COMPUTER ANALYSIS OF COHERENT ELECTRIC VIBRATIONS IN BIOLOGICAL SYSTEMS

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The Fröhlich condensed state may be created in the system of vibration modes if the energy supply is above the critical one. A model of a vibration system of a limited number of modes in the frequency range 0·1—4 THz with uniform density of state function and limited energy in the condensed state (saturation) is used for computer simulation. Energy stored in particular modes is calculated as a function of energy supply and energy leakage to the heat bath. The energy stored in the condensed state may be greater than the thermal energy of the system. In the saturated condensed state the stored energy is independent of energy supply. In the vicinity of the critical energy supply the change of the supply of the order of 10% switches on or off the condensed state. The interaction between systems with condensed states leads to interaction forces. Dependent on various conditions these forces may be attractive or repulsive.

INTRODUCTION

Systems containing charged particles are capable of long-wave electric vibrations. A system is assumed possessing vibration modes with frequencies ν_k excited by the energy supply $\varepsilon_k (k = 1, 2, \ldots, N)$. If the vibration modes are coupled to the surroundings, a state similar to the Einstein condensation of a Bose gas occurs and energy is stored in the mode with the lowest frequency. The ordered (condensed, coherent) state is reached. The condensed state pumped by metabolic energy in biological systems may have principal significance for biological activity. In [1—3] the theory and the basic properties of the condensed state are given, e.g. the existence of a critical value ε_0 of the energy supply necessary to reach the condensed state. To get quantitative results and to evaluate the effect of various parameters and conditions (e.g. single mode strong energy supply), computer simulation of the vibration modes is performed.

BASIC RELATIONS FOR COMPUTER ANALYSIS

The rate of change of the number of quanta in vibration modes is given by the master equation [4]. A slightly modified master equation with respect to that in [4] is used in the form

$$\frac{1}{A}\dot{n}_k = s_k - \phi_k\left[\frac{1}{A}n_k \exp(\beta\nu_k) - \left(\frac{1}{A}n_k + 1\right)\right] - \tag{1}$$

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$$- \sum_j \chi_{k,j} \left[\frac{1}{A} n_k \left(1 + \frac{1}{A} n_j \right) \exp(\beta v_k) - \frac{1}{A} n_j \left(\frac{1}{A} n_k + 1 \right) \exp(\beta v_j) \right] -$$

$$- \sum_j \lambda_{k,j} \left\{ \frac{1}{A^2} n_k n_j \exp[\beta(v_k + v_j)] - \left(\frac{1}{A} n_k + 1 \right) \left(\frac{1}{A} n_j + 1 \right) \right\},$$

where $\beta = h/k_B T$ (the meaning of h, k_B and T is conventional), $s_k = \varepsilon_k / h v_1$ is the rate of the energy supply, n_k is the number of quanta of the energy in the mode v_k, and ϕ_k, $\chi_{k,j}$ and $\lambda_{k,j}$ are transition probabilities for energy transport from the modes to the heat bath and energy channelling between modes. ϕ_k, $\chi_{k,j}$ and $\lambda_{k,j}$ may depend on temperature, on the frequency (i.e. on k and j) and on the energy stored in the mode (nonlinear dependence). The nonlinear dependence of transition probabilities is assumed in the form of the upper limitation of the number of quanta. We assume $\phi_k = a$ for $n_k \leqq n_{crit}$ and $\phi_k = a + b(n_k - n_{crit})$ for $n_k > n_{crit}$, where a, b are constants. This condition leads to the saturation of n_k at or just above n_{crit} and, therefore, to the saturation of the condensed state energy. The energy of the condensed state is limited. Instead of discrete frequency lines we assume rather narrow spectral peaks with more or less dense frequency lines. The quantity A in eq. (1) is, hence, the density of state function. For $A = 1$ eq. (1) is identical with that given in [4]. A depends generally on the frequency. We use a constant value given by the relation

$$A \sum_{k=1}^{N} h v_k [\exp(\beta v_k) - 1]^{-1} = N k_B T, \tag{2}$$

where N is the number of frequency peaks. Under stationary conditions there is $\dot{n}_k = 0$ in eq. (1).

According to the theorems presented in [5] there always exists at least one stationary solution of (1); under some conditions this solution is unique and in this case the time dependent solution tends for $t \to \infty$ to the stationary solution. All the above conditions are satisfied in our case. Eq. (1) is used for computation for $\dot{n}_k \neq 0$ or $\dot{n}_k = 0$. The values of n_k are changed step by step to find the stationary solution to (1). A desktop computer H-P 9845 B is used. All computer results are calculated for $\lambda_{k,j} = 0$, $\chi_{k,j} = \text{const}$ and $b = 3$.

UNIFORM ENERGY SUPPLY

The same amount of energy $\varepsilon_k = \varepsilon$ is supplied to each mode v_k. The numbers n_k of energy quanta in modes v_k in the frequency range from 0·1 to 4 THz for $N = 10$, $s_k = 1$ and $N = 40$, $s_k = 0{\cdot}25$ are in figs. 1a and 1b, respectively. The values of n_1 in the lowest frequency mode reach saturation. For $n_{crit} = 3500$ the energy in the condensed state is about 6 times greater (fig. 1a) and 2.5 times greater (fig. 1b) than the thermal equilibrium energy $N k_B T$ of the system. The total energy supply is about

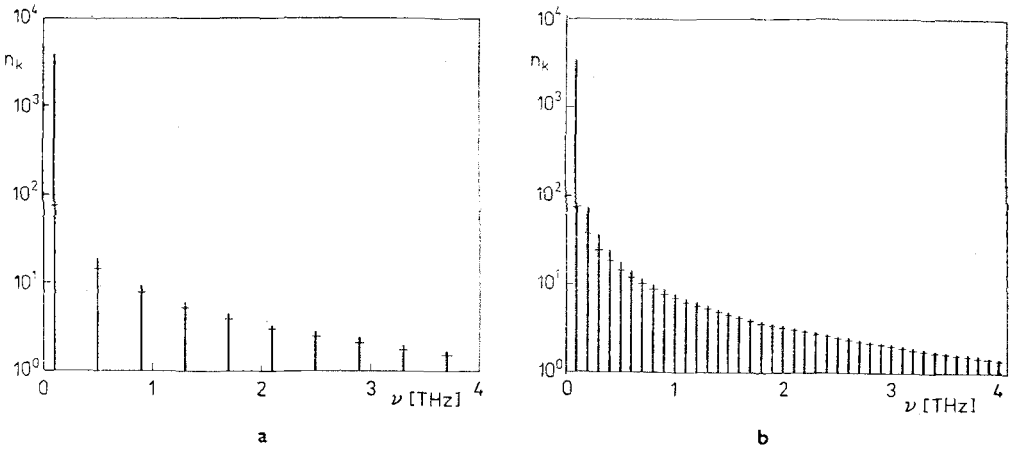


Fig. 1. Number n_k of energy quanta of vibration modes as a function of frequency in the range from 0·1 to 4 THz pumped by the uniform energy supply. $\phi_k = 0{\cdot}01$, $\chi_{k,j} = 0{\cdot}001$ (for all k), $n_{\mathrm{crit}} = 3500$. The horizontal dashes indicate the thermal equilibrium values of n_k (without energy supply). a) $N = 10$, $s_k = 1$. b) $N = 40$, $s_k = 0{\cdot}25$. Number n_1 of the energy quanta in the condensed state is saturated as a consequence of the assumed increase of energy losses at higher values of the stored energy.

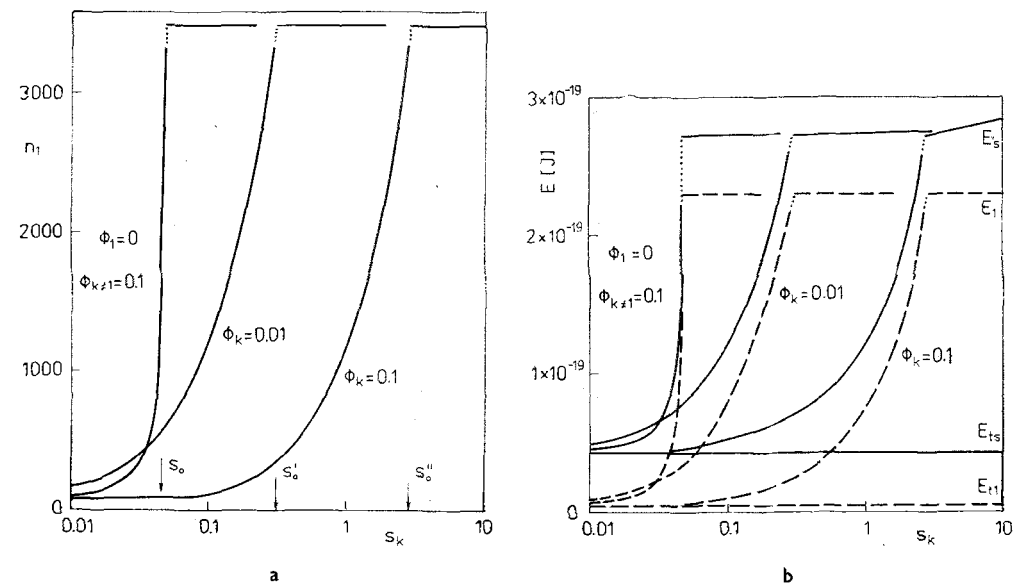


Fig. 2. Number n_1 of quanta (a), energy E_1 and total energy E_s of the system (b) as a function of s_k for $N = 10$, $n_{\mathrm{crit}} = 3500$, $\chi_{k,j} = 0{\cdot}001$. ϕ_k is a parameter. In fig. 2a the critical values s_0, s_0', s_0'' of the energy supply are indicated by arrows. In fig. 2b E_{t1} and E_{ts} are the thermal equilibrium energy of the mode with the lowest frequency and of the whole system, respectively. A significant change of curves slope occurs near the points of the critical energy supply. The dotted parts of the curves indicate that there are no computed points in this region.

1·5% (fig. 1a) and 0·4% (fig. 1b) of the energy Nk_BT. The energy leakage to the heat bath (the value of ϕ_k), however, is not large.

In fig. 2a the dependence of the number n_1 of quanta in the mode with the condensed state and in fig. 2b the dependence of the energy E_1 in the condensed state and the total energy E_s of the system on the rate of the energy supply s_k is given for $\phi_k = 0{\cdot}01$, $\phi_k = 0{\cdot}1$ and $\phi_1 = 0$ and $\phi_{k+1} = 0{\cdot}1$. The critical value $s_0 = \varepsilon_0/hv_1$ for reaching the saturated condensed state depends on ϕ_k, especially on ϕ_1 (fig. 2a). The number n_1 of quanta (and also E_1, E_s) just before reaching the saturated condensed state (approximately below the critical value s_0) increases steeply with the increase of s_k. The steepest increase of n_1 is seen in the curve for $\phi_1 = 0$, $\phi_{k+1} = 0{\cdot}1$. In the vicinity of s_0 the change of s_k of the order of 10% changes n_1 from the value just above the thermal equilibrium to the saturated one. The dependence of n_1 on s_k above s_0 in the saturated condensed state is given by the defined dependence of ϕ_k on n_k for $n_k > n_{crit}$.

In [6] the critical energy flux density $J = 0{\cdot}4\ \mathrm{mW/cm^2}$ is given. Above this value the condensation in the lowest frequency mode should occur. This value is about 4% of the thermal equilibrium energy flux from some biological systems and assuming the same rate of ε_0/k_BT the corresponding value of $s_0 \approx 3$.

If s_k is just above the critical value s_0, then even a small decrease of s_k results in a great decrease of n_1. A similar effect is noted in the increase of energy losses from particular modes, i.e. in the increase of ϕ_k. Any agent affecting the energy supply or damping of the vibration modes may have significant effect on biological systems. It is assumed [7] that e.g. the LDH virus draws metabolic energy from the host cell, exhausts the cell energy resources and may cause, therefore, significant changes of the vibration states.

SINGLE MODE INCREASED PUMPING

The energy supply to some modes may be greater or even much greater than to other modes. This may be encountered e.g. if the system with vibration modes is irradiated by external electromagnetic field.

The numbers n_k $(k = 1, \ldots, 5)$ of quanta for increased pumping of the mode v_3 and uniform basic pumping of all other modes are given in tab. 1. If the basic energy supply to all modes is sufficient to reach the saturated value of n_1 $(s_k = 0{\cdot}5)$, the increased pumping of the mode v_3 causes only a small increase of n_3 (even for very strong pumping of this mode). The n_k values are not perceivably changed even for energy supply higher than that given in tab. 1. If the basic energy supply is insufficient to reach the saturated value of n_1 $(s_k = 0{\cdot}1)$, besides a small increase of n_3 even an essential increase of n_1 is caused by the increased pumping of the mode v_3. The increase of n_1 is significant especially for $s_3 > \sum_{l \neq 3} s_l$.

In fig. 3 there are n_1 of the condensed state for the increased pumping of the mode

Table 1

The number n_k ($k = 1, \ldots, 5$) of quanta for increased energy supply to the mode ν_3 and uniform energy supply to other modes. $\phi_k = 0{\cdot}01$, $\chi_{k,j} = 0{\cdot}001$, $n_{\mathrm{crit}} = 3500$.

s_l $l \neq 3$	s_3	n_1	n_2	n_3	n_4	n_5
0·5	5	3500	18·6	10·3	5·7	4·2
	0·5	3500	18·6	8·9	5·7	4·2
0·1	5	3500	18·2	10·3	5·7	4·1
	1	1961	18·2	9·3	5·7	4·1
	0·1	1221	18·2	8·8	5·7	4·1

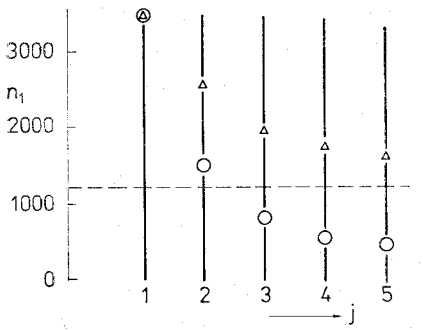


Fig. 3. The number of quanta as a function of j for $j = 1, \ldots, 5$. The mode with the frequency ν_j is strongly pumped (the rate of energy supply is s_j). $\phi_k = 0{\cdot}01$, $\chi_{k,n} = 0{\cdot}001$, $n_{\mathrm{crit}} = 3500$, $N = 10$. The upper ends of full lines: $s_j = 5$, $s_{l \neq j} = 0{\cdot}1$; Triangles: $s_j = 1$, $s_{l \neq j} = 0{\cdot}1$; Circles. $s_j = 1$, $s_{l \neq j} = 0$. The dashed line determines n_1 for the uniform rate of energy supply $s_k = 0{\cdot}1$.

with the frequency ν_j ($j = 1, \ldots, 5$). The higher the frequency ν_j of the mode with increased pumping, the smaller the value of n_1 in the condensed state and the saturated value of n_1 is reached for greater energy supply.

In tab. 2 there are the number of quanta n_j of the mode with increased pumping s_j and for the basic energy supply $s_l = 0{\cdot}5$ and $s_l = 0{\cdot}1$ ($l \neq j$). The results are similar to those for $j = 3$ given above. Besides the changes of the nonsaturated values of n_1 all other changes of n_j are small even for a very strong energy supply s_j. A system with a saturated condensed state is insensible to the energy supply above the critical value s_0. If the energy supply, however, exceeds a limit of the thermal effects, the changes and disturbances of the system may start.

The energy stored in vibration modes of a system with a saturated condensed state is, therefore, nearly unaffected by electromagnetic radiation. If the saturated condensed states are present in biological systems, then insignificant response to electromagnetic radiation may be expected. The biological processes, as a result, may be unchanged by microwave radiation as is discussed e.g. in [8]. In [8] there is even stated that no evidence of athermal biological effect of microwave irradiation was obtained. This contradicts the experimental results described e.g. in [9, 10].

Table 2

The number n_j of quanta of the modes with increased energy supply s_j and uniform energy supply s_l to other modes $(l + j)$. $\phi_k = 0{\cdot}01$, $\chi_{k,n} = 0{\cdot}001$, $n_{\mathrm{crit}} = 3500$.

s_l $l+j$	s_j \ n_j	n_1	n_2	n_3	n_4	n_5
0·5	5	3500	23·8	10·3	6·4	4·5
	0·5	3500	18·6	8·9	5·7	4·2
0·1	5	—	23·8	10·3	6·4	4·5
	1	3500	19·6	9·3	5·9	4·3
	0·1	1221	18·2	8·8	5·7	4·1

INTERACTION ENERGY

The interaction of two identical systems with vibration modes results in the change of their free energy [3]. The change of the free energy (i.e. the interaction energy) consists in frequency changes and in vibration energy changes of modes. The frequencies of two interacting modes (with equal frequencies before interaction) are given by $\nu_{k\pm}^2 = \nu_k^2 \pm \Delta$, where Δ is the interaction term. For $\nu_{k-} < 100$ GHz the screening of the electric vibrations in the conductive media of biological systems decreases the interaction term Δ and this term may even vanish.

The vibration mode with the condensed state dominates the interaction. For a nonsaturated condensed state there is $n_{1-} > n_1$ and for a saturated one $n_{1-} = n_1$ (where n_{1-}, n_1 are numbers of quanta in modes with frequencies ν_{1-}, ν_1). The numbers of quanta are considered for one of the interacting systems. If the condensed state is in the lowest frequency mode, then $n_{1+} \ll n_1$. The interaction energy I of one system is given by [11]

$$I \approx n_{1-}\nu_{1-} + n_{1+}\nu_{1+} - n_1\nu_1 \,. \tag{3}$$

The interaction energy of both joint interacting systems is $2I$. For the saturated condensed state the interaction energy given by (3) is usually negative and both systems with vibration modes are attracted. The attractive force is given by $-\mathrm{d}I/\mathrm{d}x$. For the nonsaturated condensed state the increased number of quanta n_{1-} with respect to n_1 counteracts the interaction term Δ in the expression for I and I may, therefore, be positive or negative. Under favourable conditions the condensed state may be created even in the mode ν_{1+}. The difference between ν_{1+} and ν_{1-} must be small and the value of n_{crit} low or ϕ_{1+} very much smaller than ϕ_l of other modes. (The latter condition is given in [9].) E.g. for $n_{\mathrm{crit}} = 350$, $N = 10$ (before interaction), $s_k = 0{\cdot}5$, $\phi_k = 0{\cdot}01$ and $\chi_{k,j} = 0{\cdot}001$ we get $n_{1-} = 356$ for $\nu_{1-} = 90$ GHz

and $n_{1+} = 236$ for $\nu_{1+} = 110$ GHz; or for $\phi_{1+} = 0$ and $\phi_l = 0{\cdot}3$ for other modes, $n_{\text{crit}} = 3500$, $n' = 10$, $\chi_{k,j} = 0{\cdot}001$ we get $n_{1-} = 311$ for $\nu_{1-} = 100$ GHz and $n_{1+} = 142$ for $\nu_{1+} = 150$ GHz. In both examples n_{1+} is much greater than the thermal equilibrium values.

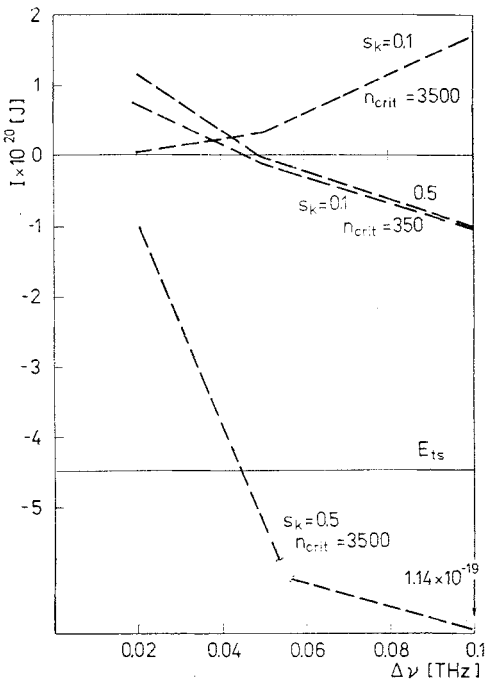


Fig. 4. Interaction energy I as a function of $\Delta\nu$. $N = 10$ (before interaction). $\phi_k = 0\,01$, $\chi_{k,j} = 0{\cdot}001$.

We present computer results of the interaction energy in a very simple case. As the influence of the mode with the condensed state is predominating it is assumed that all frequency peaks are only doubled ($\nu_{k\pm} = \nu_k \pm \Delta\nu_k$). The frequency shift $\Delta\nu_k$ of all modes is accepted to be the same and equal to $\Delta\nu$. The interaction energy as a function of $\Delta\nu$ (for $\nu_{k\pm} = \nu_k \pm \Delta\nu$) is in fig. 4 for $N = 10$ (before interaction), $\phi_k = 0{\cdot}01$, $\chi_{k,j} = 0{\cdot}001$, $n_{\text{crit}} = 3500$ or 350 and uniform energy supply $s_{k-} = s_{k+} = s_k$. The interaction energy is calculated for one of the interacting systems assuming the constant thermal energy of the vibration states. The interaction energy I is negative for the saturated condensed state ($s_k = 0{\cdot}5$) and for a strong interaction $|I|$ is much greater than the thermal energy Nk_BT. For the nonsaturated condensed state ($s_k = 0{\cdot}1$) there is $I > 0$. For considerably limited energy in the condensed state ($n_{\text{crit}} = 350$) we have $I > 0$ for a weak interaction ($\Delta\nu < 0{\cdot}05$) and $I < 0$ for a stronger interaction.

These results show that both attractive and repulsive forces may be created in interacting systems. More accurate and detailed analysis of frequency splitting is necessary. The classical definition of the interaction energy may be used.

CONCLUSION

A simple model of an oscillating system with a limited number of vibration modes is introduced for a computer simulation. The concept of spectral frequency peaks and density of state function is used instead of discrete frequency lines. The number of modes with different frequency peaks used in the calculations is from 10 to 40. Saturation of the energy in the condensed state is introduced. The computer results coincide with the theoretical conclusions in [1–4] and yield a deeper insight into the vibration systems with energy supply. The condensed state energy of the lowest frequency mode depends on the energy supply. In the vicinity of a critical value even a small change of the energy supply (of the order of 10%) results in a considerable change of the lowest frequency mode energy. LDH viruses exhausting metabolic energy from the host cell might, as a result, switch off the condensed (coherent) state. Above the critical value of the energy supply the saturated condensed state may be created whose energy is nearly independent of the energy supply. This may explain the insensibility of some biological systems to the electromagnetic radiation the power density of which is too low to cause thermal effects. On the other hand, if the metabolic energy supply is lower than the critical value, then electromagnetic radiation may bring about considerable biological effects.

Interaction between systems with condensed states may result in attractive or repulsive interaction forces. Interaction forces depend on the frequency shift as well as on the energy stored in different modes and, hence, on the energy supply, on the energy losses and differences of losses in different modes, on nonlinear limitation of the mode energy and on the lowest mode frequency.

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