CELL MEMBRANE PHYSICAL MODEL IN NEAR INFRARED, VISIBLE, AND NEAR ULTRAVIOLET SPECTRA

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ABSTRACT

From recent experimental results we deduce a physical model of the cell membrane [21]. The transparent range, stretched from 0.22 to 0.9 µm, is located between two absorbing ranges. Four resonance wavelengths of the cell membrane are chosen to be in good agreement with the experimental results. Physical theories are used to calculate the membrane complex index of refraction. The cell membrane permeability appears following its transmission coefficient which has been found. The high value of the radiation pressure calculated inside the membrane due to pulsated infrared light could explain the acceleration of the CV_1 cells microtubules array disassembly. The theory explains the increasing of the mitochondria fluorescence irradiated with an ultraviolet light. Then a physiological or artificial low frequency signal due to one nervous fiber diffraction, acting upon ions, could produce an ionizing radiation in UV spectrum.

INTRODUCTION

A pair of centrioles is able to detect the direction of a near infrared 0.8 µm wavelength source in a one-to-one fashion [1] and [2]. Several peaks of the autofluorescence spectrum in the visible range of the mitochondria of living mammalian cells flared up threefold or more when irradiated with UV light at 0.365 µm [3]. The amount of energy required for triggering the cell division turned about 5eV corresponding to $\lambda_0 = 0.247$ µm [4]. Electrons of very low energies can induce substantial yields of single and double strand breaks in D.N.A. in near I.R. spectrum [5] and [6]. To establish the theory of the cell division one supposed a high conductivity for the cell membrane [7] and [8]. Albrecht-Buchler supposed that centriolar "blades" or microtubular arrays have high conductivity [9]. In spite of a high conductivity chosen in our study we show that the displacement current is always greater than the conduction one in the cell membrane. Its selective transparence is the subject of our paper.

The physical model is shown in fig. 1. $\tilde{n} = n - jk$ is a complex index of refraction. The membrane thickness d is comprised between 7 and 9 nm. The physical parameters permittivity ε_r and conductivity σ of the living organs are given in terms of frequency [10]. We have in a no scattered medium :

$$2n^2 = \varepsilon_r + \left[(\varepsilon_r)^2 + \left(\frac{\sigma}{\varpi \varepsilon_0} \right)^2 \right]^{1/2} \quad (1) \qquad 2k^2 = -\varepsilon_r + \left[(\varepsilon_r)^2 + \left(\frac{\sigma}{\varpi \varepsilon_0} \right)^2 \right]^{1/2} \quad (2)$$

For many organs at the limit frequency of 20 Ghz we have [10] : $10 < (\varepsilon_r \text{ and } \sigma) < 30$ that is with (1) and (2) : $3.42 < n < 5.93$ and $0.81 < k < 3.06$. Beyond 20 GHz, σ trends upward very quickly while ε_r trends downward slowly. At $f = 10^{12}$ Hz with $\sigma_2 = 10^5$ S/m and $(\varepsilon_r)_2 = 30$ we calculate from (1) and (2) : $\tilde{n}_2 = 30\text{-}j30$. Nevertheless we cannot use (1) and (2) in our membrane transparent range which is located between two absorption ranges due to the forced oscillations of various particles such as : ions, electrons and so on. The interstitial medium equivalent to sea water corresponds to [12] : $\sigma_1 = 70$ S/m and $(\varepsilon_r)_1 = 7$. Then we find $n_1 = 2.65$ and with $k_1 = (k_{m1}) = 30\,\sigma_1 \lambda_0 / \sqrt{(\varepsilon_r)_1}$: $k_1 = 8.10^{-4}\,\lambda_0$ (µm) and an attenuation of 4.410^{-2} dB/µm. For the cellular medium (centrioles, microtubules, nucleus…) we adopt : $\sigma_3 = 7.10^3$ S/m and $(\varepsilon_r)_3 = 7$. With (1)

and (2) we deduce : $n_3 = 2.65$ and $k_3 = (k_m)_3 = 8.10^{-2}\ \lambda_0\ (\mu m)$ with an attenuation of 4.3. dB/µm. For the four resonances selected, from which the membrane is particularly permeable, the Table I gives $n_2(0)$ corresponding to d = 9 nm and $(\lambda_0)_M$ given by (3) :

$$(3)\ (\lambda_0)_M = \frac{2d(n_2)_0}{N} \qquad \text{N : is a positive whole number.}$$

The membrane index of refraction $(n_2)_0$ in the transparent range is given by the Sellmeier's relation (4) :

$$(4)\ \left[(n_2)_0\right]^2 = \frac{G_1}{\left(\frac{\lambda_0}{\lambda_1}\right)^2 - 1} + \frac{G_2}{\left(\frac{\lambda_0}{\lambda_2}\right)^2 - 1} + G_0 \qquad (5)\ \begin{cases} n_2^2 - k_2^2 = \dfrac{G_i\ \lambda_i^2\ (\lambda_0^2 - \lambda_i^2)}{(\lambda_0^2 - \lambda_i^2)^2 + \Gamma_i^2\ \lambda_0^2\ \lambda_i^2} + G_0 \\ 2n_2\, k_2 = \dfrac{\Gamma_i\, G_i\ \lambda_i\ \lambda_0^3}{(\lambda_0^2 - \lambda_i^2)^2 + \Gamma_i^2\ \lambda_0^2\ \lambda_i^2} \end{cases}$$

In one absorption range centered at λ_i (λ_1 or λ_2) the Ketteler-Helmholtz's formulas (5) are given.

$0.01 < \Gamma_i < 0.1$ is the constant of the forced oscillating particles at $f_i = c/\lambda_i$. λ_1 is related to heavy particles (ions, atoms, molecules) oscillating in I.R. λ_2 is related to electrons oscillating in U.V. The coefficients G_0, G_1, G_2 and λ_2 in (4) have been calculated with $\lambda_1 = 1$ µm in I.R. We found $G_0 = 2251$, $G_1 = 783$, $G_2 = 591$ and $\lambda_2 = 0.211$ µm. The fig. 2 shows $n_2(0)$ in terms of λ_0 (µm). With (5) $\tilde{n}_2$ are given around λ_1 (with $\Gamma_1 = 0.05$) in fig. 3 and around λ_2 (with $\Gamma_2 = 0.01$) in fig. 4.

For an incident wave E_{1i} (fig. 1) we can neglect the incident wave E_{3i} because a linear attenuation of 4.3 dB/µm. With the linear propagation constant $\Gamma_2 = \frac{2\pi\ k_2}{\lambda_0} + j\frac{2\pi}{\lambda_0}\ n_2$ (6), the transmission T_{13} and reflexion R_{13} coefficients are expressed in (7) and (8) :

$$\frac{1}{T_{13}} = \frac{E_{1i}}{E_{3r}} = \frac{1}{2}\left(1 + \frac{\tilde{n}_3}{\tilde{n}_1}\right) ch\ (\Gamma_2 d) + \frac{1}{2}\left(\frac{\tilde{n}_2}{\tilde{n}_1} + \frac{\tilde{n}_3}{\tilde{n}_2}\right) sh\ (\Gamma_2 d) \qquad (7)$$

$$R_{13} = \frac{E_{1r}}{E_{1i}} = \frac{\left(1 - \frac{\tilde{n}_3}{\tilde{n}_1}\right) ch\ (\Gamma_2 d) + \left(\frac{\tilde{n}_3}{\tilde{n}_2} - \frac{\tilde{n}_2}{\tilde{n}_1}\right) sh\ (\Gamma_2 d)}{\left(1 + \frac{\tilde{n}_3}{\tilde{n}_1}\right) ch\ (\Gamma_2 d) + \left(\frac{\tilde{n}_3}{\tilde{n}_2} + \frac{\tilde{n}_2}{\tilde{n}_1}\right) sh\ (\Gamma_2 d)} \qquad (8)$$

Modulus of T_{13} is shown in fig. 5 and fig. 6 with different scales for the wavelength λ_0.

We note a slight shift of the resonance wavelength when we compare tables I and II. That is due to the absorption coefficient.

In the transparent range from (7) we deduce :

$$\left|(T_0)_{13}\right|^{-2} = \cos^2\left(\frac{2\pi d}{\lambda_0} n_2\right) + \frac{1}{4}\left(\frac{n_2}{n_1} + \frac{n_1}{n_2}\right)^2 \sin^2\left(\frac{2\pi d}{\lambda_0} n_2\right) \qquad (9)$$

At the resonance wavelength : $\lambda_m = 2d / N = (\lambda_0)_M / (n_2)_0$ (10) we have : $|(T_0)_{13}| = 1$. The instantaneous electrical value inside the membrane is :

$$e_2(z,t) = E_{3r}\ \cos\left[\varpi\left(t - z n_2 \sqrt{\mu_0 \varepsilon_0}\right)\right] \qquad (10)\ \text{with :}$$

$$\frac{E_2(0)}{E_2(d)} = \frac{e_2(0,t))}{e_2(d,t))} = \cos\left(\frac{2\pi d}{\lambda_0} n_2\right) + j\frac{n_1}{n_2} \sin\left(\frac{2\pi d}{\lambda_0} n_2\right) \quad (11).\ \text{At the resonance :}\ \frac{E_2(0)}{E_2(d)} = (-1)^N$$

The fig. 7 shows some examples. For the wavelengths $(\lambda_0)_p = 2d(n_2)_0 \Big/ P + \frac{1}{2}$ we obtain : $\left|(T_0)_m\right|_{13} = 2 \Big/ \left(\frac{n_1}{n_2} + \frac{n_2}{n_1}\right)$. P is a positive or null whole number (fig. 5 and 6). As : $|E_2(d)| \geq |E_2(0)|$ from (9) we have $|E_{3r}| \geq |E_2(0)| = |E_{1i} + E_{1r}|$. We deduce the maximum pressure P_M [11] : $P_M = \frac{1}{2} n_2^2 \, \varepsilon_0 |E_{3r}|^2$ (12). In response to infrared light pulses, the centrosome may send destabilizing signals along its radial array of microtubules [9]. The migration of the epithelial CV1 cell towards a pulsed light source for $\lambda_0 = 0.8$ µm and with an isotropic radiated power $P_E = 4$ µW, is explained by extension of specific pseudopodia at the cell periphery. The migration appears when the distance ρ from the source to the cell is lower or equal to 60 µm. Then with [13] and [14] we can write : $E_{1i} = ex\rho(-\rho/\delta_1) \bullet (1/\rho) \bullet (P_E/2\pi)^{1/2} \left(\mu_0 / n_1^2 \, \varepsilon_0\right)^{1/4}$ (13)

$$\text{with } \delta_1 = \frac{\lambda_0}{2\pi}\left[-\frac{(\varepsilon_r)_1}{2} + \frac{1}{2}\sqrt{(\varepsilon_r)_1^2 + \frac{\sigma_1^2}{\varpi^2 \, \varepsilon_0^2}}\right]^{-1/2} \cong \frac{\lambda_0}{2\pi(k_m)_1} \quad (14)$$

With $P_E = 4.10^{-6}$ watts, $\rho = 60$ µm, $n_1 = 2.65$, $\sigma_1 = 70$ S/m, $\lambda_0 = 0.810^{-6}$ m we find $\delta_1 = 200$ µm, $|E_{1i}| = 117$ V/m. Then we have $|E_{3r}| = 40$ V/m (fig. 6). At $\rho = 3$ µm, $|E_{3r}|$ becomes equal to 800 V/m. Then with $n_2 = 12.9$ (fig. 3), we deduce from (12) : $P_M = 4.10^{-4}$ Pascal. This pressure is one hundred times higher than the pressure of the solar radiation at the ground level [11].

The autofluorescence of mitochondria irradiated at $\lambda_0 = 0.365$ µm has been measured with a microspectrograph [3]. The 3T3 cells emitted two major peaks at 0.53 and 0.60 µm, and three minor peaks at 0.56, 0.65 and 0.75 µm. The accuracy of the peak locations is 10 nm. When the power density level of U.V. is lower 1 µW/mm^2, that is $|E_{1i}| < 27$ V/m, the reversible excitation light induced enhancement of fluorescence could no longer be observed.

The five peaks which have been observed experimentally are in good agreement with the large bandwidth permeability shown in fig. 6.

Biophotons are photons spontaneously emitted by all living systems from near I.R. to near U.V. ranges. Actually the intensity of biophotons can be registered from 0.2 to 0.8 µm, from a few photons per second and square centimeter surface, up to some hundred photons [15], [17]. It concerns low luminescence with a coherent photon field $\vec{E}$, its function being intra and extracellular regulation and communication. The number of photons during the time t which are going through the unit surface is equal to [11] : $n = \varepsilon_0 \, \lambda_0 \left|E\right|^2 t/2h$ (15) h is the Planck constant. We deduce in table III the $\left|\vec{E}\right|$ field. If we consider $0.2 < \lambda_0 < 0.8$ µm, $0.1 < |E_{3r} / E_{1i}| < 0.8$ (fig. 5 and 6), with (15) the number n can vary of $8^2 \times 4 = 256$ following [17].

The high degree of coherence of biophotons is due to the small distance of some angströms between neighboured base pairs of the DNA compared with the λ_0 of the light under study [17]. The ultraweak energy photons can explain the division of fibroblasts and the cancer mechanisms of human skin, the main modification of DNA molecules by U.V. radiation being the formation of pyrimidine dimers [6].

Let an ion be in the interstitial medium sollicited by an electrical field $\left|\vec{E}\right|$ of frequency f. Its cinetic energy is : $W_c(eV) = (1/2) \bullet (e/m)\left(\left|\vec{E}\right| / \varpi\right)^2$ (16). For a calcium ion e/m = 4.81 10^6 and for $W_c = 5$eV the cellular division appears if : $|E(V/m)| = 9.10^{-3} \, f(Hz)$ (17). Such a low frequency signal f could be the fundamental and harmonics of pulsed solitons [20].

The endogenous electric fields are not sufficient to induce a cellular division (17), but able to induce an ionic current along a nervous fiber which gives rise to an electric field of high amplitude by diffraction in a near environment [18]. This electric field can reach several dozens of kV/m which is sufficient to induce the cellular division. Then the application of the safety and precaution principle is essential.

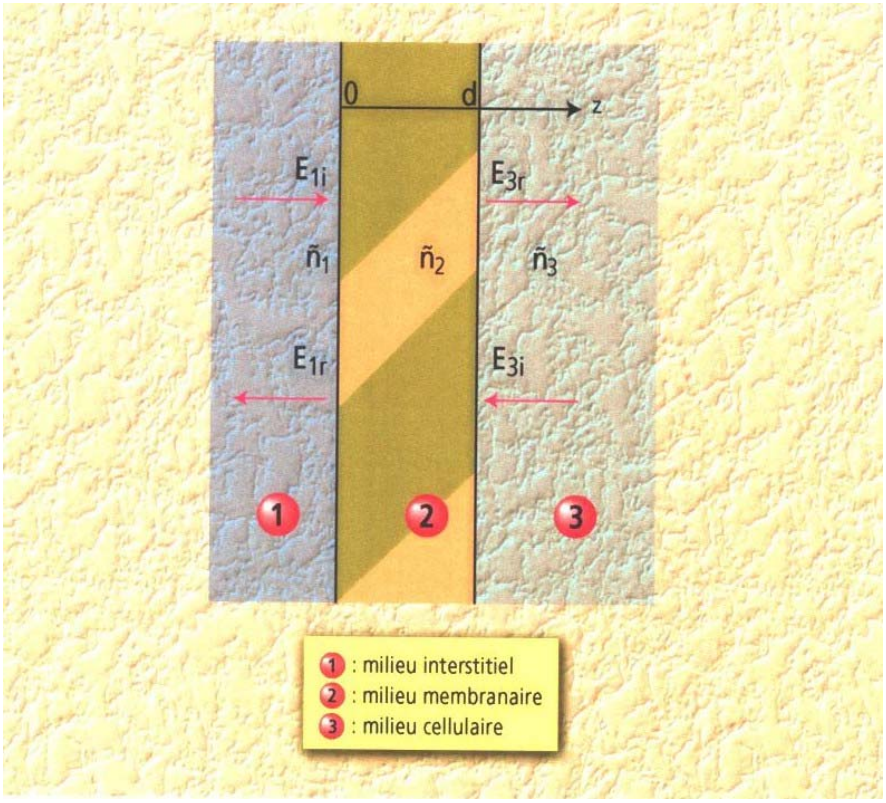

Figure 1 : Incident wave E_{3i} and reflected wave E_{1r} and E_{3r}, related to an incident wave E_{1i} of TEM mode falling with normal incidence upon the cellular plasmic membrane of a d thickness

(1) Interstitial medium (2) membrane medium (3) cellular medium

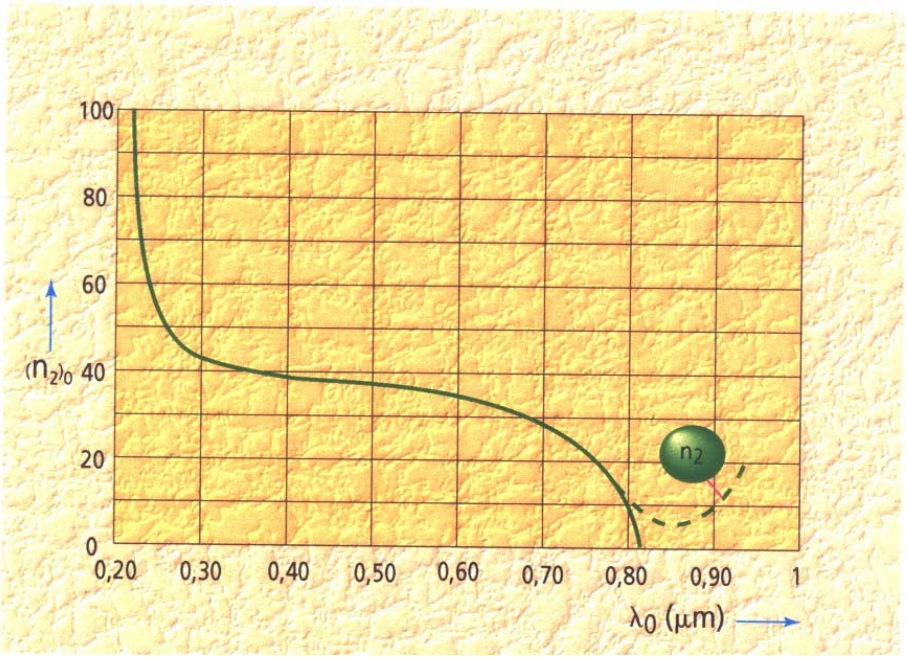

Figure 2 : Variations of the membrane index of refraction $(n_2)_0$ in the transparent range, in terms of the free space wavelength λ_0 (μm)

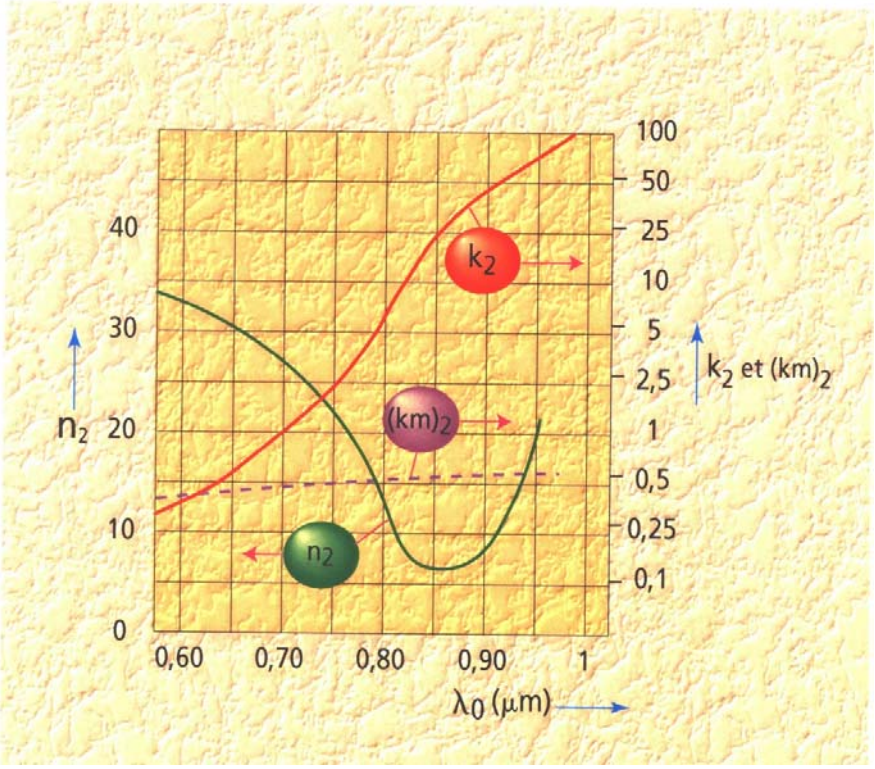

Figure 3 : Variations of the membrane complex index of refraction $\tilde{n}_2 = n_2 - jk_2$ in the infrared range in terms of the free space wavelength λ_0 (µm)

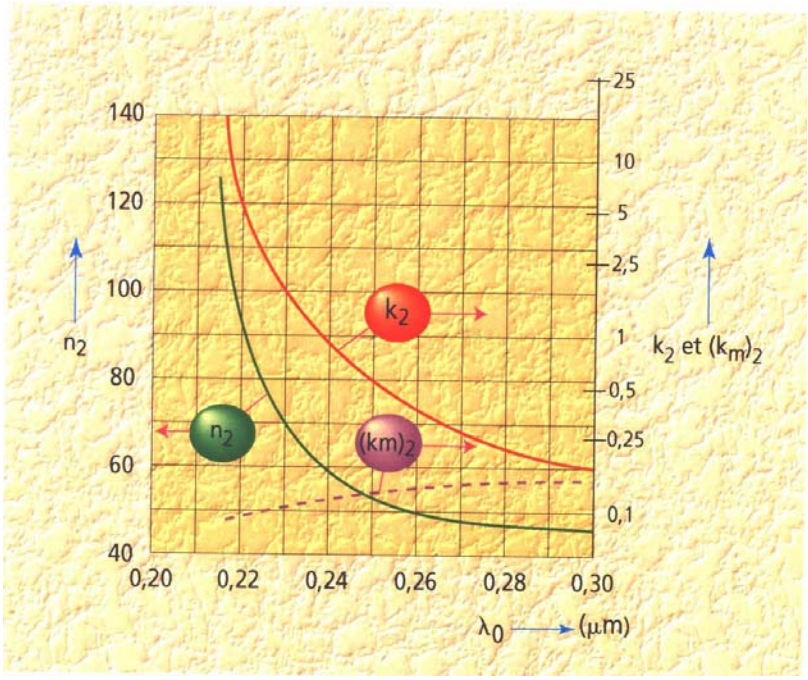

Figure 4 : Variations of the membrane complex index of refraction $\tilde{n}_2 = n_2 - jk_2$ in the ultraviolet range in terms of the free space wavelength λ_0 (µm)

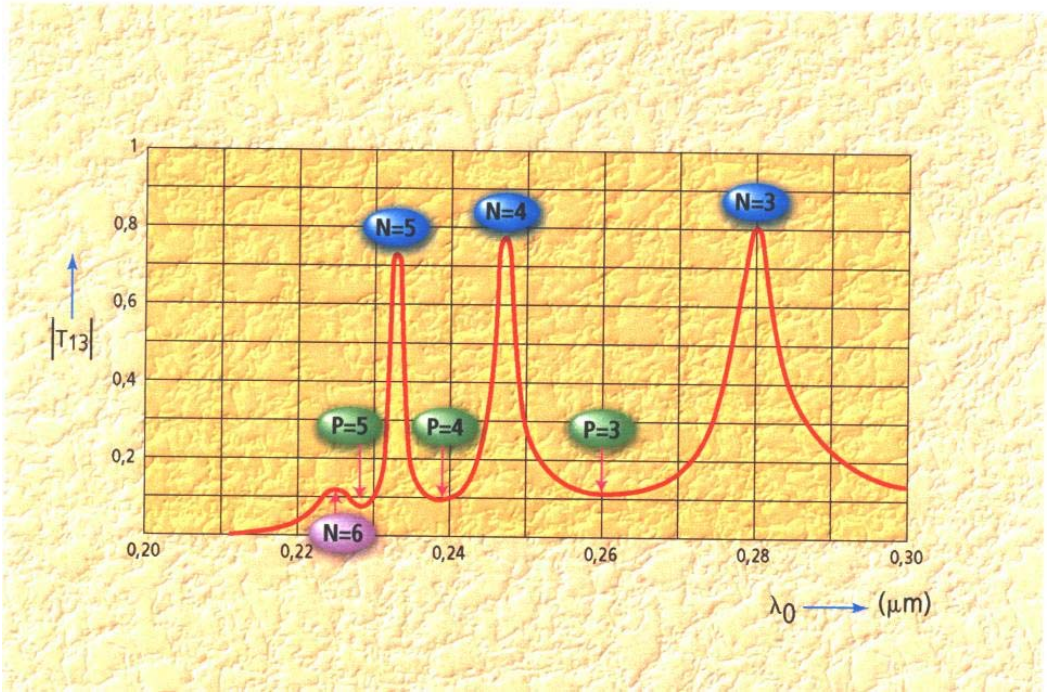

Figure 5 : Modulus variations of the membrane transmission coefficient T_{13} in the near ultraviolet range in terms of the free space wavelength λ_0 (µm)

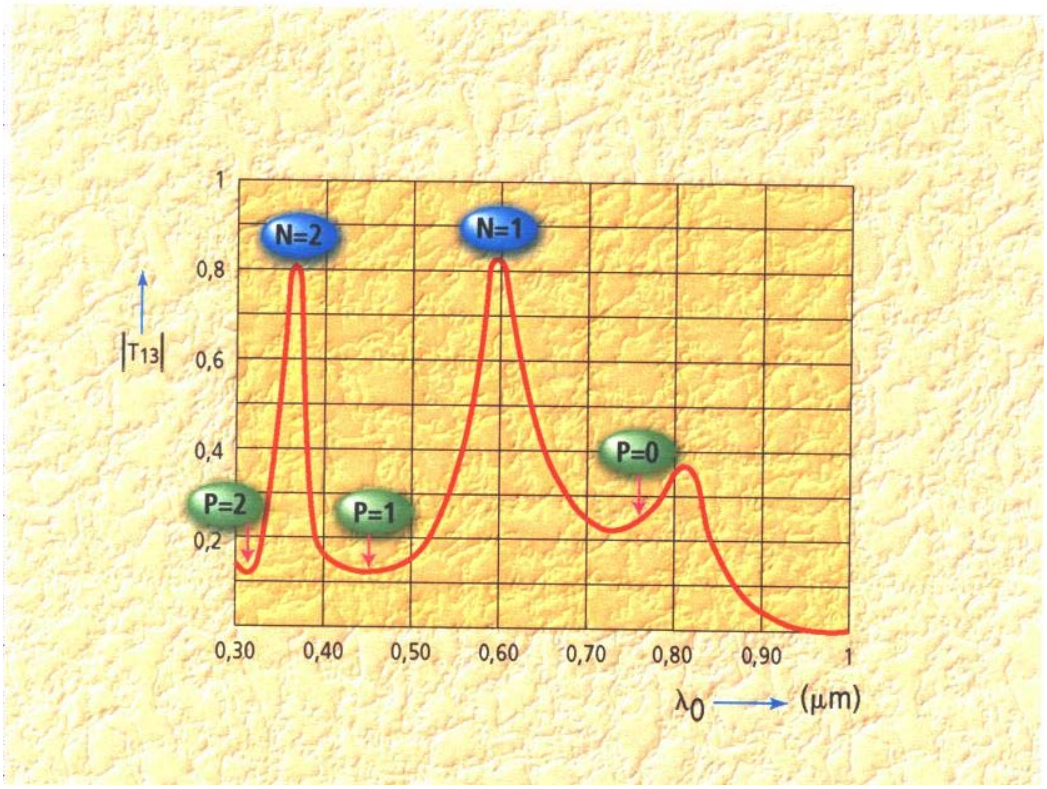

Figure 6 : Modulus variations of the membrane transmission coefficient T_{13} in the visible and near infrared range in terms of the free space wavelength λ_0 (µm)

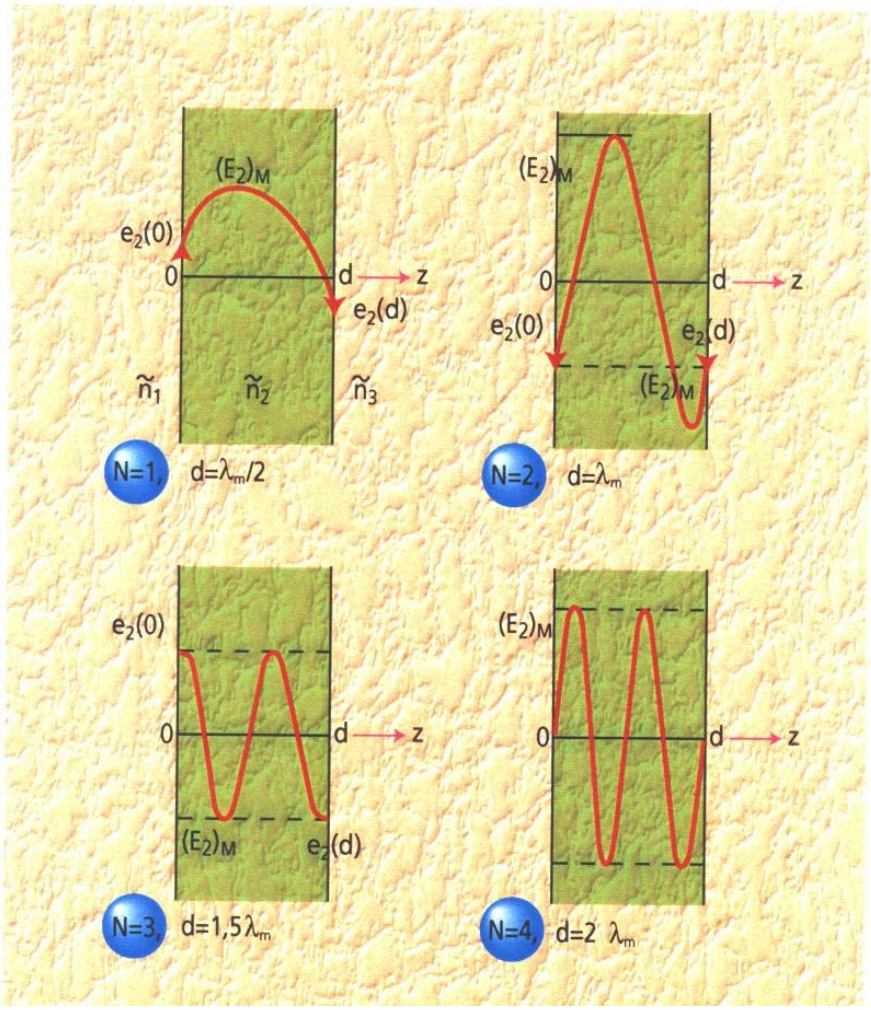

Figure 7 : Some examples of instantaneous electrical fields $e_2(z)$ of the TEM incident wave inside the cellular plasmic membrane for various resonances

N	$(\lambda_0)_M$ (3)	$(n_2)_0$ (4)	Nature of selected resonances
1	0.600 µm	33.33	Self-fluorescence of mitochondrias [3]
2	0.365	40.55	Excitation of the self-fluorescence of mitochondrias [3]
3	0.280	46.67	Denaturation of nucleoacids
4	0.247	54.89	5eV energy quantum [4]

Table I : Membrane resonances in the transparent range (without absorption)

N	$(\lambda_0)_M$	n_2	k_2	$(k_m)_2$
1	0.585 µm	32.5	0.32	0.33
2	0.373 µm	41.5	0.09	0.20
3	0.282 µm	47.0	0.25	0.15
4	0.247 µm	55.0	0.62.	0.13

Table II : Membrane resonances in the transparent range (with absorption)

λ_0 n (t=1/cm^2)	0.2 µm	0.4	0.6	0.8
1	2.7	1.9	1.6	1.35
10	8.7.	6.0	5.0	3.0
100	27.0	19.0	16.0	13.5
1000	87.0	60.0	50.0	30.0
Photon energy (eV)	6.4.	3.2.	2.1.	1.6

Table III : Coherent Electric field $\left|\vec{E}\right|(\mu V/m)$ associated with biophotons

SUMMARY

The cellular plasmic membrane is equivalent to a dispersive medium which cannot be assimilated to a metallic one for the displacement current is always higher than the conduction current. The high radiation pressure might contribute to explain the migration of the epithelial cell and the diassembly of the microtubules [9]. The large bandwidth of the membrane selectivity in the near infrared range is in good agreement with the measured autofluorescence of mitochondria irradiated with a near ultraviolet light [3]. We have shown it was possible to develop inside the human body an U.V. radiation by means of the succession of the following operations : emission of low frequency pulsed E.M. fields from a confined plasma [20], low frequency ionic currents along nervous fiber, low frequency and high amplitude electric field diffracted by the nervous fiber [18], excitation of ions inducing U.V. radiation in the interstitial medium and inside the cells [21]. A recent publication [19] discerns differences between healthy and cancer cells valid for the low frequencies; In prospects it would be important to study in the U.V. range the influence of such differences upon their indexes of refraction. Their behaviour in terms of frequency would allow to bring successful therapies with full knowledge of the facts.

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