THEORY OF THE EVANS / MORRIS SHIFTS WITH CONSERVATION OF ENERGY AND MOMENTUM: PHOTON MASS.

by

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ABSTRACT

Using a monochromatic beam and a Planck distribution of n photons it is shown that the Evans / Morris frequency shifts can be explained with simple conservation of energy and momentum in refraction and reflection. The fundamental conservation laws produce red shifts and blue shifts as observed experimentally. The theory is used to produce an estimate of photon mass in order of magnitude agreement with previous work in this series based on light deflection from the sun. A finite photon mass means that the B(3) field of ECE theory exists in nature.

Keywords: ECE theory, Evans / Morris frequency shifts, conservation laws.

UFT 279

1. INTRODUCTION

In the immediately preceding paper of this series of two hundred and seventy nine papers to date {1 - 10} it was shown that a single photon theory gives a plausible explanation of the Evans / Morris frequency shifts {11} that occur in all materials. These shifts are distinguished experimentally from fluorescence through the fact that they occur in non absorbing materials. Blue shifts and red shifts have been observed by Evans and Morris and it is shown in Section 2 that both types of shift can be explained straightforwardly by simple conservation laws applied with an n photon monochromatic beam in ordinary refraction and reflection. The theory of this paper shows that absorption is not necessary to produce these shifts, some of which have been observed to be very large shifts {11}. Shifts are observed experimentally in glasses in which there is no absorption, so there is no fluorescence. Blue shifts are observed experimentally as well as red shifts, all data are reported to be reproducible and repeatable. The great majority of fluorescence shifts are towards the red, but occasionally a blue shift is attributed to fluorescence in a molecule such as tryptophan.

In Section 2 the equations of conservation of energy and linear momentum are defined for an n photon monochromatic beam with a Planck distribution. Conservation of energy is applied to simple reflection and refraction. The energy of the incident beam is the sum of the energies of the refracted and reflected beams. The incident linear momentum is equal to the vector sum of the linear momenta of the reflected and refracted beams. This simple but powerful theory is sufficient to describe the Evans / Morris effects. A quantitative comparison is made in Section 3, where a numerical analysis is described, along with graphics. Using this theory, an estimate of the photon mass is made from the conservation laws. The order of magnitude of the estimated photon mass is similar to that deduced earlier in this series {1 - 10} from the correct ECE theory of light deflection due to gravitation.

2. CONSERVATION OF TOTAL ENERGY AND MOMENTUM

As usual this paper should be read with its background notes (for UFT279 on www.aias.us). Notes 279(1) and 279(2) show how continuity at the boundary can be satisfied with variable frequency. The dogmatic theory asserts {12} that the frequencies of the incident, reflected and refracted beams are the same. This dogma is immediately counter indicated experimentally by the Evans / Morris effects {11}, and theoretically by simple and fundamental conservation of total energy and momentum. Notes 279(3) and 279(4) develop the basic concepts of the Planck distribution. Notes 279(5) to 279(8) develop the hew theory described as follows.

Consider an incident monochromatic beam of n photons of angular frequency ω which is refracted and reflected at a boundary between two materials. The refracted beam has an angular frequency ω_1, and the reflected beam has an angular frequency ω_2. The average energy of the incident beam is given by the Planck distribution:

$$\langle \hbar\omega \rangle = \left(\frac{x}{1-x}\right)\hbar\omega \quad -(1)$$

where:

$$x = \exp\left(-\frac{\hbar\omega}{kT}\right). \quad -(2)$$

Here $\hbar$ is the reduced Planck constant, k is the Boltzmann constant, and T the temperature. Similarly, the average energy of the refracted beam is:

$$\langle \hbar\omega_1 \rangle = \left(\frac{x_1}{1-x_1}\right)\hbar\omega_1 \quad -(3)$$

and the average energy of the reflected beam is:

$$\langle \hbar\omega_2 \rangle = \left(\frac{x_2}{1-x_2}\right)\hbar\omega_2 \quad -(4)$$

By conservation of total energy:

$$\langle \hbar\omega \rangle = \langle \hbar\omega_1 \rangle + \langle \hbar\omega_2 \rangle \quad -(5)$$

and it is immediately clear that the three frequencies cannot be the same. The dogma is totally wrong, not for the first time in the history of human thought. It follows that:

$$\left(\frac{x}{1-x}\right)\omega = \left(\frac{x_1}{1-x_1}\right)\omega_1 + \left(\frac{x_2}{1-x_2}\right)\omega_2 . \quad -(6)$$

Define the incident wave vector as:

$$\underline{\kappa} = \kappa_x \underline{i} + \kappa_y \underline{j} \quad -(7)$$

where:

$$\kappa_x = \kappa \sin\theta \quad -(8)$$

$$\kappa_y = \kappa \cos\theta \quad -(9)$$

and where θ is the angle of incidence. Then:

$$\underline{\kappa} = \kappa\left(\underline{i}\sin\theta + \underline{j}\cos\theta\right). \quad -(10)$$

If the incident medium is air, then to an excellent approximation, the magnitude of the wave-vector is given by:

$$\kappa = \frac{\omega}{c} \quad -(11)$$

where c is the vacuum speed of light. Therefore the wave-vector averaged over a Boltzmann distribution of n photons is:

$$\langle \underline{\kappa} \rangle = \left(\frac{x}{1-x}\right)\frac{\omega}{c}\left(\underline{i}\sin\theta + \underline{j}\cos\theta\right) \quad -(12)$$

Similarly the refracted wave-vector is:

$$\langle \underline{\kappa}_1 \rangle = \left(\frac{x_1}{1-x_1} \right) \frac{\omega_1}{V_1} \left(\underline{i} \sin\theta_1 + \underline{j} \cos\theta_1 \right) \quad - (13)$$

where θ_1 is the angle of refraction and where:

$$V_1^2 = \frac{1}{\epsilon\mu} \quad - (14)$$

is the phase velocity of the medium of refraction of permittivity ϵ and permeability μ.

Thirdly, the reflected wave vector is:

$$\langle \underline{\kappa}_2 \rangle = \left(\frac{x_2}{1-x_2} \right) \frac{\omega_2}{c} \left(\underline{i} \sin\theta_2 - \underline{j} \cos\theta_2 \right) \quad - (15)$$

where θ_2 is the angle of reflection. Experimentally, Snell's Law gives:

$$\theta = \theta_2 \quad - (16)$$

and

$$\sin\theta = n_1 \sin\theta_1 \quad - (17)$$

where n_1 is the refractive index of the medium in which refraction takes place. Here:

$$n_1^2 = \frac{\epsilon_1\mu_1}{\epsilon_0\mu_0} \quad - (18)$$

where ϵ_0 is the vacuum permittivity in S. I. Units and μ_0 the vacuum permeability. The relative permittivity and permeability are:

$$\mu_r = \frac{\mu}{\mu_0}, \quad \epsilon_r = \frac{\epsilon}{\epsilon_0} \quad - (19)$$

The de Broglie wave particle dualism quantizes the linear momentum in terms of the wave-vector:

$$\underline{p} = \hbar \underline{\kappa} \quad -(20)$$

so the law of conservation of total momentum in reflection and refraction is:

From Eq. (21): $$\langle \underline{\kappa} \rangle = \langle \underline{\kappa}_1 \rangle + \langle \underline{\kappa}_2 \rangle \quad -(21)$$

$$\langle \underline{\kappa}_2 \rangle = \langle \underline{\kappa} \rangle - \langle \underline{\kappa}_1 \rangle \quad -(22)$$

so:

$$\langle \underline{\kappa}_2 \rangle \cdot \langle \underline{\kappa}_2 \rangle = \langle \underline{\kappa} \rangle \cdot \langle \underline{\kappa} \rangle + \langle \underline{\kappa}_1 \rangle \cdot \langle \underline{\kappa}_1 \rangle - 2 \langle \underline{\kappa} \rangle \cdot \langle \underline{\kappa}_1 \rangle \cos \theta_3 \quad -(23)$$

where

$$\theta_3 = \theta - \theta_1 \quad -(24)$$

is the angle between $\underline{\kappa}$ and $\underline{\kappa}_1$. From Eqs. (12), (14) and (15):

$$\langle \underline{\kappa} \rangle \cdot \langle \underline{\kappa} \rangle = \left(\frac{x}{1-x} \right)^2 \left(\frac{\omega}{c} \right)^2 \quad -(25)$$

$$\langle \underline{\kappa}_1 \rangle \cdot \langle \underline{\kappa}_1 \rangle = \left(\frac{x_1}{1-x_1} \right)^2 \left(\frac{\omega_1}{V_1} \right)^2 \quad -(26)$$

$$\langle \underline{\kappa}_2 \rangle \cdot \langle \underline{\kappa}_2 \rangle = \left(\frac{x_2}{1-x_2} \right)^2 \left(\frac{\omega_2}{c} \right)^2 \quad -(27)$$

and:

$$\langle \underline{\kappa} \rangle \cdot \langle \underline{\kappa}_1 \rangle = \left(\frac{x}{1-x} \right) \left(\frac{x_1}{1-x_1} \right) \frac{\omega \omega_1}{c V_1} \cos \theta_3 . \quad -(28)$$

It follows that:

$$\left(\frac{x_2}{1-x_2}\right)^2\left(\frac{\omega_2}{c}\right)^2 = \left(\frac{x}{1-x}\right)^2\left(\frac{\omega}{c}\right)^2 + \left(\frac{x_1}{1-x_1}\right)^2\left(\frac{\omega_1}{v_1}\right)^2 - 2\left(\frac{x}{1-x}\right)\left(\frac{x_1}{1-x_1}\right)\frac{\omega\omega_1}{c v_1}\left(\cos\theta\cos\theta_1 + \sin\theta\sin\theta_1\right) \quad -(29)$$

where an angle formula gives the self consistent result:

$$\cos\theta\cos\theta_1 + \sin\theta\sin\theta_1 = \cos\left(\theta - \theta_1\right). \quad -(30)$$

Eqs. (6) and (29) must be solved simultaneously. When this is done numerically as in Section 3, the refracted frequency and reflected freqeuncy can each be expressed in terms of the incident frequency ω , giving the Evans / Morris shifts.

In these equations:

$$v_1^2 = \frac{1}{\epsilon_1\mu_1}, \quad c^2 = \frac{1}{\epsilon_0\mu_0}, \quad -(31)$$

$$\frac{1}{c v_1} = \left(\epsilon\mu\,\epsilon_0\mu_0\right)^{1/2}$$

so it follows that:

$$n_1^2 = \epsilon_1\mu_1/(\epsilon_0\mu_0), \quad v_1 = c/n_1, \quad -(32)$$

$$c v_1 = \frac{c^2}{n_1}, \quad \frac{1}{v_1^2} = \frac{n_1^2}{c^2}.$$

Therefore Eq. (29) becomes:

$$\left(\frac{x_2}{1-x_2}\right)^2\omega_2^2 = \left(\frac{x}{1-x}\right)^2\omega^2 + n_1^2\left(\frac{x_1}{1-x_1}\right)^2\omega_1^2 - 2\left(\frac{x}{1-x}\right)\left(\frac{x_1}{1-x_1}\right)n_1\omega\omega_1\cos\theta_3 \quad -(33)$$

In general the refractive index is complex valued:

$$n_1 = n_1' + i n_1'' \quad -(34)$$

so its real and imaginary parts can be expressed in terms of the relative permittivity and dielectric loss as follows, assuming that the permeability is real valued and about unity:

$$n_1'^2 = \frac{1}{2}\left(\epsilon_{1r}' + \left(\epsilon_{1r}'^2 + \epsilon_{1r}''^2\right)^{1/2}\right) \quad -(35)$$

and:

$$n_1'' = \frac{\epsilon_{1r}''}{2n_1'}, \quad n_1'^2 - n_1''^2 = \epsilon_{1r}'. \quad -(36)$$

In general, the simultaneous solution of Eqs. (6) and (33) requires numerical methods, but the theory can be simplified or "linearized" by assuming:

$$\frac{x}{1-x} \approx 1 \quad -(37)$$

and:

$$\omega \approx 6.1051 \times 10^{12}\ \mathrm{Hz}, 32.39\ \mathrm{cm}^{-1} \quad -(38)$$
$$\text{at } T = 293\ \mathrm{K}$$

As shown in Section 3, these assumptions hold to an excellent approximation in the relevant temperature range. The linearized theory produces:

$$A\omega = A_1\omega_1 + A_2\omega_2 \quad -(39)$$

and

$$A_2^2\omega_2^2 = A^2\omega^2 + n_1^2 A_1^2\omega_1^2 - 2AA_1 n_1 \omega\omega_1 \cos(\theta - \theta_1) \quad -(40)$$

where:

$$A = 1, \quad A_1 = -\left(\frac{x_1}{1-x_1}\right), \quad A_2 = \left(\frac{x_2}{1-x_2}\right). \quad -(41)$$

It is shown in Section 3 that simultaneous solution of these equations leads to a quartic with four roots, and the linearized theory is capable of giving blue shifts as well as red shifts as observed experimentally {11}. A quantitative comparison is given in Section 3 for olive oil, giving acceptable results.

It is easily shown as follows that Snell's Law is compatible with varying frequency. By conservation of energy and momentum the phase law is:

$$\omega t - \underline{k}\cdot\underline{r} = (\omega_1 + \omega_2)t - (\underline{k}_1 + \underline{k}_2)\cdot\underline{r}, \quad -(42)$$

$$\omega = \omega' + \omega'' \quad -(43).$$

As a result of Eq. (43):

$$\underline{k}\cdot\underline{r} = (\underline{k}' + \underline{k}'')\cdot\underline{r} \quad -(44)$$

i. e. :

$$k_x X + k_y Y = k_x' X + k_y' Y + k_x'' X + k_y'' Y. \quad -(45)$$

Experimentally, Snell's Law is given by Eqs. (16) and (17). Here:

$$k_x = k\sin\theta, \quad k_{1x} = k_1 \sin\theta_1, \quad k_{2x} = k_2 \sin\theta_2 \quad -(46)$$

so:

$$(k - k_2)\sin\theta = k_1 \sin\theta_1 \quad -(47)$$

from Eq. (44). Therefore the refractive index is defined from conservation of energy and momentum as:

$$n' = \frac{k_1}{k - k_2}. \quad -(48)$$

In the incorrect dogma {12} the refractive index was defined as:

$$n_1 = \frac{\kappa_1}{\kappa} \quad -(49)$$

with:

$$\omega =?\ \omega_1 =?\ \omega_2 . \quad -(50)$$

The photon mass can be determined straightforwardly from ordinary reflection and refraction by using:

$$\omega_2^2 = \omega^2 + \omega_1^2 - 2\omega\omega_1 \quad -(51)$$

and

$$\kappa_2^2 = \kappa^2 + \kappa_1^2 - 2\kappa\kappa_1 \cos\theta_3 \quad -(52)$$

The photon of mass m obeys the Einstein energy equation:

$$E^2 = c^2 p^2 + m^2 c^4 \quad -(53)$$

with the de Broglie / Einstein / Planck quantization

$$E = \hbar\omega, \ \underline{p} = \hbar\underline{\kappa} . \quad -(54)$$

It follows that:

$$\omega_2^2 - c^2\kappa_2^2 = \omega_1^2 - c^2\kappa_1^2 = \omega^2 - c^2\kappa^2 = \left(\frac{mc^2}{\hbar}\right)^2 := x \quad -(55)$$

and that:

$$4c^2\kappa^2\kappa_1^2 \cos^2\theta_3 = (2\omega\omega_1 - x)^2 \quad -(56)$$

where:

$$\kappa^2 = \left(\frac{\omega}{c}\right)^2 - \left(\frac{mc}{\hbar}\right)^2 \quad -(57)$$

and:

$$\kappa_1^2 = \left(\frac{\omega_1}{c}\right)^2 - \left(\frac{mc}{\hbar}\right)^2 \quad -(58)$$

It follows that:

$$4\left(\omega^2 - x\right)\left(\omega_1^2 - x\right)\cos^2\theta_3 = \left(2\omega\omega_1 - x\right)^2 \quad -(59)$$

which is an equation for photon mass in terms of the incoming and refracted frequencies.

This equation is solved numerically in Section 3 to show that the photon mass estimated with this very simple method is similar in order of magnitude to the photon mass estimated from light deflection due to gravitation in ECE theory {1 - 10}.

3. NUMERICAL SOLUTIONS AND GRAPHICS

Section by Dr. Horst Eckardt.

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Theory of the Evans/Morris shifts with conservation of energy and momentum: photon mass

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3 Numerical solutions and graphics

3.1 Solutions of linearized theory

As shown in section 2, application of momentum conservation leads to the relation (33) between frequency of incident light ω, refracted light ω_1 and reflected light ω_2. Together with Eq.(6) from energy conservation, one of the frequencies can be eliminated so that relations $\omega_1(\omega, \theta)$ and $\omega_2(\omega, \theta)$ can be computed in principle. Since the frequencies occur in the exponential factors of the Boltzmann distribution, no analytic solution is possible. However we can make a linearized approach as following. The probability factor is given by

$$P = \frac{x}{1-x} \tag{60}$$

ω	y	x	P	$(1-y)/y$
1.0E+8	2.60693E-6	9.99997E-1	3.83593E+5	3.83592E+5
1.0E+9	2.60693E-5	9.99974E-1	3.83588E+4	3.83583E+4
1.0E+10	2.60693E-4	9.99739E-1	3.83543E+3	3.83493E+3
1.0E+11	2.60693E-3	9.97396E-1	3.83093E+2	3.82593E+2
1.0E+12	2.60693E-2	9.74268E-1	3.78615E+1	3.73593E+1
1.0E+13	2.60693E-1	7.70517E-1	3.35763E+0	2.83593E+0
1.0E+14	2.60693E+0	7.37607E-2	7.96346E-2	-6.1641E-1
1.0E+15	2.60693E+1	4.76704E-12	4.76704E-12	-9.6164E-1

Table 1: Probability P and linear approximation for $T = 293\ K$.

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with

$$x = e^{-y}, \tag{61}$$

$$y = \frac{\hbar\omega}{kT}. \tag{62}$$

Using the first two terms of the series expansion of the exponential function we obtain for (61) and (60):

$$x = 1 - y, \tag{63}$$

$$P = \frac{1-y}{y}. \tag{64}$$

The quality of this linearization can be assessed from the examples in Table 1. P is shown from the microwave over infrared to the optical frequency range of ω. As long as x is near to unity, the approximation is valid. For the temperature of $T = 293\ K$ used, this holds up to the far infrared. When temperature is significantly lowered, this is valid only in the microwave region (not shown). In general the linear approximation works well when

$$\hbar\omega << kT. \tag{65}$$

In the following we set the abbreviation

$$f_T = \frac{1}{k\,T} \tag{66}$$

for the temperature factor. With the linear approximation, Eq.(33) remains of second order. For ω_1 we obtain the two solutions

$$\omega_1 = \frac{\omega_0\,\left(2\,n_1\cos\left(\theta_3\right) - 2\right)\,\hbar\,f_T - 2\,n_1\cos\left(\theta_3\right) - n_2^2 + n_1^2 + 1}{\left(n_2^2 - n_1^2 + 1\right)\,\hbar\,f_T}, \tag{67}$$

$$\omega_1 = \frac{1}{\hbar\,f_T} \tag{68}$$

where we used $\omega_0 := \omega$ for reasons of computer algebra. Correspondingly, there are two solutions for ω_2:

$$\omega_2 = \frac{\omega_0\,\left(2\,n_1\cos\left(\theta_3\right) + n_2^2 - n_1^2 - 1\right)\,\hbar\,f_T - 2\,n_1\cos\left(\theta_3\right) + 2}{\left(n_2^2 - n_1^2 + 1\right)\,\hbar\,f_T}, \tag{69}$$

$$\omega_2 = \omega_0. \tag{70}$$

There is a non-trivial and a trivial solution in each case. The refraction index was split into a real part n_1 and an imaginary part n_2 so that the squared modulus is

$$n^2 = n_1^2 - n_2^2. \tag{71}$$

This was inserted instead of a simple n_1^2 used in section 2.

Analysing the results of the linearized theory, we see that the trivial solutions are consistent. Inserting (68) and (70) into the energy equation (6) we find that this equation is fulfilled, i.e. energy conservation on the statistical level. The two non-trivial solutions of ω_1 and ω_2 each have been graphed in Fig. 1 and Fig. 2 for the parameters

$$\begin{aligned} n_1 &= 1.5, \\ n_2 &= 0, \\ T &= 293\ K, \\ \omega_0 &= 10^{-12}/s. \end{aligned}$$

This is in the far infrared where the linear approximation is valid. Adding the refracted and reflected frequency expressions for all solutions, we find the results shown in Fig. 3 for the four possible combinations. There is energy conservation only if appropriate solutions are combined (either the trivial or the non-trivial solutions). The conserved energy frequency is about $7 \cdot 10^{12}/s$ which is much higher than ω_0 because we are dealing with a statistical ensemble.

3.2 Temperature effects and one-photon theory

In Fig. 4 the effect of the temperature is shown for the refracted frequency. Enhancing the temperature means that there are more photons and the average frequency is higher. There is a change of curve characteristics between $300K$ and $30K$. For low temperatures, the frequency drops with an incresing angle of refraction. The curve for $3K$ is near to the one photon limit whose curve is also shown for comparison. There is a continuous transition to this limit as to be expected.

3.3 Complex index of refraction

With permittivity and dielectric loss in a material, a complex-valued dielectric constant is to be used from which the complex refraction index can be calculated by Eqs.(35-36) (real part and imaginary part of n is denoted by n_1 and n_2, correspondingly for ϵ):

$$n_1 = \sqrt{\frac{1}{2}\left(\epsilon_1 + \sqrt{\epsilon_1^2 + \epsilon_2^2}\right)}, \tag{72}$$

$$n_2 = \frac{\epsilon_2}{2\, n_1}, \tag{73}$$

$$n_1^2 - n_2^2 = \epsilon_1. \tag{74}$$

As an example we show some values of these quantities in Table 2. An increase of ϵ_2 leads to an increase of n_1 even if the real part ϵ_1 remains the same. Also the modulus of the refraction index $n = \sqrt{n_1^2 - n_2^2}$ is always the same.

The refracted and reflected frequencies have been graphed for three examples in Fig. 5. The three curve pairs have been calculated for

$$n_1 = 1.5, \quad n_2 = 0.0, \tag{75}$$

$$n_1 = 1.589, \quad n_2 = 0.524, \tag{76}$$

$$n_1 = 1.771, \quad n_2 = 0.941 \tag{77}$$

and an input frequency of $\omega_0 = 10^{12}/s$. As can be seen, the difference between refracted and reflected frequency increases with growing dielectric loss ϵ_2. This

ϵ_1	ϵ_2	n_1	n_2	$n = \sqrt{n_1^2 - n_2^2}$
2.25	0.0	1.500	0.000	1.5
2.25	0.333	1.504	0.111	1.5
2.25	0.667	1.516	0.220	1.5
2.25	1.0	1.535	0.326	1.5
2.25	1.3333	1.560	0.427	1.5
2.25	1.6667	1.589	0.524	1.5
2.25	2.0	1.622	0.617	1.5
2.25	2.3333	1.657	0.704	1.5
2.25	2.6667	1.694	0.787	1.5
2.25	3.0	1.732	0.866	1.5
2.25	3.3333	1.771	0.941	1.5

Table 2: Complex dielectric constant and refraction index for some sample values.

leads to a total disappearance of the refracted beam, a kind of total reflection. In that case the reflected frequency is higher than the incident frequency ω_0. This is a blue shift by reflection, so blue shifts are possible in addition to red shifts in dielectric materials. There is always an angle θ where refracted and reflected frequency cross over. At the crossing angle, both frequencies are equal.

3.4 Refraction in olive oil

For virgin olive oil the refraction of three input frequencies has been found by G. J. Evans and T. Morris to be shifted to the same line of 680 nm [11]. This line corresponds to a chlorophyll molecule chemically bound in the oil. The shifts have been observed first by Robert Fosbury [13] who interpreted them as fluorescence effects. We thank Dennis and Russell Davis for hinting us to this. Here we give an alternative explanation by frequency shifts being always present in refraction and reflection.

There are different values for the permittivity of olive oil in the literature, these certainly depend on the particular nature of the oil. Our first calculation was for a real-valued refraction index of $n_1 = 1.4665$. This gives the lines of the refraction frequencies graphed in Fig. 6. We used the one-photon theory because we are in the optical range here. For the upper two lines there is an angle of incidence θ where the experimental value of 680 nm can be met. Another value of permittivity from the literature is $\epsilon_1 = 3.252$, which corresponds to $n_1 = 1.959$, being significantly higher. The results for this permittivity are shown in Fig. 7. Obviously, only the 404 nm incident frequency is able to reproduce the observed refraction. However, one can assume frequency-dependent permittivities. These will highly depend on the chemical structure of the oil. A parameter choice as in Table 3 allows refraction to occur at $\theta = 0$ (perpendicular incidence) for all three investigated frequencies at the oberserved 680 nm line, see Fig.8. It is possible to introduce an imaginary part ϵ_2. Then ϵ_1 has to be increased appropriately to reproduce the same curves in Fig. 8. We did this for the 404 nm curve as shown in the second line of Table 3.

λ	ω_0	ϵ_1	ϵ_2	n_1	n_2
404 nm	$4.66 \cdot 10^{15}$ /s	5.6	0.0	2.366	0.0
		6.0	2.0	2.482	0.402
532 nm	$3.54 \cdot 10^{15}$ /s	2.4	0.0	1.549	0.0
630 nm	$2.99 \cdot 10^{15}$ /s	1.35	0.0	1.162	0.0

Table 3: Permittivity and dielectric loss parameters used for Fig. 10.

3.5 Estimation of photon mass

The photon mass can be determined as a function of refracted frequency ω_1 and angular difference θ_3 between incoming and refracted angle. We do this in the one-photon approximation without statistics as derived in section 2. Eq.(59) is a quadratic equation for x defined by

$$x = \left(\frac{m\ c^2}{\hbar}\right)^2 . \tag{78}$$

Eq.(59) has the two solutions

$$\begin{aligned} x_{1,2} = {} & \frac{2}{4\cos(\theta_3)^2 - 1}\Big[\pm \cos(\theta_3) \cdot \\ & \sqrt{(\omega_1^4 - 2\,\omega_0^2\,\omega_1^2 + \omega_0^4)\ \cos(\theta_3)^2 - 2\,\omega_0\,\omega_1^3 + 5\,\omega_0^2\,\omega_1^2 - 2\,\omega_0^3\,\omega_1} \\ & + \left(\omega_1^2 + \omega_0^2\right)\ \cos(\theta_3)^2 - \omega_0\,\omega_1\Big]. \end{aligned} \tag{79}$$

The mass values then are given by

$$m_{1,2} = \frac{\hbar}{c^2}\sqrt{x_{1,2}}. \tag{80}$$

The first solution has only a very limited validity range (real valued solution) for high θ_3 values, see Fig. 9. The second solution (Fig. 10) is defined nearly everywhere in the definition range of θ_3 and is minimal at the refraction frequency of the input light with $10^{15}/s$. The mass values are about 10^{-35} kg which compares well with the results obtained by deflection of light at the sun. This is another milestone for the explanatory power of this new theory.

4 Additional Reference

[13] Robert Fosbury, Olive oil fluorescence and scattering, 30th Jan. 2012,
https://m.flickr.com/#/photos/bob_81667/6811951183/in/set-72157624831829718/

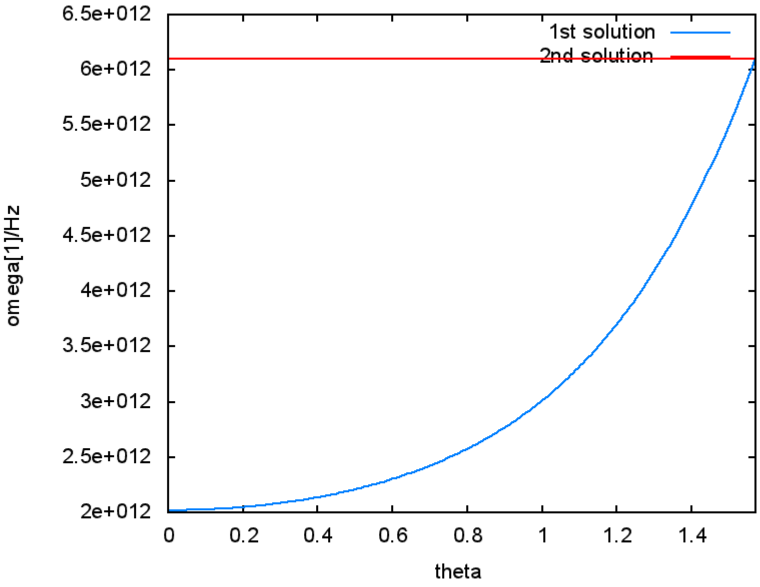

Figure 1: The two solutions for ω_1. Parameters see text.

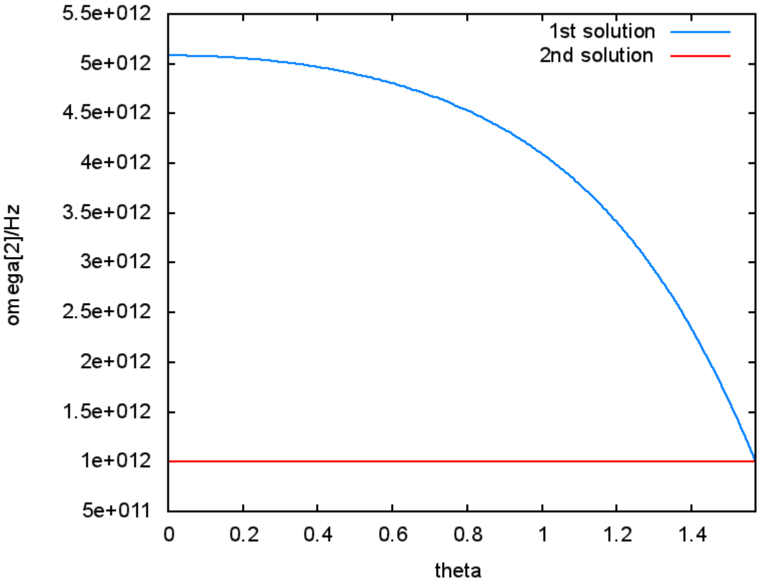

Figure 2: The two solutions for ω_2. Parameters see text.

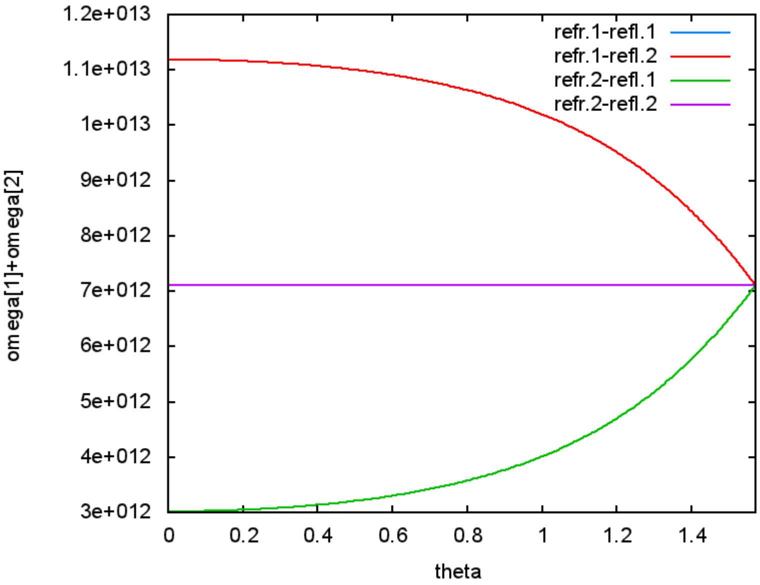

Figure 3: Summed frequencies $\omega_1 + \omega_2$ from Figs. 1 and 2.

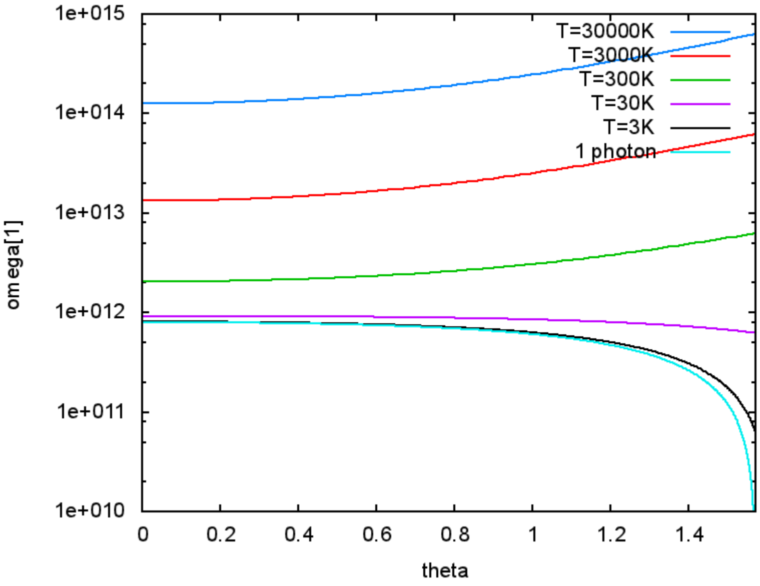

Figure 4: Temperature dependence of refracted frequency ω_1.

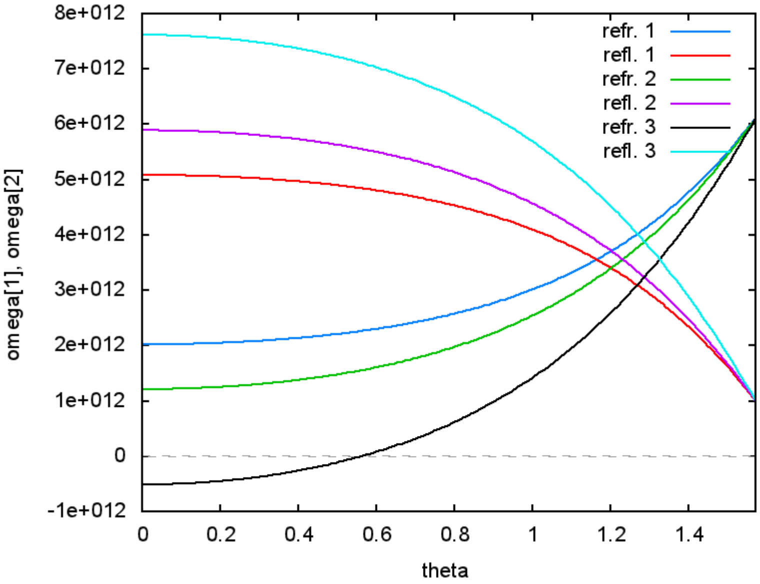

Figure 5: Refracted and reflected frequencies ω_1 and ω_2 for three parameter choices of a complex refraction index (Eqs.(75-77)).

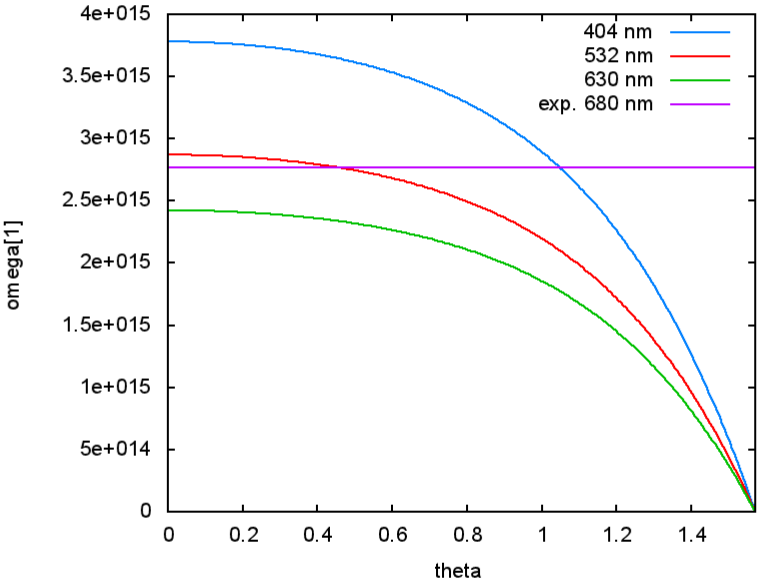

Figure 6: Refracted frequencies ω_1 for olive oil, $n_1 = 1.4665$.

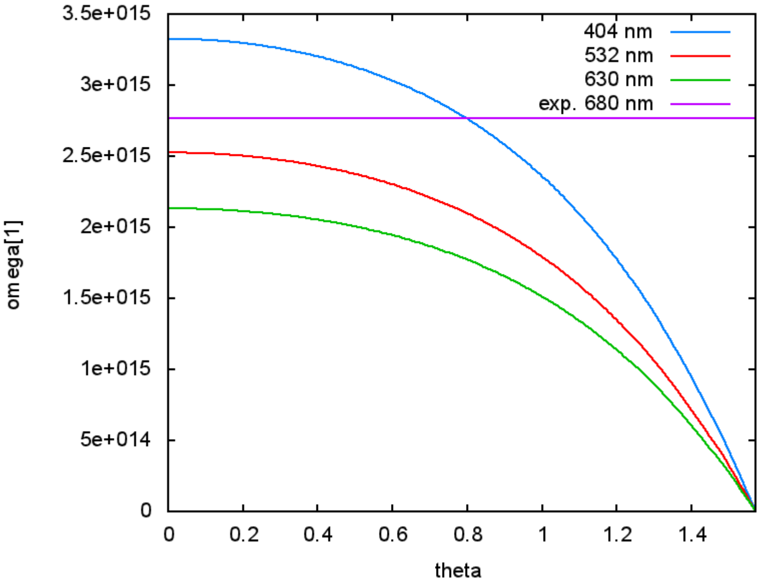

Figure 7: Refracted frequencies ω_1 for olive oil, $n_1 = 1.959$.

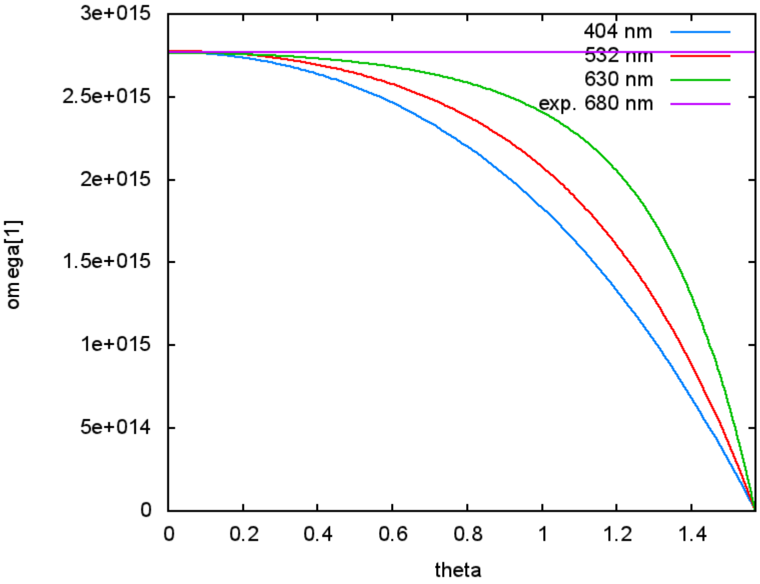

Figure 8: Refracted frequencies ω_1 for olive oil with parameters taken from Table 2.

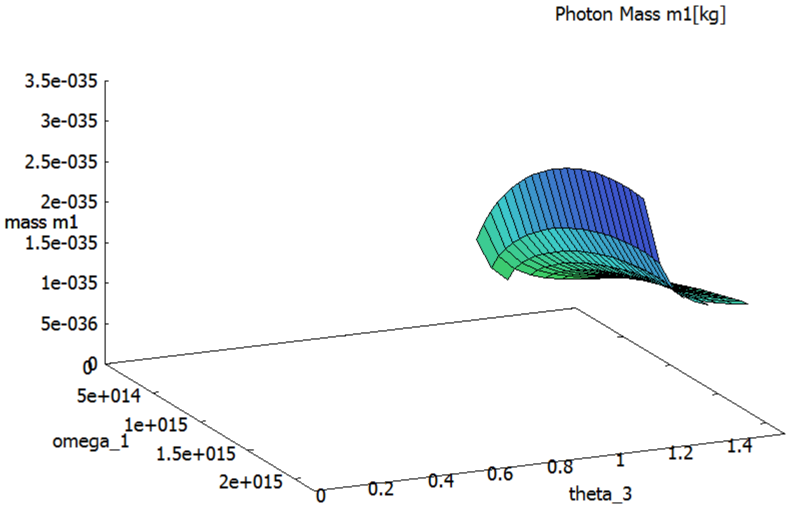

Figure 9: Calculated photon mass in dependence of ω_1 and θ_3, first solution.

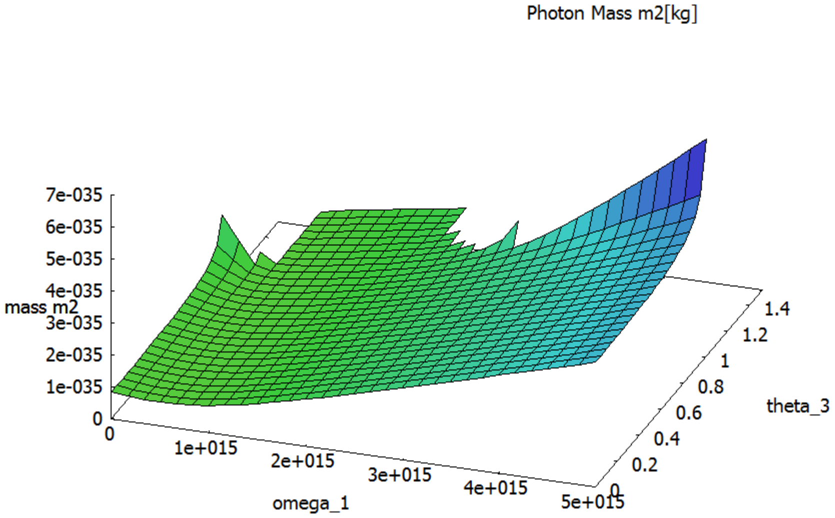

Figure 10: Calculated photon mass in dependence of ω_1 and θ_3, second solution.

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