ECE THEORY OF THE EVANS / MORRIS EFFECTS: REFLECTION FROM AN ABSORBER, BREWSTER REFRACTION AND TOTAL INTERNAL REFLECTION.

by

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ABSTRACT

It is shown straightforwardly that boundary conditions at the interface for reflection and refraction do not imply that the frequencies of the incident, reflected and refracted beam are equal, and do not lead to Snell's laws. The correct description of all effects associated with reflection and refraction must always be based on conservation of energy and momentum. In general the three frequencies are different, as observed by Evans and Morris. In this paper, three particular cases are considered: reflection and refraction form an absorber, Brewster angle refraction, and total internal reflection.

Keywords: ECE theory, Evans Morris effects, reflection and refraction from an absorber, Brewster refraction, total internal reflection.

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1. INTRODUCTION

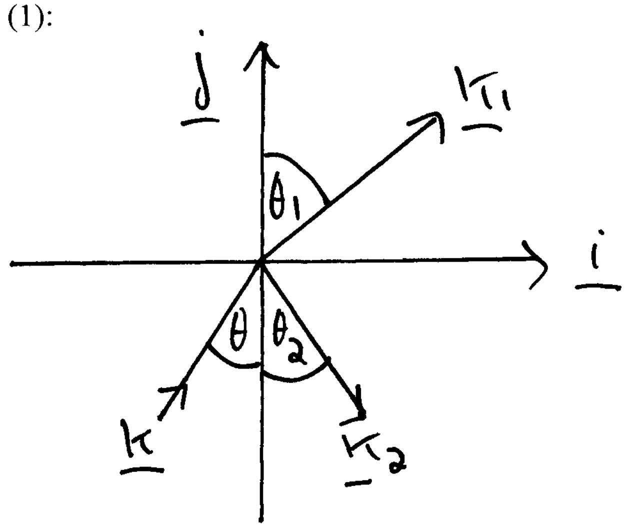
In recent papers of this series of two hundred and eighty papers to date developing the ECE theory {1 - 10}, a new theory of reflection and refraction has been proposed based on the conservation of energy and momentum. A theory has been developed based on one incident photon, and also a theory that considers a monochromatic beam made up of a Planck oscillator. The mean energy of the Planck oscillator was found as usual with the Boltzmann distribution that leads to thermodynamic equilibrium. In Section 2 this theory is applied to reflection and refraction from an absorber modelled by the Debye theory, to Brewster angle refraction and total internal reflection. In Section 3 the theory is analysed by computer algebra and graphics. It is found that the correct treatment of reflection and refraction leads to many interesting effects, notably the frequency shifts observed by Evans and Morris in a series of reproducible and repeatable experiments.

This paper should be read in conjunction with its background notes as follows. Note 280(1) gives the details of microwave reflection from water using the one photon theory and the Debye theory of absorption. Note 280(2) describes one photon theory with the memory function theory and one photon theory. Note 280(3) describes Brewster angle refraction and deduces the photon mass implied by ECE theory. Note 280(4) develops the theory of total internal reflection with the one photon theory and Planck oscillator theory. Note 280(5) corrects and develops Note 280(4). Note 280(6) is the theory of total internal reflection with the Planck oscillator theory. Note 280(7) is a summary of concepts and a detailed refutation of the standard model of reflection and refraction. Note 280(8) is a summary of the characteristics of the Planck oscillator from microwave to ultra violet frequencies.

2. REFUTATION OF THE STANDARD MODEL AND THEORETICAL DEVELOPMENT

In the standard model of optics {11} it is claimed that Snell's experimental laws can be derived from boundary conditions. At the boundary between two materials it is claimed that the phases of the incident, refracted and reflected beams are the same. These beams are sketched in Figure (1):

Fig. (1)



Therefore at the boundary:

$$\omega t - \underline{k} \cdot \underline{r} = \omega_1 t - \underline{k}_1 \cdot \underline{r} = \omega_2 t - \underline{k}_2 \cdot \underline{r} \qquad -(1)$$

Here ω, ω_1, and ω_2 are the incident, refracted and reflected angular frequencies respectively at instant t, and $\underline{k}$, $\underline{k}_1$, and $\underline{k}_2$ are the respective wave vectors at position vector $\underline{r}$. The standard model {11} assumes the particular solution:

$$\omega = \omega_1 = \omega_2 \qquad -(2)$$

of Eq. (1). This is an assumption made without experimental proof and is immediately refuted experimentally by the Evans / Morris frequency shifts {1 -10}. It is easily refuted theoretically as follows.

The particular solution (2) implies:

$$\underline{k} \cdot \underline{r} = \underline{k}_1 \cdot \underline{r} = \underline{k}_2 \cdot \underline{r} \, . \quad -(3)$$

With reference to Fig. (1):

$$\underline{k} = k\left(\underline{i} \sin\theta + \underline{j} \cos\theta\right) \quad -(4)$$

$$\underline{k}_1 = k_1\left(\underline{i} \sin\theta_1 + \underline{j} \cos\theta_1\right) \quad -(5)$$

$$\underline{k}_2 = k_2\left(\underline{i} \sin\theta_2 - \underline{j} \cos\theta_2\right) \quad -(6)$$

and the position vector is:

$$\underline{r} = X\underline{i} + Y\underline{j} \, . \quad -(7)$$

Therefore Eq. (3) implies:

$$\begin{aligned} & Xk \sin\theta + Yk \cos\theta \\ &= Xk_1 \sin\theta_1 + Yk_1 \cos\theta_1 \\ &= Xk_2 \sin\theta_2 - Yk_2 \cos\theta_2 \end{aligned} \quad -(8)$$

The standard model forces this arbitrary theory to produce Snell's experimental law by assuming without mathematical proof another particular solution:

$$k \sin\theta = k_1 \sin\theta_1 = k_2 \sin\theta_2 \quad -(9)$$

in which it is assumed from Eq. (2) that:

$$k = k_2 \, . \quad -(10)$$

This assumption is immediately refuted by the Evans / Morris frequency shifts {1 - 10}.

Therefore:

$$\sin\theta = \sin\theta_2, \quad -(11)$$

$$\theta = \theta_2, \quad -(12)$$

and it is claimed incorrectly that the theory produces what is known as Snell's first experimental law, the angle of incidence is equal to the angle of reflection. In fact this law was known in ancient times. The particular solution (9) is claimed to produce Snell's second law, in fact discovered long before Snell:

$$\kappa \sin\theta = \kappa_1 \sin\theta_1 \quad -(13)$$

with arbitrary assumption:

$$\frac{\kappa_1}{\kappa} = \frac{n_1}{n} = \left(\frac{\mu_1 \epsilon_1}{\mu \epsilon}\right)^{1/2}. \quad -(14)$$

However, the assumption (9) implies:

$$\kappa \cos\theta = \kappa_1 \cos\theta_1 = -\kappa_2 \cos\theta_2 \quad -(15)$$

so:

$$\frac{\kappa_1}{\kappa_2} = -\frac{\cos\theta_2}{\cos\theta_1} \quad -(16)$$

and:

$$\frac{\kappa}{\kappa_2} = -\frac{\cos\theta_2}{\cos\theta}. \quad -(17)$$

For values of θ_1 and θ_2 as follows:

$$0 \leq \theta_1 \leq \pi/2, \quad -(18)$$

$$0 \leq \theta_2 \leq \pi/2, \quad -(19)$$

Eq. (15) is absurd, because the magnitude of κ_1 is negative if the magnitude of κ_2 is positive. This is unphysical because the physical magnitude of wave-vectors is positive valued.

The correct development of the boundary condition must be based on the fundamental laws of conservation of energy and momentum {1 - 10}:

$$\hbar\omega = \hbar\omega_1 + \hbar\omega_2, \quad -(20)$$

$$\hbar\underline{\kappa} = \hbar\underline{\kappa_1} + \hbar\underline{\kappa_2}, \quad -(21)$$

so the following phase law is always true, and is also true at the boundary:

$$\omega t - \underline{\kappa}\cdot\underline{r} = (\omega_1 + \omega_2)t - (\underline{\kappa_1} + \underline{\kappa_2})\cdot\underline{r}. \quad -(22)$$

So:

$$\underline{\kappa}\cdot\underline{r} = (\underline{\kappa_1} + \underline{\kappa_2})\cdot\underline{r}. \quad -(23)$$

By experiment:

$$\theta = \theta_2 \quad -(24)$$

and:

$$\sin\theta = \frac{n_1}{n}\sin\theta_1 \quad -(25)$$

and in general

$$\omega \neq \omega_1 \neq \omega_2 \quad -(26)$$

and

$$\underline{\kappa} \neq \underline{\kappa_1} \neq \underline{\kappa_2} \quad -(27)$$

as is immediately apparent from the fundamental conservation laws (20) and (21). The old standard model diametrically violated these conservation laws.

The conservation laws also apply to beams made up of the Planck oscillator { 1 - 10}, defined by an oscillator at angular frequency ω and energy levels:

$$E = n\hbar\omega, \quad n = 0, 1, \ldots, m \qquad -(28)$$

Note carefully that the lowest energy level of the Planck oscillator is defined by:

$$n = 0 \qquad -(29)$$

in which case the oscillator has no energy and no momentum. The usual definition of the photon is :

$$E = \hbar\omega \qquad -(30)$$

at any temperature T. At thermodynamic equilibrium the usual definition (30) implies that:

$$\langle \hbar\omega \rangle = \hbar\omega \left(\frac{\sum_n n x^n}{\sum_n x^n} \right) = \hbar\omega, \qquad -(31)$$

$$x = \exp\left(-\frac{\hbar\omega}{kT} \right) \qquad -(32)$$

if it is assumed that:

$$\langle \hbar\omega \rangle = \hbar\omega. \qquad -(33)$$

This means that the usual definition of the photon is that of a Planck oscillator with this energy. The Boltzmann averaged energy of the Planck oscillator is {1 - 10}:

$$\langle \hbar\omega \rangle = \hbar\omega \left(\frac{\sum_n n x^n}{\sum_n x^n} \right) \qquad -(34)$$

where:

$$x = \exp\left(-\frac{\hbar\omega}{kT}\right). \quad -(35)$$

So the conservation laws for this average are:

$$\langle \hbar\omega \rangle = \langle \hbar\omega_1 \rangle + \langle \hbar\omega_2 \rangle, \quad -(36)$$

$$\langle \omega \rangle = \langle \omega_1 \rangle + \langle \omega_2 \rangle \quad -(37)$$

and

$$\langle \hbar \underline{\kappa} \rangle = \langle \hbar \underline{\kappa}_1 \rangle + \langle \hbar \underline{\kappa}_2 \rangle. \quad -(38)$$

These laws mean that the thermal or Boltzmann averaged energy and momentum of the Planck oscillator in the incident beam are equal to their respective sums in the refracted and reflected beam. So total average energy and momentum are conserved.

In the usual development of the Planck oscillator it is assumed that there is an infinite number of states of the oscillator:

$$n = 0, 1, 2, \ldots, m \rightarrow \infty \quad -(39)$$

so by the Maclaurin series:

$$\sum_n x^n = 1 + x + x^2 + \ldots = \frac{1}{1-x} \quad -(40)$$

provided that:

$$x < 1. \quad -(41)$$

With these assumptions the thermal average of the Planck oscillator is:

$$\langle \hbar\omega \rangle \sim \left(\frac{x}{1-x}\right)\hbar\omega, \quad x < 1 \qquad (42)$$

Some values of this thermal average are given in Table 1:

Table 1: Thermal Averages of the Planck Oscillator at 293 K

ω / rad s^{-1}	f / Hz	$\tilde{\nu}$ / cm^{-1}	$\hbar\omega/(kT)$	$1/(e^{\hbar\omega/kT}-1)$	Range
10^{10}	1.59×10^{9}	0.053	2.61×10^{-4}	3835.47	microwave
10^{11}	1.59×10^{10}	0.53	0.00261	383.09	microwave
10^{12}	1.59×10^{11}	5.3	0.0261	37.86	Far IR
10^{13}	1.59×10^{12}	53	0.261	3.36	Far IR
10^{14}	1.59×10^{13}	530	2.61	0.07	Mid IR
10^{15}	1.59×10^{14}	5,300	26.1	4.8×10^{-12}	IR
10^{16}	1.59×10^{15}	53,000	260.7	~ 0	UV

At room temperature up to the far infra red at about 10 cm^{-1}, the thermal average is much larger than $\hbar\omega$, indicating that many energy levels are occupied at this frequency.

The assumption that the photon energy is:

$$E = \hbar\omega \qquad -(43)$$

is equivalent to assuming that the entire energy of the Planck oscillator is given by the lowest state in which the energy is not zero, i.e. by:

$$n = 1. \qquad -(44)$$

At 293 K, this is the case from about 100 cm^{-1} upwards in frequency. So in the visible range the conservation of energy and momentum are given by Eqs. (20) and (21). In the very far infra red and microwave range of frequencies, many energy levels are populated at 293 K so the mean energy of the Planck oscillator is much greater than $\hbar\omega$ as shown in Table 1. So in the microwave range the conservation of energy and momentum are given by Eqs. (36) and (38). These are valid up to about 10 cm^{-1}, which is 300 GHz.

Note carefully that the usual development of the theory of intensity in a polychromatic beam is based on the Rayleigh Jeans density of states corrected by the Planck distribution in the approximation (42). The energy density U in joules per cubic metre of a polychromatic beam is given by:

$$U = \frac{1}{\pi c^3}\int \omega^2 \langle \hbar\omega \rangle \, d\omega \qquad -(45)$$
$$= \frac{\hbar}{\pi c^3}\int \frac{\omega^3 x}{x-1}\, d\omega$$

The intensity of the beam in watts per square metre is given by:

$$I = cU = \frac{\hbar}{\pi c^2}\int \omega^3 \left(\frac{x}{x-1}\right) d\omega \qquad -(46)$$

It is claimed that the Stefan Boltzmann law is obtained from:

$$I = \frac{\hbar}{\pi c^2} \int_0^\infty \omega^3 \left(\frac{x}{1-x} \right) d\omega = \left(\frac{\pi^2 k^4}{15 c^2 \hbar^3} \right) T^4 \quad -(47)$$

inite.

These points are almost never made in textbooks of the standard model, but they are fundamentally important. The standard model of physics is riddled with errors and hidden assumptions that this series of papers has brought to light {1 - 10}.

The correct theory of reflection of microwaves from a material must therefore be based on Eqs. (36) and (38). As shown in Note 280(1) the relevant simultaneous equations are:

$$\left(\frac{x}{1-x} \right) \omega = \left(\frac{x_1}{1-x_1} \right) \omega_1 + \left(\frac{x_2}{1-x_2} \right) \omega_2 \quad -(48)$$

and:

$$\left(\frac{x_1}{1-x_1} \right)^2 n_1^2 = \left(\frac{x}{1-x} \right)^2 \omega^2 + \left(\frac{x_2}{1-x_2} \right)^2 \omega_2^2 - 2 \left(\frac{x}{1-x} \right) \left(\frac{x_2}{1-x_2} \right) \omega \omega_2 \cos(2\theta) \quad -(49)$$

This is tractable in the approximations:

$$1 - x \sim 1, \quad -(50)$$

$$x \sim 1 - \frac{\hbar \omega}{kT}, \quad -(51)$$

giving the results of Section 3. The latter shows clearly that

$$\omega \overset{?}{=} \omega_1 \overset{?}{=} \omega_2 \quad -(52)$$

is incorrect, and gives a plausible explanation of the experimental Evans / Morris effects. The refractive index in Eq. (49) is defined by:

$$n_1'^2 = \frac{1}{2}\left(\epsilon_{1r}' + \left(\epsilon_{1r}'^2 + \epsilon_{1r}''^2\right)^{1/2}\right) \quad -(53)$$

in terms of the relative permittivity ϵ_{1r}' and the dielectric loss ϵ_{1r}''. In the refracting medium these may be roughly modelled with the Debye theory {1 - 10} which is valid up to the high microwave range but then fails qualitatively:

$$\epsilon_{1r}' = \epsilon_{r\infty} + \left(\epsilon_{r0} - \epsilon_{r\infty}\right) / \left(1 + \omega_1^2 \tau^2\right) \quad -(54)$$

$$\epsilon_{1r}'' = \left(\epsilon_{r0} - \epsilon_{r\infty}\right) \omega_1 \tau / \left(1 + \omega_1^2 \tau^2\right) \quad -(55)$$

where τ is the Debye relaxation time, and ϵ_{r0} and $\epsilon_{r\infty}$ are the static and infinite frequency relative permittivities. This theory is described in detail in Note 280(1) and the results are discussed in Section 3. There is a rich variety of effects.

This theory is a test of the Planck hypothesis. If the predicted effects are not observed then the Planck theory has failed at a fundamental level.

At the Brewster angle of incidence in the visible range, where the Planck oscillator is in its ground state, then:

$$\theta = \theta_B = \tan^{-1}\left(n_1 / n\right), \quad -(56)$$

$$\theta_B + \theta_1 = \pi / 2, \quad -(57)$$

the following condition applies:

$$n \sin\theta_B = n_1 \sin\left(\frac{\pi}{2} - \theta_B\right) = n_1 \cos\theta_B \quad -(58)$$

and in one polarization there is no reflection. If it is considered that a beam is incident at the Brewster angle with frequency ω, and is refracted at frequency ω_1, and if it is assumed that there is no reflected frequency or energy, then conservation of energy demands that:

$$\hbar\omega = \hbar\omega_1 \quad -(59)$$

where the refracted energy is given by:

$$\hbar\omega_1 = \gamma mc^2 \quad -(60)$$

through the de Broglie equation as in UFT158ff and UFT166. Here m is the photon mass of ECE theory, and the Lorentz factor is given by:

$$\gamma = \left(1 - \frac{v^2}{c^2}\right)^{-1/2} \quad -(61)$$

where v is the photon velocity. As inferred originally by de Broglie as in UFT166:

$$v v_p = c^2 \quad -(62)$$

where v_p is the phase velocity in the refracting medium. Assuming for the sake of argument that:

$$v = v_p \quad -(63)$$

then v may be found from the ordinary refractive index of the refracting medium, so the photon mass may be estimated from Eq. (60), giving (Section 3):

$$\left(1 - \frac{1}{n_1^2}\right)^{-1/2} mc^2 = \hbar\omega \quad -(64)$$

in good agreement with previous estimates in the UFT series {1 - 10}.

Total internal reflection is defined by Fig (1) when the angle of refraction θ_1 is ninety degrees, so the refracted entity is directed in the X axis. If no light is observed to be refracted along the X axis, or boundary between the two layers, then the theory is a simple one of reflection in which the conservation of energy and momentum is:

$$\hbar\omega = \hbar\omega_2 \quad -(65)$$

and

$$\hbar \underline{\kappa} = \hbar \underline{\kappa_2} \quad -(66)$$

In this case there is no change of frequency and energy and momentum are conserved in a simple way. This is what might occur for example in an optical fibre in which reflection is the only mechanism. If a refracted beam of light or electromagnetic radiation is observed experimentally to be present along the boundary between layers (or X axis) then by conservation of energy and momentum there are Evans / Morris shifts present. Total internal reflection can be developed as a single photon theory (n = 1 in the Planck oscillator) or as a theory using the average energy of a Planck oscillator (all states occupied, n = 0, 1, 2, ..., m). In both theories the wave vector propagates as in Eqs. (4) to (6) with:

$$\underline{\kappa_1} = \kappa_1 \underline{i} \quad -(67)$$

and

$$\underline{\kappa_2} = \kappa_2 \left(\underline{i} \sin\theta - \underline{j} \cos\theta \right) -(68)$$

where we have used:

$$\theta = \theta_2 . \quad -(69)$$

For total internal reflection to occur the refractive index of the medium of incident propagation (the glass of an optical fibre) must be higher than the medium in which refraction occurs (for example air of effective refractive index unity). If the phase velocity of the incident medium is v, and if the phase velocity in air is c, then the magnitudes of the wave-vectors are:

$$\kappa = \frac{\omega}{v}, \quad \kappa_2 = \frac{\omega_2}{v}, \quad \kappa_1 = \frac{\omega_1}{c} . \quad -(70)$$

From Snell's experimental second law:

$$n \sin\theta = n_1 \sin\theta_1 = \sin\theta_1 \quad -(71)$$

and in total internal reflection:

$$\sin\theta_1 = 1 \quad -(72)$$

so:

$$\sin\theta = \frac{1}{n} . \quad -(73)$$

As shown in detail in Note 280(4) conservation of energy and momentum under these conditions and for a one photon theory demands that:

$$(\omega-\omega_2)^2 = n^2\left(\omega^2+\omega_2^2-2\omega\omega_2\left(1-\frac{1}{n^2}\right)\right). \quad -(74)$$

This equation is solved numerically using Maxima in Section 3 to give the reflected angular frequency ω_2 in terms of the incident angular frequency ω. Many interesting results are obtained in the presence of refracted electromagnetic radiation of angular frequency ω_1. Evans and Morris report light travelling along boundaries (see numerous photographs in the diary or blog of www.aias.us). However, if there is no refracted energy and momentum the theory is the simple one of Eqs. (65) and (66).

Finally the general theory of total internal reflection is given in note 280(6) using the average energy of a Planck oscillator with all states occupied, n = 0, 1, ..., m. This theory results in:

$$\left[\left(\frac{x}{1-x}\right)\omega-\left(\frac{x_2}{1-x_2}\right)\omega_2\right]^2 \quad -(75)$$

$$= n^2\left[\left(\frac{x}{1-x}\right)^2\omega^2+\left(\frac{x_2}{1-x_2}\right)^2\omega_2^2-2\left(\frac{x}{1-x}\right)\left(\frac{x_2}{1-x_2}\right)\omega\omega_2\left(1-\frac{2}{n^2}\right)\right]$$

where:

$$x = \exp\left(-\frac{\hbar\omega}{kT}\right),\ x_1 = \exp\left(-\frac{\hbar\omega_1}{kT}\right),\ x_2 = \exp\left(-\frac{\hbar\omega_2}{kT}\right) \quad -(76)$$

Eq. (75) is solved numerically in Section 3 and again gives many interesting results.

ECE theory of the Evans/Moris effects: reflection from an absorber, Brewster refraction and total internal reflection

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3 Numerical results and graphics

3.1 Refraction and reflection with and without temperature effects

We first compile the equations used for solving $\omega_1(\theta)$ and $\omega_2(\theta)$. We used two refraction indices n_0 and n_1 for the regions of $\boldsymbol{\kappa}$ and $\boldsymbol{\kappa}_1$ as indicated in Fig. 1. Energy conservation is given by

$$\omega_0\, A_0 = \omega_1\, A_1 + \omega_2\, A_2 \tag{77}$$

with a linearized Boltzmann distribution based on Planck oscillator theory:

$$A_i = \frac{1 - y_i}{y_i} \tag{78}$$

$$y_i = \hbar\omega_i f_T \tag{79}$$

$$f_T = \frac{1}{k\,T}. \tag{80}$$

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Statistics	Type	Refr. index	Eq.	Fig.	frequency shift
1-photon	refraction	$n_1 > n_0$	(83)	2	yes
	reflection		(86)	3	no
Planck	refraction		(83)	4	yes
	reflection		(86)	5	no
1-photon	refraction	$n_0 > n_1$	(83)	6	yes
	reflection		(86)	7	no
Planck	refraction		(83)	8	yes
	reflection		(86)	9	no

Table 1: Classification of refraction and reflection frequencies.

In case of the single-photon model we can simply set $A_i = 1$. The equations for momentum conservation have been chosen for refraction and reflection differently.

Refraction:

$$\boldsymbol{\kappa}_1 = \boldsymbol{\kappa} - \boldsymbol{\kappa}_2, \tag{81}$$

$$\kappa_1^2 = \kappa^2 + \kappa_2^2 - 2\kappa\ \kappa_2 \cos(\pi - 2\theta), \tag{82}$$

$$n_1^2\,\omega_1^2\,A_1^2 = n_0^2\,\omega_0^2\,A_0^2 + n_0^2\,\omega_2^2\,A_2^2 + 2\,n_0^2\,\omega_0\,\omega_2, A_0\,A_2 \cos{(2\,\theta)} \tag{83}$$

with $\cos(\pi - 2\theta) = -\cos(2\theta)$.

Reflection:

$$\boldsymbol{\kappa}_2 = \boldsymbol{\kappa} - \boldsymbol{\kappa}_1, \tag{84}$$

$$\kappa_2^2 = \kappa^2 + \kappa_1^2 - 2\kappa\ \kappa_1 \cos(\theta_3), \tag{85}$$

$$n_0^2\,\omega_2^2\,A_2^2 = n_0^2\,\omega_0^2\,A_0^2 + n_1^2\,\omega_1^2\,A_1^2 - 2\,n_0\,n_1\,\omega_0\,\omega_1\,A_0\,A_1 \cos{(\theta_3)} \tag{86}$$

where

$$\theta_3 = \theta_1 - \theta \tag{87}$$

$$\theta_1 = \arcsin\left(\frac{n_0}{n_1}\sin(\theta)\right). \tag{88}$$

The results are graphed in Figs. 2-9. Two differences can be studied: single photon theory vs. statistical photon theory, and normal refraction/reflection vs. total reflection. So both situations of normal and total reflection can be handled by the same model. The results are classified in Table 1. It can be seen that a frequency shift occurs only in refraction. In all reflection cases, there is at least one solution with $\omega_2 = \omega_0$ which implies that there is no refraction ($\omega_1 = 0$). On the other hand, if Eq.(83) is used for the reflection process instead of (86), then the results are non-constant and there is a frequency shift. Actually the results for refraction and and reflection are interchanged. This shows that Eqs.(83) and (86) describe different models of reflection as well as refraction. This leads to the conjecture that a single-photon theory is not sufficient to explain all optical effects consistently.

The temperature effects lead to an inversion of the frequency shifts, compare the first solution each of Fig. 2 and Fig. 4. The second solution changes from negative to positive values, so there could be a second type of refraction in case of photons in statistical ensembles. This has to be decided experimentally. Similar results hold for the reflected frequencies (Figs. 3 and 5).

3.2 Total reflection

In transition to total reflection we have

$$\theta_1 = \frac{\pi}{2}, \tag{89}$$

$$\theta_3 = \frac{\pi}{2} - \theta \tag{90}$$

with

$$\sin(\theta) = \frac{n_1}{n_0}. \tag{91}$$

From this we then obtain

$$\begin{aligned} \cos(\theta_3) &= \cos\left(\frac{\pi}{2} - \arcsin(\frac{n_1}{n_0})\right) = \sin\left(\arcsin(\frac{n_1}{n_0})\right) \\ &= \frac{n_1}{n_0}. \end{aligned} \tag{92}$$

As can be seen from Figs. 6-9, in case of total reflection (i.e. $n_0 > n_1$), non-constant solutions are only defined in the range below the angle of total reflection defined by Eq.(91). For $n_0 = 1.5,\ n_1 = 1$ we obtain $\theta = 0.73$. We can compute how the frequency ω_2 at the transition angle behaves in dependence of a variable n_0. Inserting (92) into (86) gives the result shown in Fig. 10. There are two constant solutions, one is identical to the single photon frequency ω_0, which is consistent with Fig. 9 where no shift is visible too.

3.3 Debye theory with temperature effects

The Debye model of Eqs.(32-35) of UFT 278 has been recalculated with temperature effects according to Eq.(83). Because the refraction index depends on the refraction frequency ω_1, this equation can no more be solved analytically. A numerical method was used to calculate the dependence of ω_1 on θ and the relaxation time τ on a two dimensional grid. The resut is graphed in Fig. 11. The frequency increases with θ as in Fig. 4 but decreases with higher relaxation times. This reflects the energy loss by relaxation processes.

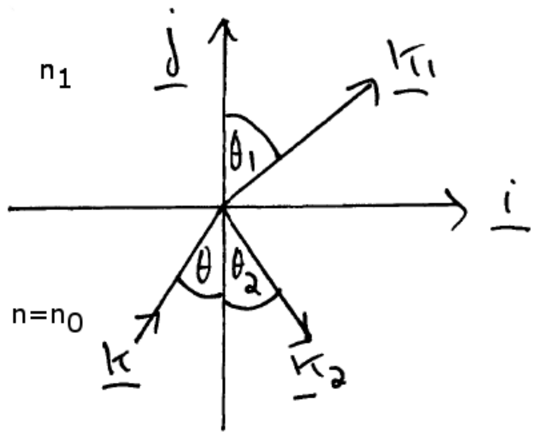

Figure 1: Diagram of refraction/reflection.

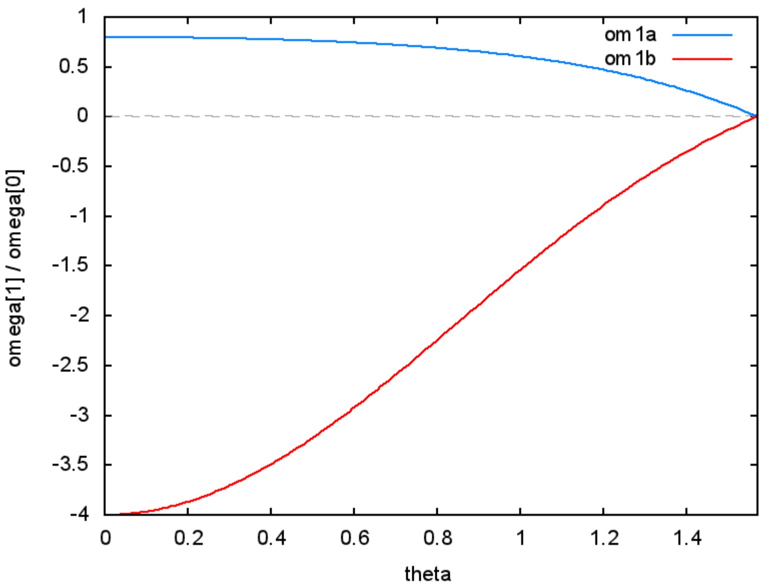

Figure 2: Refracted frequency ω_1, $n_1 > n_0$, single-photon model.

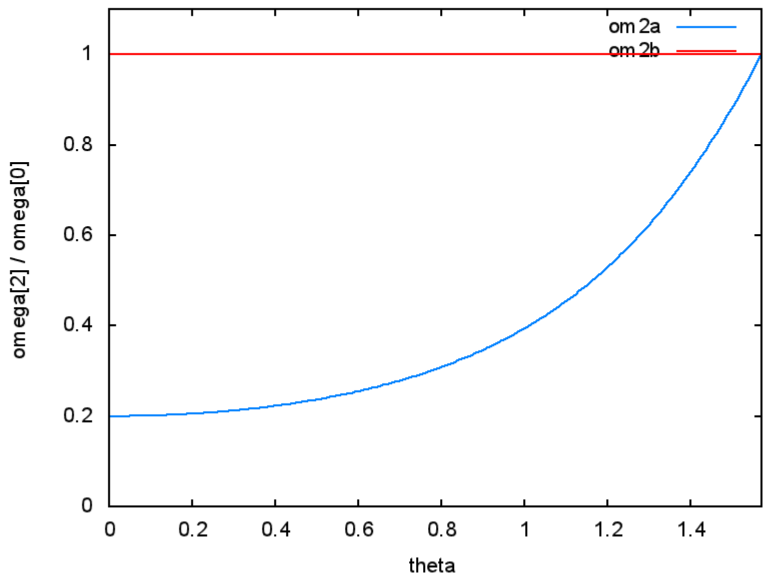

Figure 3: Reflected frequency ω_2, $n_1 > n_0$, single-photon model.

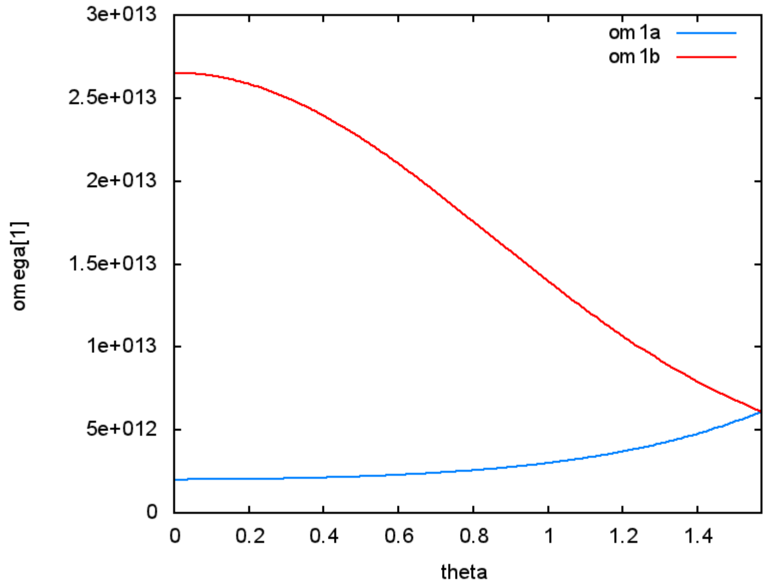

Figure 4: Refracted frequency ω_1, $n_1 > n_0$, multiple oscillator model.

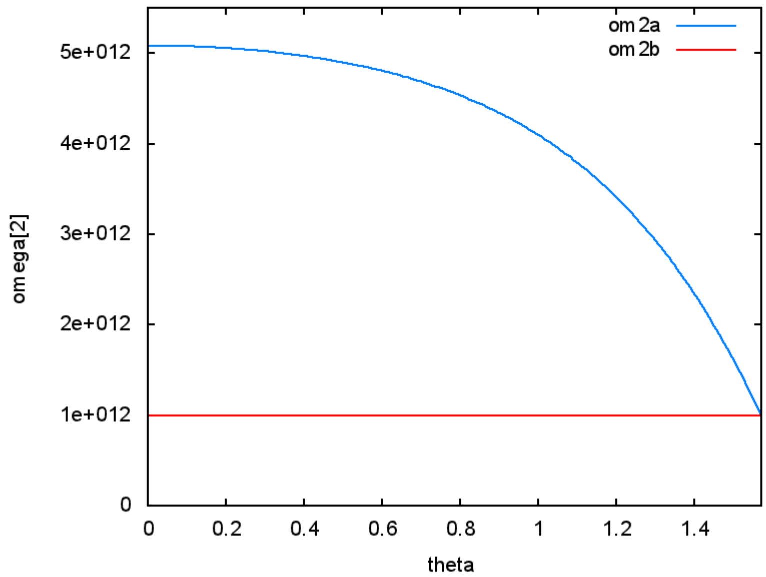

Figure 5: Reflected frequency ω_2, $n_1 > n_0$, multiple oscillator model.

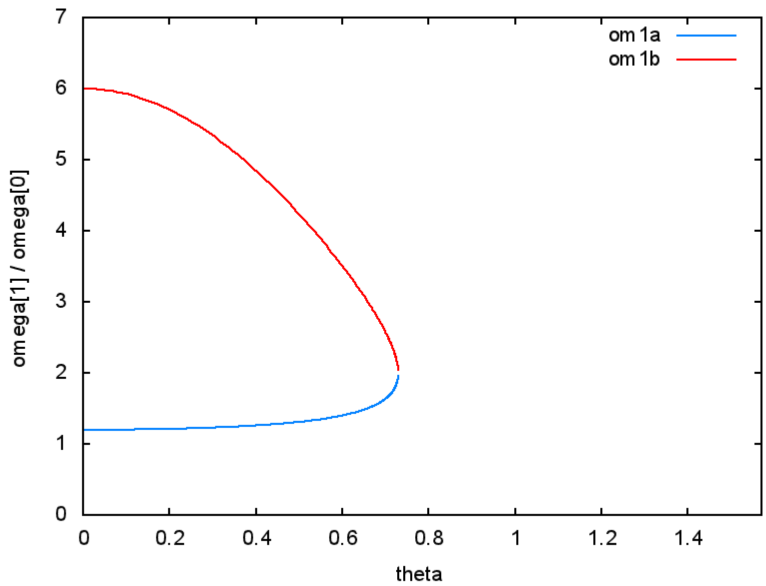

Figure 6: Refracted frequency ω_1, $n_0 > n_1$ (total reflection), single-photon model.

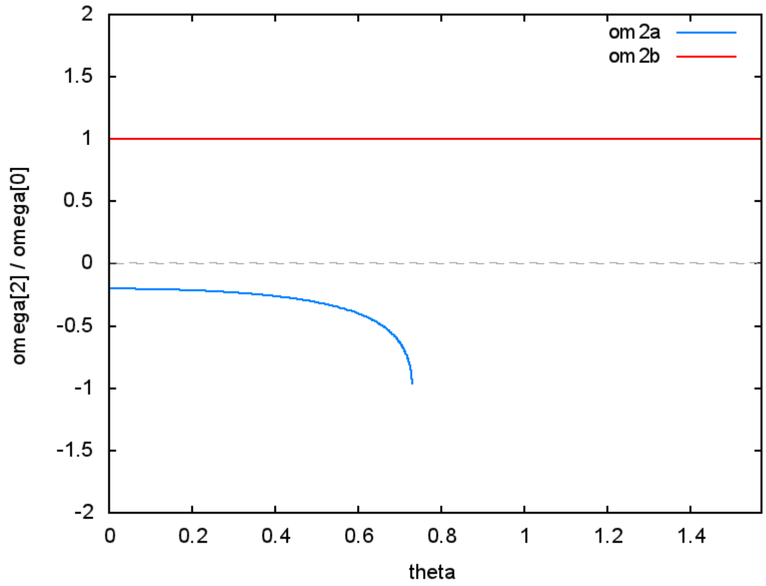

Figure 7: Reflected frequency ω_2, $n_0 > n_1$ (total reflection), single-photon model.

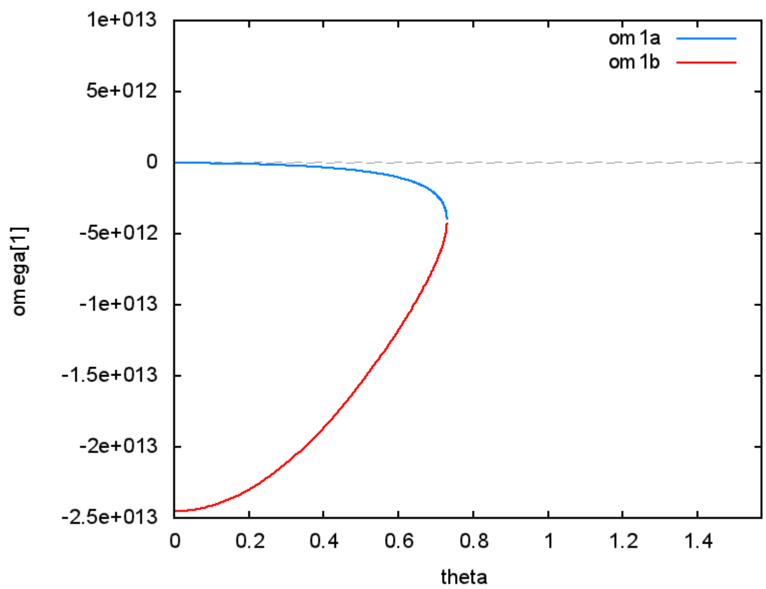

Figure 8: Refracted frequency ω_1, $n_0 > n_1$ (total reflection), multiple oscillator model.

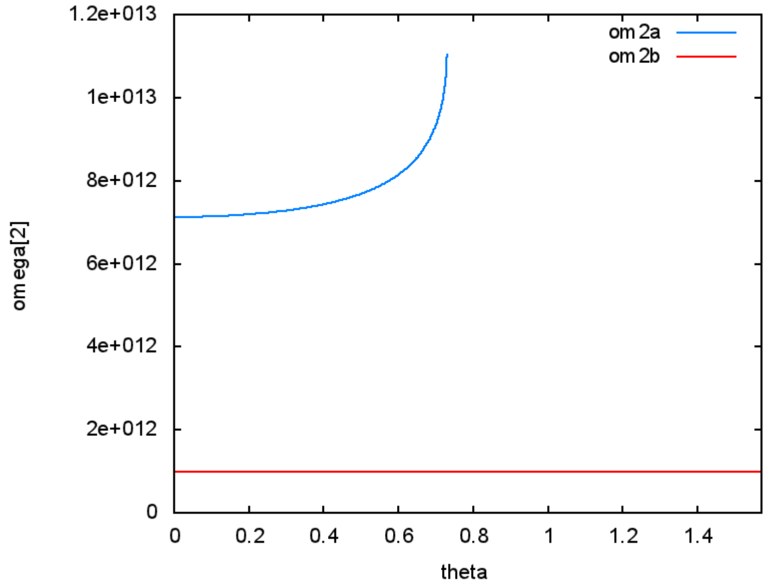

Figure 9: Reflected frequency ω_2, $n_0 > n_1$ (total reflection), multiple oscillator model.

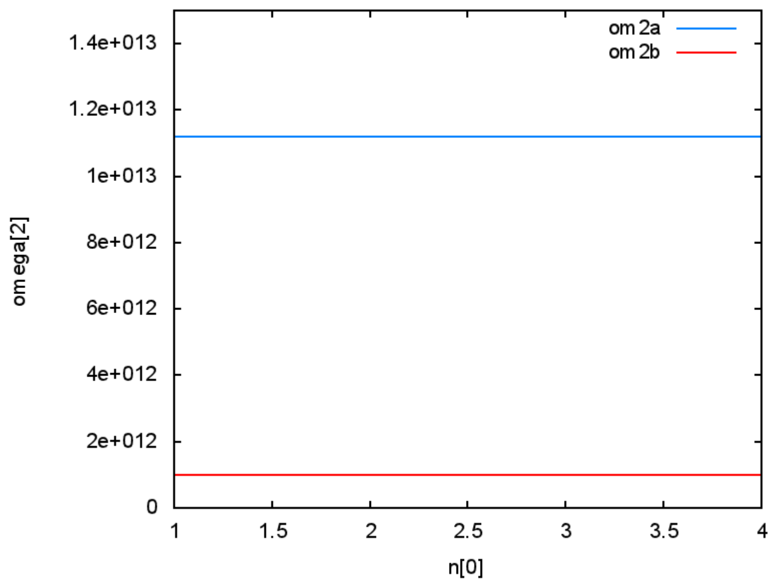

Figure 10: Reflected frequency ω_2, multiple oscillator model, dependence on refraction index for respective angle of total reflection.

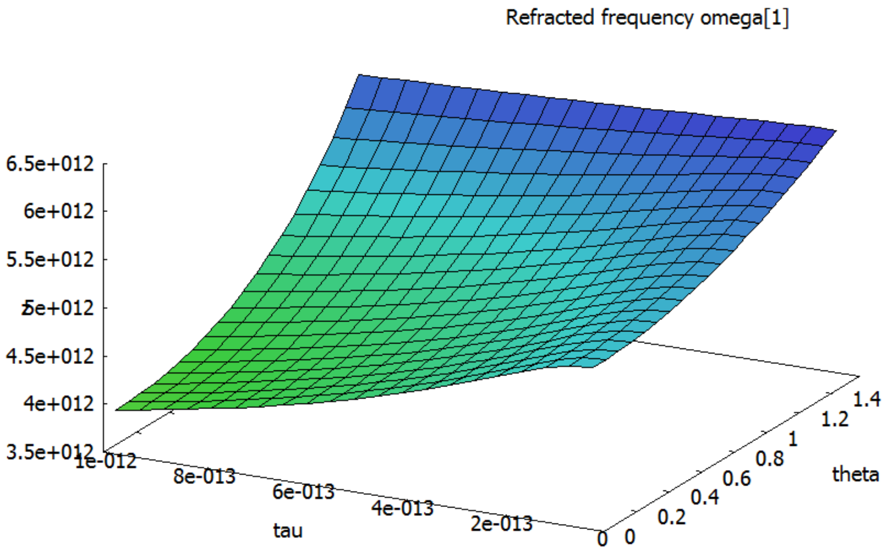

Figure 11: Debye model, multiple oscillator model, ω_1 in dependence of θ and relaxation time τ.

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