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Modelling superposition of 3- & N-polarized beams on an isotropic photo detector

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========== Slide #1 ==========

Abstract. In a previous paper [SPIE Proc.Vol.7063, paper #4 (2008)], we have attempted to model possible modes of excitations that detecting dipoles carry out during the interaction process with EM waves before absorbing a quantum cupful of energy out of the two simultaneously stimulating EM waves along with experimental validations. Those experiments and analyses basically corroborate the law of Malus. For these two-beam cases, the cosθ-factor, (θ being the angle between the two polarization vectors), is too symmetric and too simple a case to assure that we are modeling the energy absorption process definitively. Accordingly, this paper brings in asymmetry in the interaction process by considering 3-beam and N-beam cases to find out whether there are more subtleties behind the energy absorption processes when more than two beams are simultaneous stimulating a detector for the transfer of EM energy from these multiple beams. We have suggested a possible experimental set up for a three-polarized-beam experiment that we plan to carry out in the near future. We also present analyses for 3-beam and simplified N-beam cases and computed curves for some 3-beam cases. The results strengthen what we concluded in our two-beam experimental paper. We also recognize that the mode of mathematical analyses, based upon traditional approach, may not be sufficient to extract any more details of the invisible light-dipole interaction processes going on in nature.

Keywords: Interference with polarized beams; 3-slit 3-polarized beam experiment, Dipolar excitation modes for multiple polarized beams, Quantum cup filling by multiple EM waves.

========== Slide #2 ==========

REFERENCES

[1] C. Roychoudhuri and A. Michael Barootkoob, "Generalized quantitative approach to two-beam fringe visibility (coherence) with different polarizations and frequencies"; Proc. SPIE Vol.7063, paper #4 (2008).
[2] C. Roychoudhuri, [Causal Physics: Photon Model by Non-Interaction of Waves], Taylor & Francis (2014).

========== Slide #3 ==========

OBJECTIVE

Mapping light-matter interaction process as the E-vector stimulating a molecule as a possible linear dipole.

The question is:

What is the physical stimulation process model when there are multiple polarized E-vectors present simultaneously?

We are developing interaction process visualization model for measurable superposition effects using polarized light.

Multiple polarization states give us an extra manipulate-able parameter to differentiate between different possible postulates in dipolar stimulations.

========== Slide #4 ==========

CASES TO ANALYZE

I. **Energy transfer process during quantum transition out of multiple superposed polarized beams:**

(i) ***Vector product model:*** The QM dipole takes all possible paired vector products of the stimulating E-vector amplitudes.

(ii) ***Pre-polarization model:*** QM dipole is pre-polarized by the strongest E-vector; then the projected components of other vectors are taken into account by the dipole.

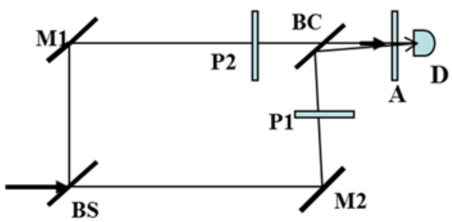
(iii) ***Light beams interfere by themselves***: E-vector amplitudes first sum themselves and then the resultant E-vector stimulates the detecting dipole. ***This model has already been dropped*** in view of extensive experimental supports for Non-Interaction of Waves (NIW) [2]

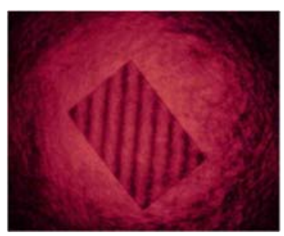
II. ***Energy transfer process due to multiple polarized beams during propagation through bulk polarized material*** **(**comparing with classical physics**)**

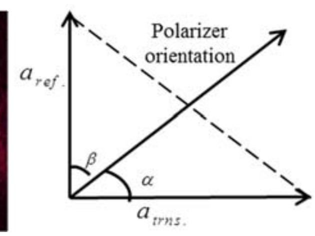
========== Slide #5 ==========

A brief review of the past work on which the current work is built upon

1. Proc. SPIE Vol.7063, paper #4 (2008).] Down load the paper from web. Paper, # "2008.5": http://www.natureoflight.org/CP/
2. C. Roychoudhuri, "Causal Physics: Photon Model by Non-Interaction of Waves"; CRC, 2104.







1. There are profound differences between the equations representing Superposition Principle, dealing with the amplitudes, and the Superposition Effect, dealing with the registered intensity. Mathematical operators in the equation representing superposition of the amplitudes do not represent any measurable; only the detecting dipoles are stimulated. The operator "+", at this stage, implies that the dipole is executing a summed (resultant) amplitude oscillation.

$$\Psi(\tau) = \psi_1 + \psi_2 = \chi\hat{\chi}_1 a_1 e^{i2\pi\nu t} + \chi\hat{\chi}_2 a_2 e^{i2\pi\nu_2(t+\tau)} \tag{1}$$

2. A quantum detector absorbs the necessary quantum ***cupful of energy from multiple superposed sources***. This is validated by the equation, following QM recipe, for the absorbed energy (fringe distribution). The energy absorbed is contributed by both the beams, a_1 and a_2.

$$\begin{aligned} D(\tau) &= \left\langle \left|\Psi^*\Psi\right|^2 \right\rangle = \left\langle \left|\chi\left[\hat{\chi}_1 a_1 e^{i2\pi\nu t} + \hat{\chi}_2 a_2 e^{i2\pi\nu_2(t+\tau)}\right]\right|^2 \right\rangle \\ &= \chi^2 \left\langle [a_1^2 + a_2^2 + 2a_1 a_2 \cos\phi \cos 2\pi\nu\tau] \right\rangle \end{aligned} \tag{2}$$

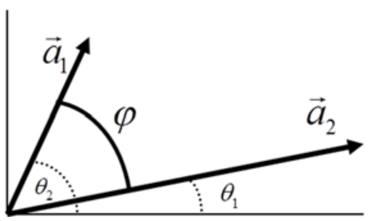
========== **Slide #6** ==========

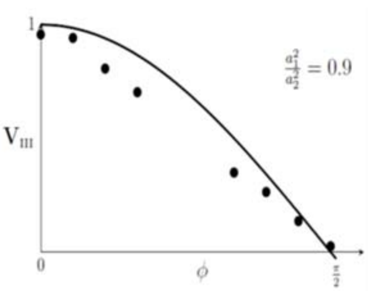
A review of the past paper [continued]

Vector product model**:** Electric vectors remain independent. Dipoles take the vector product of the joint stimulations. ***This model is supported by experimental visibility data in the figure below.***

$$\begin{aligned} D(\tau) &= \left|\chi\left[\hat{\chi}_1 a_1 e^{i2\pi\nu t} + \hat{\chi}_2 a_2 e^{i2\pi\nu_2(t+\tau)}\right]\right|^2 \\ &= \chi^2[a_1^2 + a_2^2 + 2a_1 a_2(\hat{\chi}_1\cdot\hat{\chi}_2)\cos 2\pi\nu\tau] \\ &= \chi^2(a_1^2 + a_2^2)[1 + V_{VP}\cos\varphi\cos 2\pi\nu\tau] \end{aligned} \qquad (3)$$

$$V_{VP} = 2a_1 a_2\cos\varphi \big/ (a_1^2 + a_2^2)$$

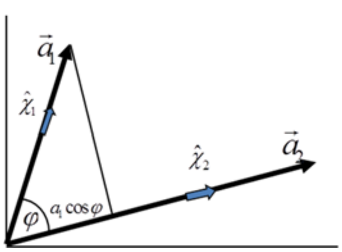


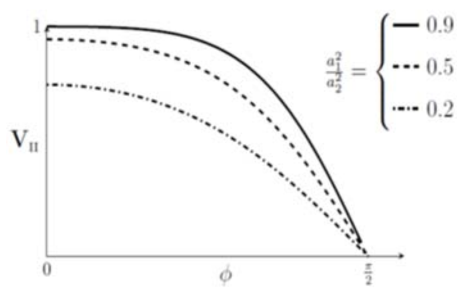


Pre-polarizing model: Material dipoles are first polarized by the strongest E-vector. The polarized material dipoles then take the projections of the weaker E-vectors to create the resultant response.

$$\begin{aligned} D(\tau) &= \left|\chi\hat{\chi}_1[a_1 e^{i2\pi\nu t} + a_2\cos\varphi e^{i2\pi\nu(t+\tau)}]\right|^2 \\ &= \chi^2(\hat{\chi}_1\cdot\hat{\chi}_1)[a_1^2 + a_2^2\cos^2\varphi + 2a_1 a_2\cos\varphi\cos 2\pi\nu\tau] \\ &= \chi^2\{a_1^2 + a_2^2\cos^2\varphi\}[1 + V_{II}\cos 2\pi\nu\tau] \end{aligned} \qquad (4)$$

$$V_{SEV} = 2a_1 a_2\cos\varphi \big/ [a_1^2 + a_2^2\cos^2\varphi]$$





The Pre-polarization model is not supported by very slow fall in visibility when compared with the curve for Vector product model, above.

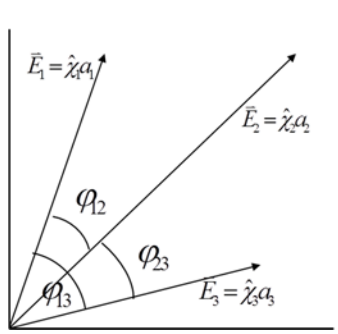
Two polarized beam superposition is not that strongly discriminating!
So we have decided to study 3 and N-beam cases!

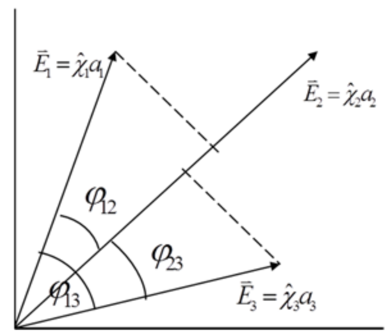
========== **Slide #7** ==========

CASE FOR 3-POLARIZED BEAMS

How do the QM dipoles (uniaxial stimulation) respond to the simultaneous presence of multiple stimulating E-vectors of different orientations?

Does it follow *(i) Vector product mode, or:* (ii) *Pre-polarization model*





(i) Does the QM dipole take all possible paired vector products? (ii) Does the strongest E-vector polarize the dipole in its preferred axis?

========== **Slide #8** ==========

The QM dipole takes all possible paired vector products (traditional square modulus).

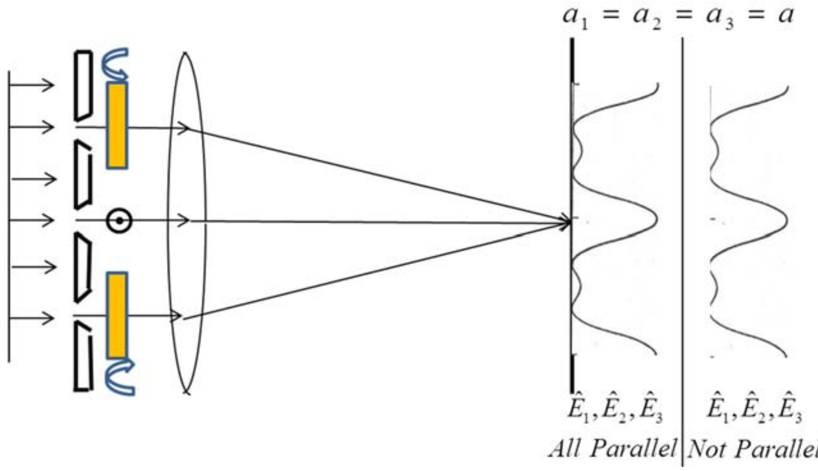
$$\Psi(t,\tau) = \hat{\chi}_1 \chi a_1 e^{i2\pi\nu t} + \hat{\chi}_2 \chi a_2 e^{i2\pi\nu(t+\tau)} + \hat{\chi}_3 \chi a_3 e^{i2\pi\nu(t+2\tau)}$$

$$D_{Dif.pol}(\tau) \equiv \Psi^*\Psi = \chi^2[a_1^2 + a_2^2 + a_3^2] + \chi^2[(\hat{\chi}_1 \cdot \hat{\chi}_2)a_1 a_2 e^{-i2\pi\nu\tau} + (\hat{\chi}_2 \cdot \hat{\chi}_1)a_2 a_1 e^{+i2\pi\nu\tau}$$
$$+(\hat{\chi}_1 \cdot \hat{\chi}_3)a_1 a_3 e^{-i4\pi\nu\tau} + (\hat{\chi}_3 \cdot \hat{\chi}_1)a_3 a_1 e^{+i4\pi\nu\tau}$$
$$+(\hat{\chi}_2 \cdot \hat{\chi}_3)a_2 a_3 e^{-i2\pi\nu\tau} + (\hat{\chi}_3 \cdot \hat{\chi}_2)a_3 a_2 e^{+i2\pi\nu\tau}]$$

$$D_{Dif.pol}(\tau) = \chi^2[a_1^2 + a_2^2 + a_3^2] + 2\chi^2[a_1 a_2 \cos\varphi_{12}\cos 2\pi\nu\tau + a_1 a_3 \cos\varphi_{13}\cos 4\pi\nu\tau$$
$$+a_2 a_3 \cos\varphi_{23}\cos 2\pi\nu\tau] \qquad (5)$$
$$\equiv \chi^2 A_{123}^2 + 2\chi^2[(a_1 a_2 \cos\varphi_{12} + a_2 a_3 \cos\varphi_{23})\cos 2\pi\nu\tau + a_1 a_3 \cos\varphi_{13}\cos 4\pi\nu\tau]$$

$$D_{\text{AllPrlal}}(\tau) = \chi^2 A_{123}^2 + 2\chi^2[(a_1 a_2 + a_2 a_3)\cos 2\pi\nu\tau + a_1 a_3 \cos 4\pi\nu\tau]$$
$$= \chi^2 a^2[3 + 4\cos 2\pi\nu\tau + 2\cos 4\pi\nu\tau]; \quad \text{For } \begin{cases} a_1 = a_2 = a_3 = a \\ \varphi_1 = \varphi_2 = \varphi_3 = 0 \end{cases}$$

========== **Slide #9** ==========

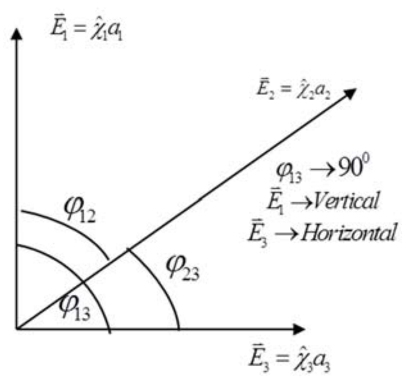


(Gathering equipment. Measurement of a_1, a_2 & a_3 must be done with extreme precision.)

========== **Slide #10** ==========

CASES TO ANALYZE

The QM dipole takes all possible paired vector products (3-beam case)
Special case: **Two outer vectors are orthogonal to each other,** $\varphi_{13} = 90^0$**.**



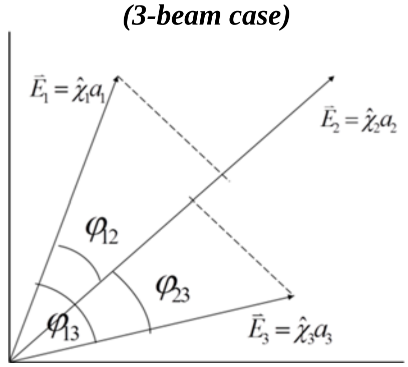
$$\begin{aligned} D_{Dif.pol}(\tau) &= \chi^2[a_1^2 + a_2^2 + a_3^2] + 2\chi^2[a_1 a_2 \cos\varphi_{12} \cos 2\pi\nu\tau + a_1 a_3 \cos\varphi_{13} \cos 4\pi\nu\tau \\ &\qquad + a_2 a_3 \cos\varphi_{23} \cos 2\pi\nu\tau] \\ &= \chi^2 A_{123}^2 + 2\chi^2[(a_1 a_2 \cos\varphi_{12} + a_2 a_3 \cos\varphi_{23}) \cos 2\pi\nu\tau + a_1 a_3 \cos\varphi_{13} \cos 4\pi\nu\tau] \\ &= \chi^2 A_{123}^2 + 2\chi^2[(a_1 a_2 \cos\varphi_{12} + a_2 a_3 \cos\varphi_{23}) \cos 2\pi\nu\tau] \end{aligned} \tag{6}$$

========== **Slide #11** ==========

CASES TO ANALYZE

(ii) Pre-polarization model: **QM dipole is pre-polarized by the strongest E-vector; then the projected components of other vectors are taken into account by the dipole.**

(3-beam case)



Strongest E-vector polarizes the dipole. Then it takes projection of other E-vectors.
Cosine projection of E_1 and E_3 onto the strongest E_2 are taken:

$$\Psi(t,\tau) = \hat{\chi}_1\chi a_1 e^{i2\pi\nu t} + \hat{\chi}_2\chi a_2 e^{i2\pi\nu(t+\tau)} + \hat{\chi}_3\chi a_3 e^{i2\pi\nu(t+2\tau)}$$

$$= \hat{\chi}_2\chi a_1 cos\varphi_{12} e^{i2\pi\nu t} + \hat{\chi}_2\chi a_2 e^{i2\pi\nu(t+\tau)} + \hat{\chi}_2\chi a_3 cos\varphi_{23} e^{i2\pi\nu(t+2\tau)}$$

$$= \hat{\chi}_2\chi [a_1 cos\varphi_{12} e^{i2\pi\nu t} + a_2 e^{i2\pi\nu(t+\tau)} + a_3 cos\varphi_{23} e^{i2\pi\nu(t+2\tau)}]$$

Conjugate: $a_1 cos\varphi_{12} e^{-i2\pi\nu t} + a_2 e^{-i2\pi\nu(t+\tau)} + a_3 cos\varphi_{23} e^{-i2\pi\nu(t+2\tau)}$

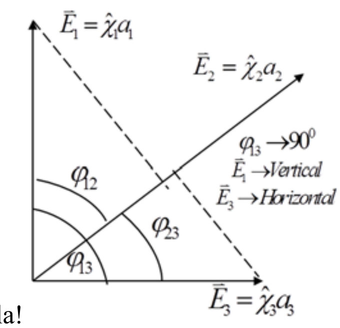
$$\begin{aligned}
D_{All.pol.}(\tau) \equiv \Psi^*\Psi &= \chi^2[a_1^2 cos^2\varphi_{12} + a_2^2 + a_3^2 cos^2\varphi_{23}] + \\
&+\chi^2[a_1 a_2 cos\varphi_{12} e^{-i2\pi\nu\tau} + a_1 a_3 cos\varphi_{12} cos\varphi_{23} e^{-i4\pi\nu\tau} \\
&+a_2 a_1 cos\varphi_{12} e^{+i2\pi\nu\tau} + a_2 a_3 cos\varphi_{23} e^{-i2\pi\nu\tau} \qquad (7)\\
&+ a_3 a_1 cos\varphi_{23} cos\varphi_{12} e^{+i4\pi\nu\tau} + a_3 a_2 cos\varphi_{23} e^{+i2\pi\nu\tau}] \\
&=\chi^2[a_1^2 cos^2\varphi_{12} + a_2^2 + a_3^2 cos^2\varphi_{23}] + 2\chi^2[(a_1 a_2 cos\varphi_{12} \\
&\quad + a_2 a_3 cos\varphi_{23})\cos 2\pi\nu\tau + a_1 a_3 cos\varphi_{12} cos\varphi_{23} \cos 4\pi\nu\tau]. \\
&= \chi^2 a^2 (cos^2\varphi_{12} + 1 + cos^2\varphi_{23}) + 2\chi^2 a^2[(cos\varphi_{12} + cos\varphi_{23})\cos 2\pi\nu\tau \\
&\quad + cos\varphi_{12} cos\varphi_{23} \cos 4\pi\nu\tau]\text{ ; For } a_1 = a_2 = a_3 = a.
\end{aligned}$$

$$D_{ParlalPol.}(\tau) = \chi^2 a^2 [3 + 4\cos 2\pi\nu\tau + 2\cos 4\pi\nu\tau];\ \varphi_{23} = \varphi_{12} = 0$$

========== **Slide #12** ==========

The QM dipoles are polarized by the strongest E-vector.

Special case: Two outer vectors are orthogonal to each other



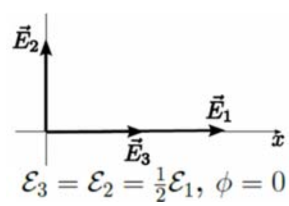
$\varphi_{13} = 90^0$ does not come into play in the formula!

$$D_{All.pol.}(\tau)$$
$$= \chi^2[a_1^2 cos^2\varphi_{12} + a_2^2 + a_3^2 cos^2\varphi_{23}] + 2\chi^2[(a_1 a_2 cos\varphi_{12} + a_2 a_3 cos\varphi_{23})\cos 2\pi\nu\tau + a_1 a_3 cos\varphi_{12} cos\varphi_{23} \cos 4\pi\nu\tau] \quad (8)$$

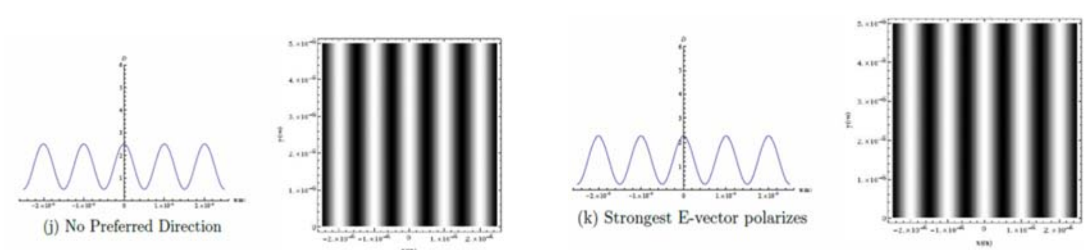
========== **Slide #13** ==========

Comparing fringe visibility. Special Case -1 (Effectively 2-parallel polarized beams in action)

E_2 is orthogonal to both E_1 & E_3



$$V = \frac{D_{\max} - D_{\min}}{D_{\max} + D_{\min}} \quad (9)$$



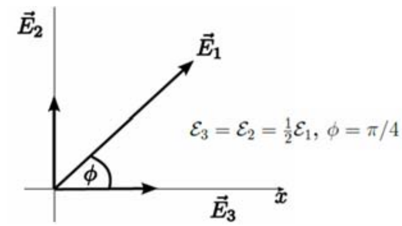
Vector product model (Left): Note that the visibility is a bit ***poorer*** than that for the ***pre-polarization model (Right).***

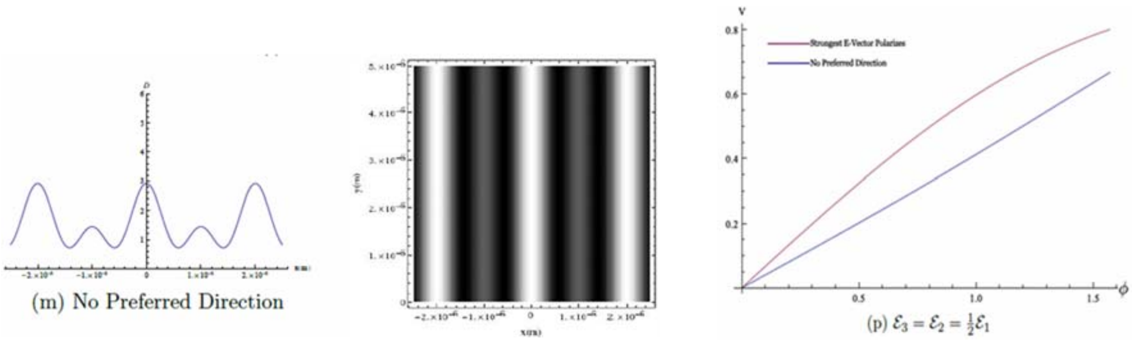
Note: We found the same analytical and measured result for the two beams cases.

========== Slide #14 ==========

Comparing fringe visibility. Special Case -2 (3-polatrized beams in action)

E_2 & E_3 are both orthogonal to E_1



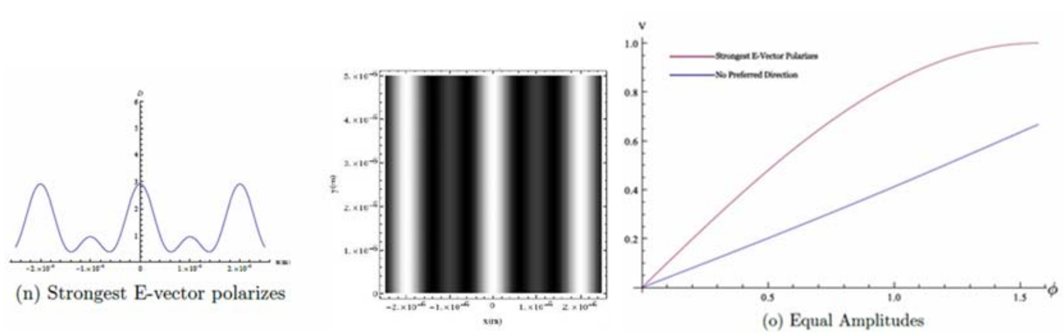


(m) No Preferred Direction

(p) $\mathcal{E}_3 = \mathcal{E}_2 = \frac{1}{2}\mathcal{E}_1$

Vector product model

Note that the visibility is a bit ***poorer*** (lower curve) for the vector product model (hence higher energy absorption per fringe interval) than that for the pre-polarization model. The angle of $\vec{E}_1$ is varied to obtain visibility variation.



(n) Strongest E-vector polarizes

(o) Equal Amplitudes

Pre-polarization model

Note that the visibility is always a bit stronger for the pre-polarization model and hence less energy absorption per fringe interval (upper curve); when compare with that for the vector product model. The angle of $\vec{E}_1$ is varied to for visibility variation.

========== **Slide #15** ==========

Formulations for N-polarized beams

I (i) Vector product model: The QM dipole takes all possible paired vector products. We are assuming the simple case of periodic phase delays, as if we have an N-slit grating with alterable polarization states.

$$\Psi(t,\tau) = \chi \sum_{n=1}^{N} \hat{\chi}_n a_n e^{i2\pi\nu(t+n\tau)}$$

$$D_{pol}(\tau) \equiv \Psi^*\Psi = \chi^2 \left[\sum_{n=1}^{N} \hat{\chi}_n a_n e^{-i2\pi\nu(t+n\tau)} \right] \left[\sum_{m=1}^{N} \hat{\chi}_m a_m e^{i2\pi\nu(t+m\tau)} \right]$$

$$= \chi^2 \left[\sum_{n=1}^{N} a_n^2 \right] + \chi^2 \sum_{\substack{m,n=1 \\ m \neq n}}^{N} (\hat{\chi}_m \cdot \hat{\chi}_n) a_m a_n e^{2\pi\nu(m-n)\tau} \qquad (10)$$

$$= \chi^2 \left[\sum_{n=1}^{N} a_n^2 \right] + 2\chi^2 \sum_{\substack{m,n=1 \\ m \neq n}}^{N} a_m a_n cos\varphi_{mn} \cos 2\pi\nu(m-n)\tau$$

$$= \chi^2 a^2 \left[N + 2 \sum_{\substack{m,n=1 \\ m \neq n}}^{N} cos\varphi_{mn} \cos 2\pi\nu(m-n)\tau \right]; \text{ For all } a_m = a_n = a$$

========== **Slide #16** ==========

Formulations for N-polarized beams

I (ii) Pre-polarization model: The QM dipole is pre-polarized by the strongest E_N-vector; cosine projections are taken for all other vectors on the E_N-vector .

$$\Psi(t,\tau) = \chi \sum_{n=1}^{N} \hat{\chi}_n a_n e^{i2\pi\nu(t+n\tau)}$$

$$= \chi \sum_{n=1}^{N} \hat{\chi}_N (\hat{\chi}_n \cdot \hat{\chi}_N) a_n e^{i2\pi\nu(t+n\tau)}; \text{ Vector projections on strongest } \hat{\chi}_N$$

$$= \hat{\chi}_N \chi \sum_{n=1}^{N} a_n cos\varphi_{Nn} \; e^{i2\pi\nu(t+n\tau)}; \; \varphi_{Nn} \text{angle between } \hat{\chi}_N \; \& \; \hat{\chi}_n \qquad (11)$$

$$D_{pol.}(\tau) \equiv \Psi^*\Psi = \chi^2 \left[\sum_{n=1}^{N} a_n cos\varphi_{Nn} \; e^{-i2\pi\nu(t+n\tau)} \right] \left[\sum_{m=1}^{N} a_m cos\varphi_{Nm} \; e^{+i2\pi\nu(t+n\tau)} \right]$$

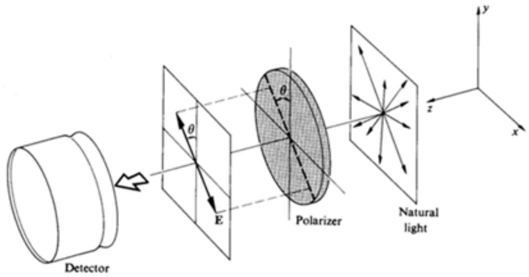
$$= \chi^2 \sum_{n=1}^{N} a_n^2 cos^2\varphi_{Nn} + 2\chi^2 \sum_{\substack{m,n=1 \\ m \neq n}}^{N} a_m a_n cos\varphi_{Nm} cos\varphi_{Nn} \cos 2\pi\nu(m-n)\tau \; ; [\varphi_{N0} \equiv 0]$$

========== **Slide #17** ==========

CASES TO ANALYZE

II. Energy transfer process due to multiple polarized beams during propagation through bulk polarized material:

In the absence of quantum transitions, classical optical analyses are correct. Malus' cosine-squared-law gives the energy. But?



[From "Optics" by Hecht, Addison-Wesley]

Intensity law: $I_{out} = I_{in}\cos^2\theta$. Amplitude law: $a_{out} = a_{in}\cos\theta$

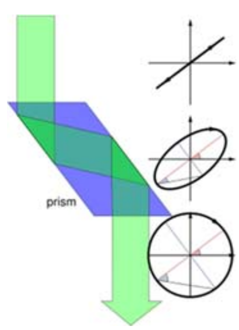
But, the light-matter interactions are still initiated by amplitude-amplitude stimulations. Jones' coherent matrix formulation correctly formulates the situation. Energy is quantified only after the absorption by a detector. Nicol Prism and Fresnel Rhomb re-organize the amplitudes of the incident beams. Non-Interaction of Waves (NIW) remains valid. Next slide explains how the NIW-property is accepted by the Jones" matrices

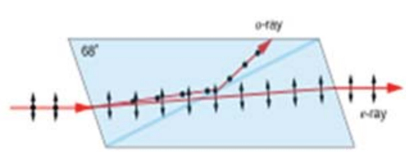
========== **Slide #18** ==========

Polarization beam propagation theory remains correct! Each component is propagated separately. E_x and E_y never interact (interfere) with each other, validating the NIW-property [2]!

$$\begin{vmatrix} E_{out-x} \\ E_{out-y} \end{vmatrix} = \begin{vmatrix} a_{1x} a_{1y} \\ a_{2x} a_{2y} \end{vmatrix} \begin{vmatrix} E_{in-x} \\ E_{in-y} \end{vmatrix} \qquad (12)$$

$$\text{Intensity is: } I = \left|\vec{\chi}_x E_{out-x}\right|^2 + \left|\vec{\chi}_y E_{out-y}\right|^2$$
$$\text{and not : } \quad I = \left|E_{out-x} + E_{out-y}\right|^2 \; ! \qquad (13)$$





[From Wikipedia]

Fresnel Rhomb ***Nicol Prism***

A 45-degree polarized beam generates
a circularly polarized beam. Energy is split into two beams.

Nicol Prism

Polarized bulk molecules in a Nicol prism can convert the randomly polarized light into two perfectly polarized beams, phase-random or phase-steady.

========== Slide #19 ==========

Summary and Conclusions

We have been pursuing the development of a visualizable model for light-mater interactions process during energy absorption. We are assuming that the electric field of a light wave behaves like a linear vector defined in the space by the Poynting vector and the magnetic vector (Maxwell's wave equation). Interaction models explored are:

1. ***Vector product model:*** In the presence of multiple stimulating electric vectors (multiple polarized beams), the resultant amplitude stimulation experienced by a detecting molecule is given by the sum of all possible pair-wise vector product of all the stimulating E-vectors. This is the more likely model from the standpoint of our experiments, analyses and higher energy absorption capability out of the field. This has been the standard approach in classical and quantum physics.
2. ***Pre-polarization model:*** In the presence of multiple stimulating electric vectors (multiple polarized beams), the resultant amplitude stimulation experienced by a detecting molecule is given by the cosine projection of all the stimulating E-vectors onto the strongest E-vector direction, which preferentially pre-polarizes the detecting molecule because of its strength. **This is a less likely model even though expressions and the quantitative values are closely similar.**
3. ***Observation****:* The mathematical rule behind taking the square modulus of a complex function consisting of multiple linearly summed parameters, will always produce a set of "DC" squared terms and a set of "AC" terms consisting of cosine cross-products. Measured data is validated by the sum of all these terms together, not separately. Hence, it may not be the best investigative approach to seek out physically significant interaction process models by separating out the cross-product terms from the "DC" squared-terms, as we have done here. We cannot always trace such separated sets of terms to un-ambiguously validate-able physical interaction process. ***Our current mathematical tools may be limiting our search for visualization of invisible interaction processes.***