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PHOTON SUCKING AS AN ESSENTIAL PRINCIPLE OF BIOLOGICAL REGULATION

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1. INTRODUCTION

The term *photon sucking* we understand as the *active* absorption of light. Contrary to passive absorption, this means that light becomes partially reabsorbed as soon as it is emitted or reemitted by the tissue under study. A typical example is displayed in Fig. 1.

The first observations of "photon sucking" in living tissues can be traced back to the strange phenomenon of oscillations around the relaxation curve of delayed luminescence (Popp et al., 1981). After confirmation of these findings by Chwirot et al. (1987), Schamhart and van Wijk (1987) observed some kind of photon-induced photon absorption in normal cell cultures of sufficiently high cell density, whereas this effect disappeared completely in tumor cell cultures (Fig. 2). As shown by Scholz et al. (1988), these effects are strongly correlated with the degree of coherence of the reemitted photons (Fig. 3). An even deeper understanding of this phenomenon was provided by the dissertation of M. Galle (1993). Figure 4 shows evidence of maxima and minima of biophoton emissions that were documented in populations of daphnia (and other animals), dependent on their average distances. These interference structures could be assigned to long-range interactions of the living organisms, establishing the organization of swarming, or, in more general terms, the "Gestaltbildung," of cell populations and the basis of intercellular communication. Beloussov (1997) pointed to photon sucking effects in eggshells, which behave rather differently depending on whether they are bound to their eggs or isolated. He generalized the results in case of embryonic batches of neurula stage frog embryos and loach embryos (Beloussov and Louchinskaia, 1998; Beloussov, 2002), and he established the connection to organization and communication of biological systems.

Further indications of photon sucking can be gathered from the experimental results of Vogel et al. (1998), who showed under our guidance in our laboratory that some bacteria suck up light from their nutrition medium (Fig. 5).

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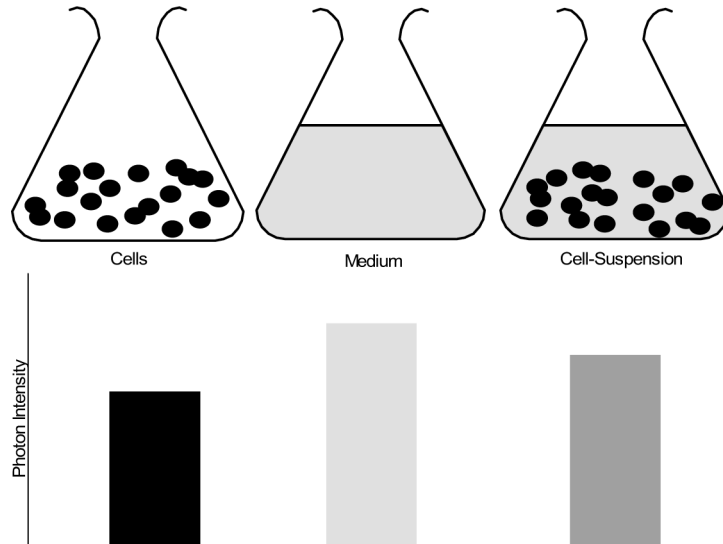
Figure 1. Cells without medium have, say, a photon emission intensity I_c. The medium shall display an intensity I_m. Both together, cells+medium, emit photons of an intensity $I < I_c+I_m$. The difference I_c+I_m-I is highly significant, indicating active absorption (sucking) of the cells within the medium.

Thus, the experimental evidence for photon sucking is already quite reliable. Therefore, the time is ripe for models of explanation, which are, however, at the present time, more or less the same, but different in the approach that is used.
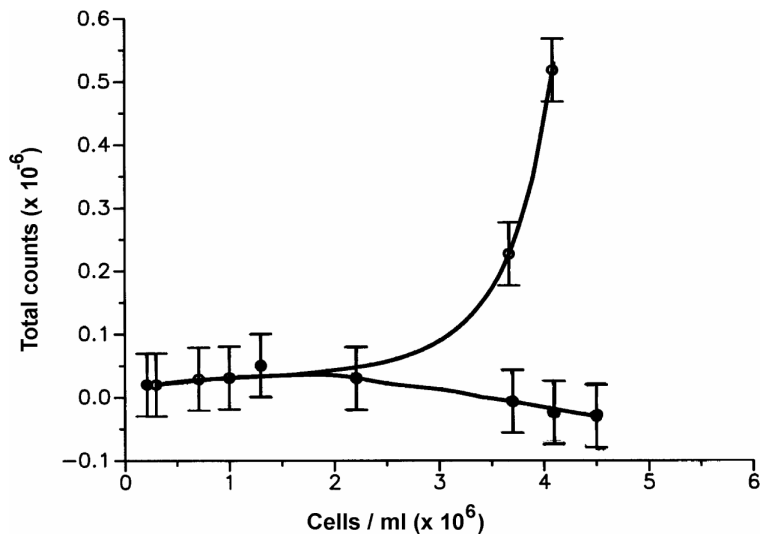

Figure 2. "Delayed luminescence" from tumor cells (upper curve) and normal cells (lower curve), as measured by Schamhart (1997). The normal cells suspended in medium display "induced absorption of photons" with increasing cell density. Tumor cells show in contrast non-linear increase of photon intensity with increasing cell density.
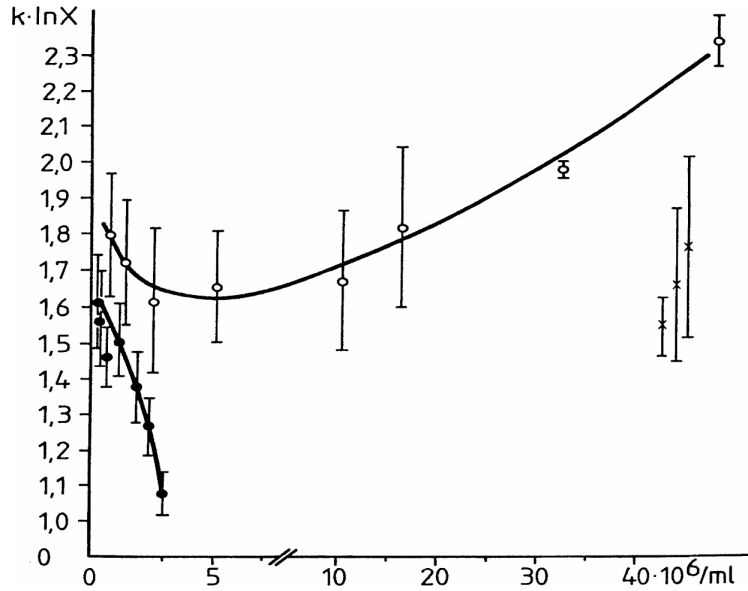
Figure 3. The decay parameter of the hyperbolic approximation that is adjusted to the relaxation dynamics of the afterglow of different cell suspensions after exposure to weak white light illumination is shown versus cell density. The lower curve displays the improvement of hyperbolic relaxation of normal amnion cells with increasing cell density. The upper curve shows the opposite dependence exhibited by malignant Wish cells. The three measurements at the right side of the figure correspond to the nutritive medium alone (Scholz et al., 1988).
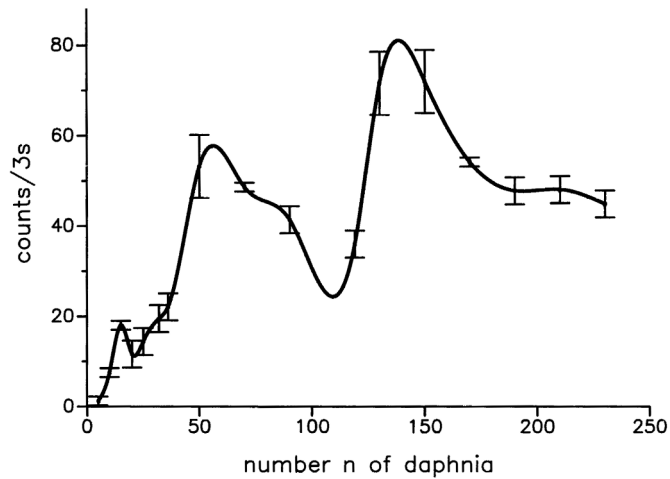
Figure 4. Mean values of the photon intensity of adolescent daphnia in 15 ml volume with the weighted standard deviation. Instead of the expected continuous increase of photon intensity with increasing number of daphnia, one measures interference-like changes (Galle, 1993).
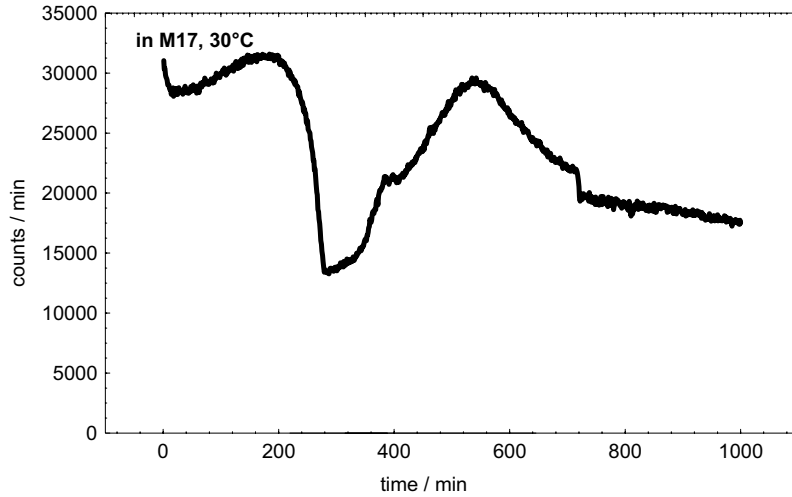
Figure 5. Growing bacteria in culture medium, that by oxidative reactions always emits light, absorb from a definite density on the light of the medium. For higher densities, this absorbance may decrease again (Vogel et al., 1998).
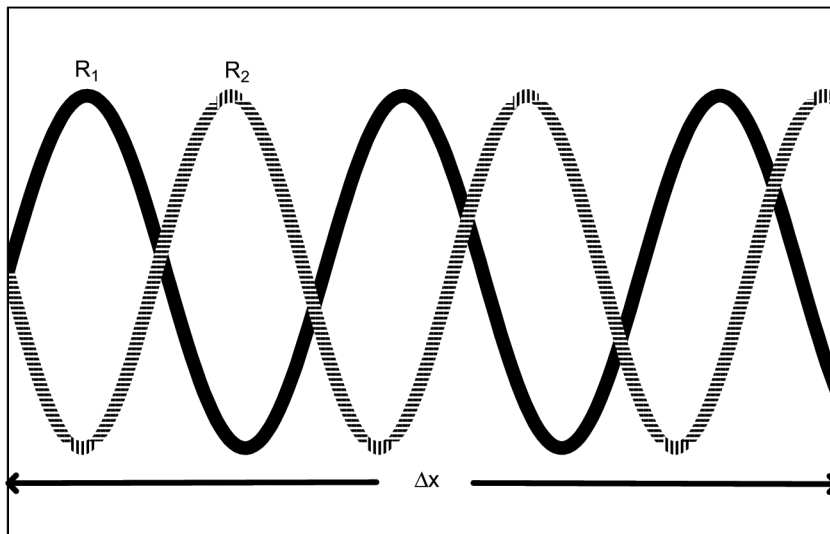
Figure 6. Zone Δx of destructive interference of two superimposing waves with different phase relations.

2. SIMPLE MODELS

Measured photons are the result of localized energy exchange of electromagnetic waves with the photon counting detector. By careful consideration using the uncertainty principle, it is never completely wrong to

model them as waves. Let us start with the simple example of two wave trains of just the same wavelength λ superimposing in a way that they interfere destructively (Fig. 6). Obviously, this is a process where energy disappears over the zone just where destructive interference takes place. The question arises whether this local process of energy annihilation is possible, and over what region it is allowed, if it could take place at all. Actually, there is no reason to reject the existence of destructive interference, because it belongs to the generally accepted and much-observed physical principles of all interference effects. However, a simple calculation shows that destructive and constructive interference will always become balanced in such a way that the energy conservation law is not violated, as has been shown by Popp (1992). Actually, according to the fundamentals of Quantum Theory, it is never possible to superimpose two waves without any uncertainty in the wavelengths. One of the waves shall have the wavelength λ, the second the wavelength $\lambda+\Delta\lambda$. Then it is clear that the superposition over the distance of one wavelength will always lead to an increasing phase difference $\varphi(\Delta\lambda)$ between the waves. Destructive interference over n_u consecutive wavelengths will take place only as long as

$$n_u\Delta\lambda < \lambda/2 \tag{1}$$

As soon as with increasing number n_u Eq. (1) is not satisfied, the phase difference between the superimposing waves leads to constructive interference for the next n_u wavelengths.

It is well-known that a photon of wavelength λ carries the momentum

$$p = h/\lambda \tag{2a}$$

with the uncertainty

$$|\Delta p| = |\Delta\lambda| \, h/\lambda^2 \tag{2b}$$

Because n_u is the number of wavelengths that superimpose over a distance Δx of destructive interference, we can rewrite the position uncertainty in the form

$$\Delta x \equiv n_u\lambda \tag{3}$$

By the insertion of (3) and (2b) into (1), we find finally that

$$\Delta x \Delta p < h/2 \tag{4}$$

However, Eq. (4) obviously violates the uncertainty principle because always $\Delta x \Delta p \geq h$. We learn from this that

- destructive (and correspondingly also constructive) interference can always take place without any confinement, but only over limited regions of space and time,
- the energy conservation law and the uncertainty relation are mutually dependent.

Photon sucking takes place in the region of destructive interference where photons are really trapped. This effect would always be observed in a system, if on the outside essentially destructive interference took place while for reasons of energy conservation the inside had then to be consequently subject to constructive interference.

An example how this can be realized has been documented in a previous paper about phase conjugation effects in biology (Popp and Chang, 2000). Necessary for this phenomenon is a nonlinearly electrically polarized double layer (i.e., a biological membrane or exciplex structure) with a small distance d between the layers such that

$$d < \lambda \tag{5}$$

where λ is the wavelength under study.

We arrive at the most stable state of the system if and only if the double layer gets a nodal point of incoming waves, where on one side destructive and on the other side constructive interference has to take place. This discontinuity in the impinging wave trains is at the same time the source of a sucking force K_λ,

$$K_\lambda = - n_\lambda \lambda F h(c/\lambda)(Q\lambda/d), \tag{6}$$

where n_λ is the spectral photon density, F the surface area of the layer, h the Planck's constant, and Q the (dimensionless) resonator value. It is worthwhile to mention that $n_\lambda \lambda F h(c/\lambda)$ is just the radiation pressure that works in the opposite direction as the sucking force and is $(Q\lambda/d)$-times smaller.

This sucking force may provide, for instance, the phototropism of plants or the aggregation of cells and many other related biological phenomena.

3. COHERENCE AND PHOTON SUCKING

The simple examples above already tell us that the coherence of photons plays a fundamental role in the possible photon sucking. Take a coherence length L << D, where D are relevant biological dimensions, and then photon sucking certainly cannot play a relevant role. However, for L ≈D, this effect has always to be taken into account. When including infrared light, microwaves, and even radio waves, there are manifold possibilities where this effect may play an important biological role for phenomena that are not known or understood or are in question at present. In order to reveal the basic and general character of photon sucking, we have to extend our investigation to quantum theory and to find possible photons that become actively stored without violation of the energy conservation law, in line with the laws of quantum theory.

Several times we pointed to Dicke´s theory (Dicke, 1954) of sub- and superradiance that could be assigned to destructive and constructive interference, respectively. Dicke developed it as a quantum theoretical model, and it is worthwhile to note that (5) is just the same condition as has been

provided for the application of his model. Because biological systems are "optically thick" media, (5) is always relevant.

However, the most accurate model is the description of "photon sucking" in terms of coherent states (Popp et al., 2002). Let us start with a well-known Hamiltonian **H** that keeps coherent states coherent. According to Glauber (1963) and Mehta (1966), this Hamiltonian generally takes the following form

$$\mathbf{H} = F(t)\mathbf{a}^+\mathbf{a} + G(t)\mathbf{a}^+ + G^*(t)\mathbf{a} + B(t), \tag{7}$$

where $\mathbf{a}+$, $\mathbf{a}$ are the creation- and annihilation operators, respectively, and F, B are real functions, while G is a complex function. For photons of frequency ω we have $F(t)= \hbar\omega$. Take $|\beta>$ as a coherent eigenstate of (7), then we write for

$$<\beta |\mathbf{H}|\beta> = E \tag{8a}$$

$$<\beta |\mathbf{a}+\mathbf{a}|\beta> = n \tag{8b}$$

Let us introduce the resonator value

$$Q = \omega(E-B)/[\partial/\partial t(Fn)] \tag{9}$$

The Q-value is a measure of the storage capacity of the system under consideration. From (8b) we get

$$n= n_{ch} + n_c = (E-B)/F + (G\beta^* +G^*\beta)/F, \tag{10}$$

where the first term can be assigned to a chaotic part of a photon number n_{ch} and the second certainly to a coherent part n_c.

For the coherent part we provide

$$<\partial/\partial t(n_c)>\approx0, \tag{11}$$

describing an oscillatory behavior.

Take F as a constant value and insert F of (10) into (9), then we obtain and consequently

$$F = \omega/(\partial/\partial t(n))(E-B)/Q = (E-B)/n + (G\beta^*+G^*\beta)/n,$$

$$Q = \omega n/(\partial/\partial t(n_{ch})) \, 1/(1-(G\beta^*-G^*\beta)/(E-B)) \tag{12}$$

In contrast to chaotic states, the Q-value of coherent states provides what we call "active photon storage," which may be called "photon sucking" or "photon trapping" . Actually, as soon as $(G\beta^*-G^*\beta)$ is oscillating around $(E-B)$, the resonator becomes rather active in "sucking" photons for Q<0, highest storage capacity for $Q \rightarrow\infty$, and even transparency for $Q \rightarrow1$.

After these plausibility considerations, it is certainly necessary to show evidence of this sucking process by taking account of the accurate solutions of

Eq. (7). This has been done in previous papers (Popp et al., 2002), but is worthwhile to repeat the results at least as far as they reflect directly the effects of photon sucking.

A particular solution of (7) can be expressed in terms of coherent states $|\alpha(t)>$, which are eigenstates of the annihilation operator **a** according to

$$\mathbf{a}\ |\alpha(t)> = \alpha\ |\alpha(t)>, \tag{13}$$

where α is the field amplitude of this state under study.

We showed that under conditions of homeostatic regulation, Eq. (7) can be split into two parts, the first one concerning the photon number n, and the second one responsible for the field amplitude $\alpha(t)$.

Taking $F = \hbar\omega(t)$, the solution for n(t) follows the equation

$$\omega(\partial/\partial t(n)) + (\partial/\partial t(\omega))n + 1/\hbar[\partial/\partial t(B(t))] = 0 \tag{14a}$$

In addition to the trivial solution n = const., where ω is a constant, we obtain under ergodic conditions a non-trivial solution

$$\omega(t) = \omega(0)/(1+\upsilon t), \tag{14b}$$

where υ is a constant.

Under these conditions of homeostatic regulation, $\alpha(t)$ has to be derived from a function G that satisfies the equation

$$\partial/\partial t G(t) + i\omega(t)G(t) = 0 \tag{15a}$$

This result explains again the well-known fact that delayed luminescence relaxation functions follow a hyperbolic decay law (Popp and Li., 1993, Bajpai et al., 1998).

For G(t) we then get

$$G(t) = G(0)\ \exp\ (-i\ \ln(1+\upsilon t)) \tag{15b}$$

This solution provides the oscillation with linearly increasing period. It can be observed as taking place around the hyperbolic relaxation of the photon emission after external light illumination.

It could be shown that it is not possible to see these oscillations in monochromatic fields with the same field amplitudes $\alpha(t)$. A necessary condition for these oscillations is the coupling of at least two modes, in order to get destructive interference for mutual photon sucking between the modes, as has been shown by Popp (2002) (Figs. 7a, 7b).
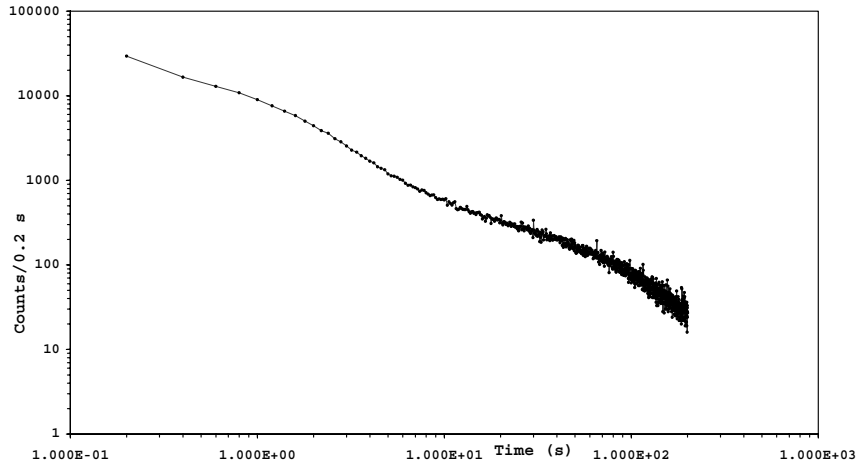
Figure 7a. Delayed luminescence of *Acetabularia acetabulum* after 10s white-light illumination by a tungsten lamp (150W). Courtesy of Rafael Moreno (IIB, Neuss). The relaxation displays oscillations around the hyperbolic decay behaviour (Popp et al., 2002).

$$I_R(t) = -A \cdot \sin\left[\kappa \ln\left(\frac{1 + \lambda_2 t}{1 + \lambda_1 t}\right) + \varphi\right]$$
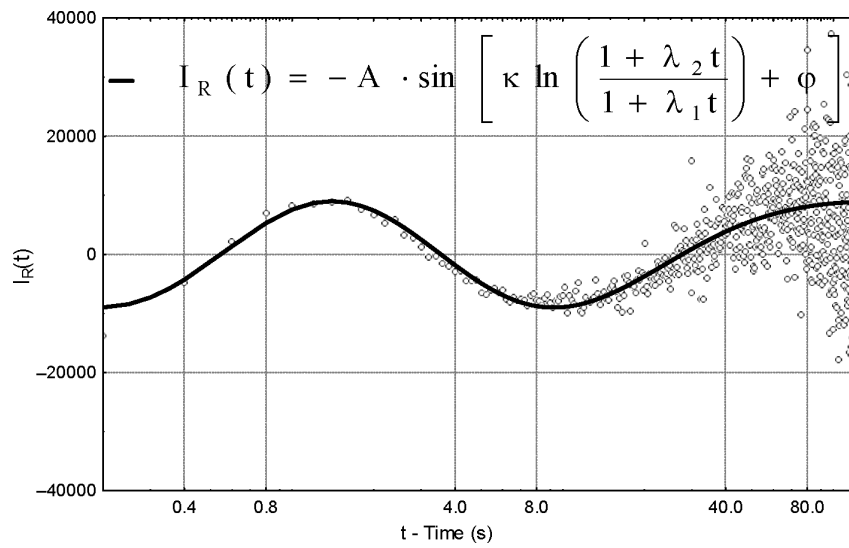
Figure 7b. The oscillations around the hyperbolic relaxation function can be calculated analytically (Popp et al., 2002).

The most general solution of the intensity I(t) of delayed luminescence under ergodic conditions and by providing homeostatic effects takes the form (Popp 2005):

$$I(t) = I(0)\{\prod_j (1+b_j t)^{P_j}\} \sin\{[\sum_j \gamma_j \ln(1+\kappa_j t)]+\Phi\} \qquad (15c)$$

The investigations have demonstrated that by superimposition of coherent modes in biological systems, there is extremely high stability of frequency and phase, which is likely a basis of biological communication in terms of frequency and phase modulations of the signals.

4. MOLECULAR ANALYSIS

We are unsatisfied with the solution of the problem as long as we are not seeing the molecular interaction between field and matter. If "photon sucking" takes place, there must be excited states of molecular matter that are subject to photon absorption for sufficiently long periods. In order to trap photons, the excited state has to display a higher stability than the state before absorption. This condition can be fulfilled by an energy gap between the former and the latter electronic state. The rather strange condition has to be satisfied that, despite the absorbing of a photon, the latter state should have a lower energy than the former one. How is this possible?

We would like to show now that by a phase transition from chaotic to coherent states and vice versa, it is actually possible to construct such a mechanism. Let us start with a Hamiltonian $H_0 = \hbar\omega a^+ a$ that creates number states of photons of energy $\hbar\omega$. Influenced by coherent photons we switch on a coherent field $H_1 = Ga^+ + G^*a$ and add it to the Hamiltonian H_0, in order to get the complete Hamiltonian $H = H_0 + H_1$. Our goal is to compare the solutions before and after absorption by comparing that of the original Hamiltonian with the complete one. For simplicity, we take a basis set of two number states $/0>$ and $/1>$ of energy 0 and $\hbar\omega$. We provide then

$$a/0> = 0/0>; \quad a/1> = /0>; \quad <0/a^+ = <1/ \tag{16a}$$

The elements of the secular matrix are then

$$<0/H_0/0> = 0; \quad <1/H_0/1> = \hbar\omega; \quad <0/H_0/1> = 0; \quad <0/H_1/0> = 0; \quad <0/H_1/1> = G^*;$$
$$<1/H_1/0> = G; \quad <1/H_1/1> = 0; \tag{16b}$$

The solution of the Schrödinger equation in terms of this basis set gets the form

$$/\Psi> = c/0> + ((1-c^2)^{1/2})/1> \tag{16c}$$

and by solving $H/\Psi> = E/\Psi>$ we arrive after straightforward calculation at the following results

$$E = \tfrac{1}{2} [\hbar\omega +/- ((\hbar\omega)^2 + 4G^*G)^{1/2})] \tag{17a}$$

$$c^2 = (G^*G)/[G^*G + \hbar\omega] \tag{17b}$$

The solution, which can be understood completely also in classical terms, shows evidence that

- as soon as a coherent field is switched on, the photon gets stored in a new ground state with lower energy than the former ground state,

- the energy gap increases with increasing G*G and provides photon sucking,
- the conservation of energy is due to an excited state that has a higher energy than the former one,
- Time-dependent perturbation theory shows that the system starts to oscillate between the new ground state and the other states of the system.

The energy gap ΔE between the two states is according to (17a)

$$\Delta E = [(\hbar\omega)^2 + 4G*G]^{1/2} \tag{17c}$$

It is understandable from this point of view why the oscillation frequency Ω of the "delayed luminescence oscillations" gets smaller and smaller during the relaxation. Note that the coupling factor of the states will increase with the product of the amplitudes of the different modes of the stored photon field ($\alpha_0^*\alpha_1 - \alpha_0\alpha_1^*$). They may likely increase proportionate to the number n_0 of stored photons. Consequently, the oscillation parameter λ follows the same hyperbolic law as Eq. (15a), but with an imaginary exponent:

$$n(t)=n(0)/(1+\lambda t)^{i\gamma} = \exp(-i\,\gamma\ln(1+\lambda t)) \tag{18}$$

This kind of photon sucking may work permanently in all biological systems. It becomes a relevant and even macroscopic effect because the oscillation frequency will always take low enough values after some time. Consequently, a considerable part of photons of all possible frequencies may get trapped and stored. The system can take the role of a most fundamental process, as a source of sensitivity, rhythmic tuning, as well as of long-range communication within the organism and with the environment. Actually, the fact that not only the visible range is included and that this process is connected to communication channels within the body shall be shown now in the example of infrared radiation.

5. PHOTON CONDUCTION (LIGHT PIPING) AND PHOTON SUCKING IN HUMAN TISSUE

Some years ago, Mandoli and Briggs (1982) evoked attention by impressive examples of "light piping in plant tissues." Smith (1982) showed that the results could be understood only in terms of coherent radiation that is conducted along light fibers in biological tissues. Not long ago, Schlebusch, Maric-Ohler, and Popp (Schlebusch et al., 2005) were successful in demonstrating that at least in the wavelength range from 3 to 5 micrometers, channels of light emission appeared on the body, and it turns out that they are mirrored by what the ancient Chinese introduced as "meridians." Figure (8a) displays an example of the "bladder meridian" after spinal moxibustion. Figure (8b) documents a part of the stomach meridian on the face of a patient with a facial paralysis without any external influence. The molecular basis of this effect can be described in terms

of a differential equation that has been derived by Thomas (1961) from Non-Equilibrium Thermodynamics in the presence of a radiation field. He formulated the basic equation in rather simple terms

$$dI_v/d\tau_v = I_v - S_v \qquad (19a)$$

where

$$dI_v = h\nu\,[-I_vB_{LU}n_L + I_vB_{UL}n_U + A_{UL}n_U]dl/(4\pi) \qquad (19b)$$

I_v is the spectral intensity of radiation that travels through a medium with n_U molecules in the upper excited state and n_L molecules in the lower one. B_{LU} and B_{UL} are Einstein`s coefficients of induced absorption and induced emission, respectively, and A_{UL} is Einstein´s coefficient of spontaneous emission. dl is the infinitesimal distance of the light path. Thomas defined the optical depth τ_v and the source function S_v as follows:

$$d\tau_v = -h\nu\,B_{LU}n_L\,(1\text{-}X)dl/4\pi \qquad (19c)$$

$$S_v = 2h\nu^3/c^2\,(1/X\text{-}1)^{-1}, \qquad (19d)$$
$$\text{where } X = g_Ln_U/g_Un_L \qquad (19e)$$

g_L and g_U are the degeneracy factors of the lower and upper excited states, respectively.

Equation (19a) is the simple result of (19b) after insertion of (19c), (19d), and (19e). For simplicity, we confine to a homogeneous medium.
In the case of Figs. (8a) and (8b), which are confirmed by our experimental results of infrared photography, we can immediately see the solution I_v of the form

$$I_v = I_v(0)\,f(\delta) \qquad (20a)$$

where δ is the vertical distance from the radiation channel (the "meridian"). $I_v(0) = S_v(0)$ along the meridian line. This provides that $I_v(0)$ does not change along $\delta = 0$, where

$$\partial I_v/\partial\tau_v = 0 \qquad (20b)$$

$f(\delta)$ describes the change of I_v in the perpendicular direction. It is obvious that in case of the bladder meridian (Fig. 8b), where $\partial I/\partial\delta < 0$, also

$$\partial f/\partial\delta < 0 \qquad (20c)$$

This describes a bright optical soliton, as it does not change its shape along the direction $\delta = 0$, where it displays its maximum intensity.

Figure 8a. Documentation of a part of the bladder meridians by moxibustion. They can be described in terms of bright solitons (see color plate).

Figure 8b. Documentation of a part of the stomach meridian. There is no external excitation. This case corresponds to a black soliton where photon sucking from the surrounding tissue may take place. (see color plate).

Figure 8c. Documentation of the superposition of bright and black solitons, giving rise to transparency. One can see three bones of the legs. (see color plate).

For the case of the stomach meridian, which can be seen in Fig. (8b) on the face (in a pathological case without external illumination), I_v increases with increasing vertical distance δ from the meridian:

$$\partial f/\partial \delta > 0 \tag{20d}$$

Because its center is certainly "colder" than its environment, it describes a so-called black soliton which "sucks up" light from its environment.

After insertion of (20a) into (19a), we arrive generally at

$$I_v(\delta) = S_v(0)/[1-1/f(\delta)(\partial f/\partial \delta)(\partial \delta/\partial \tau_v)] \tag{20e}$$

Take for S(0) (19d) and evaluate (19c), then we can write also

$$I_v(\delta) = 2\pi h v^3/c^2/(1/(X(0)-1)[1-4\pi/f(\delta)(\partial f/\partial \delta)/(B_{LU}n_U(1-X))] \tag{20f}$$

In view of (20c), I_v can decrease with increasing δ only if $\partial \delta/\partial \tau_v > 0$. From Eq. (19c), with $l = \delta$ we learn that this is possible only if the occupation X according to (19c) follows

$$g_L n_U/(g_U n_L) > 1 \tag{20g}$$

This means that the meridians after moxibustion are understandable only if the electronic states of the corresponding molecules along the meridians and in

the vicinity of the meridians are over-occupied. The radiation emitted from these areas should be at least partially coherent, where the matter may show optical anisotropy, as the requirement of X>1 is valid only for the direction perpendicular to the channels.

Just the same requirement of (20g) holds also for the black solitons of Fig. (8b). Actually, Eq. (20d) provides an increase of $I_v(\delta)$ if and only if $\partial\delta/\partial\tau_v > 0$, and consequently X>1. But photons are sucked up instead of being emitted in these meridians. However, in both cases of Figs. (8a) and (8b), concerning bright and black solitons, the matter is electronically over-occupied and approaches a zone of X≈1 at large distances from the meridians, where the matter becomes more and more transparent. Figure (8c) displays such a case where the transparency becomes evident.

Because $S_v(0)$ may take positive (Fig. 8a) as well as negative values (possibly in Fig. 8b), X may take values higher than 1 as well as values lower than 1. For X = 1, we arrive at equal occupation of the lower and upper electronic states. Actually, the transition from X<1 to X>1 is at the same time a phase transition from chaotic to coherent radiation, corresponding to the LASER threshold in technical devices. Note that for X=1, the dependency on l may disappear completely. It impressively displays the holistic character of this mechanism.

The most interesting region of X is ½<X<2, because this corresponds first to the occupation of exciplexes, passing the threshold and arriving at the most sensitive zones of photon sucking. Note here that in view of (20f), the second term is symmetric in X and 1/X. It is very likely that the molecular mechanisms of life are based on these fundamental functions, which have been discussed several times before by Popp (Popp et al., 1994). The real situation reflects the permanent superposition of emitting and sucking zones such that the mean value <df/dδ> tends to get zero. Local (non, random) fluctuations of $I_v > S_v$ and $I_v < S_v$ may work then for extremely sensitive but homeostatic regulation of the body.

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