not give us values of the coefficients, but only their ratios. However, if we compute the spontaneous emission coefficient A_{21} from quantum mechanics, we then can obtain the other coefficients from these formulas.

There is much of physical interest here. For one thing, we find from Equation (19) that the coefficients of stimulated emission and stimulated absorption are equal only for the Einstein photon for which $N=1$. For another, we see from Equation (20) that the ratio of the spontaneous emission coefficient to the stimulated emission coefficient varies with frequency as ν^3. This means, for example, that the bigger the energy difference between the two states, the much more likely is spontaneous emission compared to stimulated emission. Still another result is that we can obtain the ratio of the probability A_{21} of spontaneous emission to the probability $B_{21}\,\rho(\nu)$ of stimulated emission, namely

$$\frac{A_{21}}{B_{21}\rho\left(\nu\right)} = e^{h\nu/kT} - 1 \tag{21}$$

just as it is for the Einstein photon. This shows that, for atoms in thermal equilibrium with phat radiation, spontaneous emission is far more probable than stimulated emission if $h\nu >> kT$ regardless of the value of N. Since this condition applies to electronic transitions in both atoms and molecules, stimulated emission can be ignored in such transitions. Stimulated emission can become significant, however, if $h\nu = kT$, and it may be dominant if $h\nu << kT$, a condition that applies at room temperature to atomic transitions in the microwave region of the spectrum where ν is relatively small.

3.1 Phat Laser

We are now in a position to understand how the concept of phat lasers compares to what we currently understand about ordinary lasers and masers. In general, the ratio of the emission rate to the absorption rate can be written as $n_2 R_{2\to1} / n_1 R_{1\to2}$ or

$$\frac{n_2 R_{2\to1}}{n_1 R_{1\to2}} = \frac{n_2 A_{21} + n_2 B_{21}\rho\left(\nu\right)}{n_1 B_{12}\rho\left(\nu\right)} = \left[\frac{B_{21}}{B_{12}} + \frac{B_{21}A_{21}}{B_{12}B_{21}\rho\left(\nu\right)}\right]\frac{n_2}{n_1} = \frac{B_{21}}{B_{12}}\frac{n_2}{n_1}e^{h\nu/kT} = \frac{n_2}{n_1}e^{N^2 h\nu/kT} \tag{22}$$

If we have energy states such that $E_2 - E_1 << kT$, or $N^2 h\nu << kT$, then Equation (22) shows that we obtain

$$\frac{n_2 R_{2\to1}}{n_1 R_{1\to2}} \approx \frac{n_2}{n_1} .$$

This result is general in the sense that we have not assumed an equilibrium situation. In situations of thermal equilibrium, where the Boltzmann factor applies, we expect $n_2 \prec n_1$. But in non-equilibrium situations any ratio is possible in principle. If now we have a means of inverting the normal population of states so that $n_2 \succ n_1$ then the emission would exceed the absorption rate. This means that the applied radiation of frequency $\nu = \frac{E_2 - E_1}{N^2 h}$ will be *amplified* in intensity by the interaction process, more such radiation emerging than entering. Of course, such a process will reduce the population of the upper state until equilibrium is reestablished. In order to sustain the process, therefore, we must use some method to maintain the *population inversion* of the states. Devices that do this are called lasers or masers, depending upon the portion of the electromagnetic spectrum in which they operate.

4. RAYLEIGH SCATTERING

4.1 Rayleigh Scattering from a constant stimulated energy level

Rayleigh scattering is due to the displacement of bound electrons by the incident electric field. The incident harmonic field induces a dipole in the molecule whose polarizability determines the displacement. The induced dipole oscillates at the same frequency as the incident radiation. This radiation constitutes the scattered light.

We begin the derivation of the Rayleigh scattering cross section for phat photons by assuming that each molecule contains electrons that can be acted on by the oscillating electric field of the laser beam and that the wavelength of the beam is considerably larger than the size of the molecule. This latter assumption permits us to ignore the spatial variation of the electric field $\vec{E}$ over the molecular charge distribution. The beam is furthermore assumed to be incident along the *z* direction and is polarized along the *x* direction. The scalar equation of motion of each oscillating electron of such a system is of the familiar form

$$\ddot{x} + \Gamma\dot{x} + \omega_o^2 x = \left(\frac{e}{m}\right) NE_o e^{-i\left(\omega/N^2\right)t}, \tag{23}$$

where N is the quantum number of the phat photon, NE_o is the magnitude of the electric field of the phat photon, and $\left(\omega/N^2\right)$ is the angular frequency of the phat laser beam according to the energy of the phat photon as given by

$$\in = N^2 h\omega, \tag{24}$$

where $\in$ is the energy step involved and is taken to be a constant in the immediately following investigation.

If we now follow the classical analysis of Rayleigh scattering we arrive at

$$\sigma_{sp} = \frac{\sigma_s}{N^8}. \tag{25}$$

Thus, we see that the scattering cross section for phat lasers is inversely proportional to the phat quantum number to the eighth power[15].

4.2 Rayleigh Scattering Cross Section independent of Phat Photon Source

In the previous section the energy step was taken to be held fixed throughout the calculation. Now we would like to investigate the comparison of the Rayleigh scattering cross section between phat photons of the same frequency as a function of the photon quantum number. In this case we find that equation of motion for each oscillating electron of the system to be of the form

$$\ddot{x} + \Gamma\dot{x} + \omega_o^2 x = \left(\frac{e}{m}\right) NE_o e^{-i\omega t}, \tag{26}$$

where N and ω determine the energy of the phat photon in accordance with Equation (24).

By assuming a steady-state solution of $x = x_o \exp\left[-i\omega t\right]$, we find the solution to Equation (26) to be

$$x = \frac{\left(\frac{e}{m}\right) NE_o e^{[-i\omega t]}}{\omega_o^2 - \omega^2 - i\Gamma\omega} = x_o e^{[-i\omega t]}. \tag{27}$$

Using Equation (27) in the same procedure as above we find that the Rayleigh scattering cross section to be the classical cross section, or

$$\sigma_s = \frac{f e^4 \lambda_o^4}{6\pi\varepsilon_o^2 m^2 c^4} \frac{1}{\lambda^4}. \tag{28}$$

5. CONCLUSIONS

5.1 Photon definition

A photon may be defined as a gauge vector potential with the quantum number set to unity and which satisfies the wave equation. Further, the light quanta come from Weyl's quantum principle which also provides the basis for radiation and needs no connection to statistics or thermodynamics. Weyl's quantum principle provides the logical connection between waves and quanta that Einstein was trying to find.

5.2 Spontaneous emission

The probability of spontaneous emission of phat photons is inversely proportional to the square of the phat quantum number, or $1/N^2$. Phat photons may be found to be emitted from all lasers with lower intensities at the phat frequencies with the higher phat quantum numbers. These should be looked for in the output of an existing laser.

5.3 Rayleigh scattering cross section

Since the scattering cross section compares the energy scattered to the incident energy, the photon quantum number does not enter into the Rayleigh scattering cross section when comparing the scattering of photons of any quantum number. That is; the Rayleigh scattering cross section depends only upon the frequency of the incident beam.

On the other hand, should one desire to compare the Rayleigh scattering cross section for a given laser that may be set up to operate with any photon quantum number, the results are drastically different. In this case the energy of the photon, and the total beam energy, remains the same independent of the quantum number. However, the frequency must decrease as $1/N^2$, or the wavelength must increase as N^2. This means that for any given laser less energy is lost due to Rayleigh scattering by the atmosphere thereby providing more energy on target, though at increased wavelength. The phat photon scattering cross section is given by $\sigma_{sp} = \dfrac{\sigma_s}{N^8}$.

5.4 Increased energy of transmission

Thermal blooming depends upon the electric field which is proportional to the photon quantum number N. On the other hand the photon energy is proportional to N^2. Therefore, a reduction in the number of phat photons by a ratio of $1/N$ compared to the number of Einstein photons that lies just below the thermal blooming threshold will be able to transport N times the energy that is possible by Einstein photons.

Because the breakdown of fiber optics is caused by the electric field the same increased energy of transmission seen for thermal blooming is true for the energy of transmission through fiber optics. This means that by using phat photons the energy through fiber optics may be increased as N before breakdown of the fiber.

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