Coherent Electric Vibrations in Biological Systems and the Cancer Problem

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Abstract—**The existence of coherent electric vibrations in the 5×10^{10}–3×10^{12} Hz region has now been established experimentally for biologically active microorganisms. It is shown that such vibrations might play a decisive role in the control of growth of tissues and, hence, in the cancer problem.**

I. Survey

SEVERAL YEARS AGO, it had been proposed [1] that electric vibrations with frequencies of the order of 10^{11}–10^{12} Hz should be excited coherently in active biological materials through metabolic processes. The given frequency range is to be considered as a very rough order of magnitude. It thus borders closely on the now accessible microwave range. Excitations of the proposed type could have far-reaching biological consequences, for they would lead to selective long-range interactions which probably are required to control growth in normal tissue and whose absence might lead to cancer.

Verification of the theoretical conjecture posed considerable experimental difficulties. During recent months, however, conclusive experimental evidence for their existence has been obtained in bacteria [2], [3] and in yeast cultures [4]. This latter followed and extended earlier work [5] on the action of coherent millimeter waves on biological systems for which it was found difficult to obtain detailed experimental information.

Existence of such extraordinary physical properties in biological systems must be the result of long evolutionary processes. It may be hoped, therefore, that such vibrations exist not only in the monocellular systems for which their existence has been verified, but also in higher systems and particularly in tissues.

While the stimulus for this work has arisen from theoretical considerations, it must be emphasized that the role of the theory must first be the introduction of relevant concepts—coherent electric vibrations in the present case. Model calculations are useful (Section IV) in that they may further specify such concepts. More detailed predictions, however, require experimental corroboration. For, in contrast to the physics of materials where, from their structure, many properties can be derived theoretically through the theory of linear response, biological systems are largely characterized through nonlinear response.

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II. The Model and Its General Consequences

Membranes of biological systems usually have a thickness of about 10^{-6} cm across which an electric potential difference of the order of 100 mV is maintained. An enormous electric field of the order of 10^5 V/cm thus acts on the membrane which, therefore, is strongly polarized electrically. The only generally accepted role of this field refers to nerve conduction, but membranes of other than nerve cells also maintain such a field. A possible role of such fields may refer to proteins dissolved in a membrane which, under the influence of the field, may undergo configurational changes, particularly if they possess metastable states with high electric dipole moments as has been discussed on other occasions [6]–[9].

For the present purpose, it will be noted that a section of the membrane oscillating (with displacement) perpendicular to the surfaces represents an electric wave with half-wavelength of the width of the membrane, and (in view of its polarization) an oscillating electric dipole. Assuming elastic properties corresponding to a velocity of sound of 10^5 cm/s this yields a frequency of one-half 10^{11} Hz. Proteins built into the membrane and possessing a high dipole moment may, of course, also oscillate, probably with higher frequency. Sections of giant molecules such as DNA or larger complexes might oscillate with lower or higher frequencies. All this assumes that the damping of such oscillations is not unduly high. In each such case, harmonics which no longer represent dipolar oscillations—with appropriately higher frequencies—should exist.

Oscillating polar systems of this type interact with each other, and their resulting oscillations can usually be presented in terms of normal modes. It will now be assumed that the lowest of these modes is excited very strongly (coherently) through the supply of energy from metabolic processes. In general, this will involve nonlinear features. A mathematical treatment for a possible model will be presented in Section IV, but much more complex features than these considered may be at work. The existence of such vibrations, however, will have consequences which

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are far reaching and largely independent of the manner in which they are excited, provided they involve oscillating electric dipoles.

The most important of these consequences refers to a long-range attractive selective interaction [8], [10]. It should be noticed first that, in biological systems, static charges are usually screened at relatively short distances in contrast to electric vibrations in the frequency region of 10^{11} Hz which have a range much larger than the dimensions of a cell. Consider now two such oscillating systems with frequencies ω_1 and ω_2, respectively, at a distance R, large compared with their linear dimensions. In this case, dipolar terms in the interaction only need be considered, leading to normal mode frequencies $\omega_\pm$

$$\omega_\pm^2 = \frac{1}{2}(\omega_1^2+\omega_2^2)\left[1 \pm \left\{\left(\frac{\omega_1^2-\omega_2^2}{\omega_1^2+\omega_2^2}\right)^2 + \frac{M^2}{R^6}\right\}^{1/2}\right]. \quad (1)$$

Here, for given displacements of the oscillators, M/R^3 measures the ratio of the interaction energy between the dipoles and of their individual potential energies. Thus as long as the { } bracket is small compared to unity,

$$\omega_\pm = \left(\frac{\omega_1^2+\omega_2^2}{2}\right)^{1/2}\left[1 \pm \frac{1}{2}\left\{\left(\frac{\omega_1^2-\omega_2^2}{\omega_1^2+\omega_2^2}\right)^2 + \frac{M^2}{R^6}\right\}^{1/2} - \frac{1}{8}\left\{\left(\frac{\omega_1^2-\omega_2^2}{\omega_1^2+\omega_2^2}\right)^2 + \frac{M^2}{R^6}\right\} + \cdots\right]. \quad (2)$$

The energy of interaction between the two systems is now obtained by subtracting from the free energy at distance R the free energy as $R \to \infty$. In thermal equilibrium, both ω_+ and ω_- contribute, and the result is the well-known van der Waals interaction $\alpha 1/R^6$, whether or not $\omega_1 = \omega_2$. In our case, when ω_- is very strongly excited, say with $n_- \gg 1$ quanta, the thus defined interaction energy I becomes (let $\omega_1 \geqslant \omega_2$)

$$-I \simeq \hbar n_- \left(\frac{\omega 2_1+\omega_2^2}{2}\right)^{1/2}\left[\frac{1}{2}\left\{\left(\frac{\omega_1^2-\omega_2^2}{\omega_1^2+\omega_2^2}\right)^2 + \frac{M^2}{R^6}\right\}^{1/2} - \frac{1}{2}\frac{\omega_1^2-\omega_2^2}{\omega_1^2+\omega_2^2} - \frac{1}{8}\frac{M^2}{R^6} + \cdots\right]. \quad (3)$$

When $\omega_1 \simeq \omega_2$, an attractive interaction $\alpha 1/R^3$ thus arises in contrast to the case $\omega_1 \neq \omega_2$ when the attraction is again $\alpha 1/R^6$ at large distances.

Furthermore, since the magnitude of the interaction depends on the strength of excitation, such interaction will be switched on or off depending on whether or not metabolic energy is supplied. This might apply to the attraction of an enzyme and a substrate at certain stages of cell development [6].

The case of a whole assembly of such pumped equal systems which should be of particular interest for the control of tissue growth has not yet been treated in detail but general theorems concerning normal modes do, of course, apply although such theorems usually refer to regular arrangements of the individual oscillating systems, frequently though not necessarily with nearest neighbor interaction only. In our case, e.g., in an assembly of cells pumped metabolically to oscillate with equal frequency, interaction with more distant neighbors will be relevant and, in the lowest normal mode, each individual oscillator will exhibit a definite phase relation to the phase of the mode so as to make the total (negative) interaction energy a minimum. This will cause certain contractions and in this way, will very likely involve nonlinear terms. The total interaction energy may thus be expected to become size and shape dependent.

An individual cell in the neighborhood of this assembly may then be expected to be attracted to it much more strongly when its frequency is the same as that of the assembly than when it is different. Assuming that this frequency is different for differently differentiated cells [11], this would explain the great attraction that equally differentiated cells exert on each other.

The possibility of switching on or off the collective mode through metabolic processes might give rise to changes in the configuration of larger regions such as required prior to cell division. The supply of metabolic energy, in turn, would have to be regulated so as to be available at the correct time. A whole temporal succession would thus arise.

Models for such processes could be treated mathematically in some detail. At the present stage of development, it seemed to be more important to find conclusive experimental proof for the existence of the conjectured vibrations.

III. Experimental Evidence

If vibrational states with frequencies of the order one-half 10^{11}–10^{12} Hz (or higher) are strongly excited by metabolic processes, then corresponding Raman lines should be found when the system is metabolically active but not when it is nonactive. The excitation, moreover, should be much stronger than thermal excitation.

An alternative approach would be to attempt interfering with the biological processes by exciting the systems from outside.

A. Raman Effect

Careful investigation of the Raman spectrum of an enzyme (lysozyme) in aqueous solutions yields broad bands in the region of 100 cm^{-1}(3×10^{12} Hz) [12]. Such broadening indeed should be expected from the high friction with water.

The Raman spectrum of resting (not metabolizing) bacterial cells was found to be of a similar nature [2]. If synchronized cells (i.e., they are all in the same stage of development) are supplied with an appropriate nutrient (which on its own also shows a broadband), then a number of relatively sharp strong Raman lines appear in a

range between 7×10^{10} and 5×10^{12} Hz. They thus fall into the expected membrane frequency region and may well be due to the predicted excitations. In principle, however, they might also arise from intermediate chemical products which for unknown reasons are not subject to the friction with water. The crucial experiment consists in the measurement of the ratio R of the intensities of anti-Stokes and Stokes lines. If the lines (frequency ν) arise from an intermediate chemical, then this ratio should be

$$R_0=\exp(-h\nu/kT) \tag{4}$$

for their excitation would, in a very short time, reach the thermal equilibrium value (temperature $T\simeq300$ K). If the excitation arises from metabolic pumping, however, and is very large compared with thermal excitation, then $R_0\simeq1$ must be expected.

Experiments on active synchronized E coli B bacteria conclusively proved the existence of strong excitations [3]. A Raman line which, during the life cycle of the bacteria, shifts from 118 to 125 cm^{-1} (3.75×10^{12} Hz) showed $R_0=1.01\pm0.09$ for 118 cm^{-1} and $R_0=0.93\pm0.13$ for 125 cm^{-1}, while the respective thermal equilibrium values (3.1) are $R_0=0.57$ and $R_0=0.55$. When the thermal value of R_0 is larger, such tests would, of course, require much higher accuracy.

Experiments to date showed that a multiplet near 40 cm^{-1} appeared during a short period in the cell cycle only; many more such temporary lines may be anticipated since nonsynchronized cells show many more lines though they are of much lower intensity than those of synchronized cells. The hope thus exists that these excitations may be attributed to definite cell activities as suggested in Section II.

Lines also seem to exist near 5 cm^{-1} (1.5×10^{11} Hz) or possibly lower, though this was beyond the available resolving power.

B. Action of Coherent Millimeter Waves

Already several years ago, it had been observed that electromagnetic (EM) radiation of 7.1 and 7.3×10^{10} Hz depresses the growth of E coli bacteria [13]. These findings were confirmed recently [14].

A series of most startling results on the influence of coherent millimeter waves on various properties of biological materials was presented in the U.S.S.R. Academy of Sciences [5]. According to this report, irradiation in the range of 5–8 mm ($4–6\times10^{10}$ Hz) can influence certain properties of biological objects ranging from microorganisms to higher organisms. It is claimed that in almost all cases, sharp frequency resonances in the biological effects are found while only optically broadbands have been observed. Also, the dependence on intensities exhibits threshold properties. A critical value S_0 of the rate of energy supply exists such that no effect is observed when $S<S_0$, while for $S>S_0$ the effect is nearly independent of S. These findings confirm our general conjecture of the biological importance of frequency selective vibrations [15].

Details of these experiments are not available, and it was decided, therefore, to repeat one of the experiments with the greatest care aiming at the highest possible accuracy [4]. The influence of the radiation on the rate of growth of yeast was selected where, in [5], results at four frequencies had been reported: one showing an increase and three showing a depression of this rate. The culture was different in the two cases so that one could not expect exactly the same results. The reproducibility of the measured rate was ±3 percent; the long-time frequency stability was ±3 MHz (a single rate determination takes about 10 hours). Yeast was suspended in a stirred aqueous nutrient medium and the growth was measured optically. A frequency range between 4.14 and 4.19×10^{10} Hz was investigated. About 40 values with 20 control (absence of microwaves) were measured. Power (a few milliwatts) and temperature in and near the sample were monitored. The finite penetration depth of the waves in water implied that at most 20 percent of the suspension was illuminated at a time. The results show five minima with growth rates between 70 and 85 percent of the control within 4.65 and 4.79×10^{10} Hz, separated by maxima of rates between 100 and 115 percent of the control, and no noticeable effect outside this range. Thus the effect is largely negative and exhibits extremely sharp biological frequency resonances. The dependence on the intensity of the radiation has not yet been investigated.

These findings strongly support the conjecture that coherent electric vibrations play an important role in biological activities. The extremely narrow frequency resonances pose most interesting problems whose answers demand further investigation. A model for the predominantly negative effects might arise from the assumption that the active biological system excites certain frequencies in terms of limit cycles. Application of radiation at slightly different frequencies might then destroy the original limit cycle and, hence, reduce the biological activity connected with it.

In conclusion, we have evidence for the biological importance of vibrations in the region of 5×10^{10} Hz from experiments with coherent millimeter waves. The strongest evidence from the Raman effect is at about 3×10^{12} Hz, but it extends to lower frequencies, possibly to about 10^{11} Hz. The interconnection of these various frequencies is unknown at present.

IV. A Model Calculation

The original proposal of coherent excitation of electric vibrations (polarization waves) through supply of metabolic energy was supported by the calculation of a model [13] which can be generalized in the following manner. Consider a band of z polarization waves with frequencies $\omega_k(k=1,2,\cdots,z;\omega_1<\omega_2\cdots<\omega_z)$ in strong interaction with a heat bath at temperature T, referring thus to the interaction of our vibrations with the rest of the system. In lowest order, this can be described in terms of emission of quanta $\hbar\omega_k$ from the polarization waves into the heat bath and of the corresponding absorption. To obtain interest-

ing effects, it will be necessary to consider the lowest nonlinear processes involving two quanta. Suppose that energy is supplied to the k mode at the rate S_k. Then, if this mode contains n_k quanta $\hbar\omega_k$, the following kinetic equation holds:

$$\dot{n}_k = S_k - \phi\left(n_k \exp^{(\beta\hbar\omega_k)} - (n_k+1)\right) - \chi\sum_l \left\{n_k(1+n_e)\exp^{(\beta\hbar\omega_k)} - n_e(1+n_k)\exp^{(\beta\hbar\omega_e)}\right\} - \lambda\sum_e \left\{\dot{n}_k n_e \exp^{(\beta\hbar(\omega_k+\omega_e))} - (n_k+1)(n_e+1)\right\}. \quad (5)$$

Here $\beta = 1/kT$ and the exponential factors arise from the condition of detail balancing. The transition probabilities ϕ, χ, λ are averages depending on temperature and a possible dependence on frequency is neglected. They are largely connected with the interchanged energy with nearly free ions and dipoles in the cell media.

Under stationary conditions then, $n_k = 0$, so that

$$\sum S_k = \phi\sum_k \left(n_k \exp^{(\beta\hbar\omega_k)} - (n_k+1)\right) + \lambda\sum_k\sum_l \left\{n_k n_e \exp^{(\beta\hbar(\omega_k+\omega_e))} - (n_k+1)(n_e+1)\right\} = \sum_k \left(n_k \exp^{(\beta\hbar\omega_k)} - (n_k+1)\right) \cdot \left\{\phi + \lambda\sum_e \left(n_e \exp^{(\beta\hbar\omega_e)} + (n_e+1)\right)\right\} \quad (6)$$

and

$$n_k = \left(1 + \frac{S_k}{\phi + \chi\Sigma n_e \exp^{(\beta\hbar\omega_e)} + \lambda\Sigma(n_e+1)}\right)\frac{1}{\exp^{(\beta\hbar\omega_e-\mu)}-1} \quad (7)$$

where

$$1 - e^{-\beta\mu} = \frac{(\chi-\lambda)\Sigma\left(n_e \exp^{(\beta\hbar\omega_e)} - (n_e+1)\right)}{\phi + \chi\Sigma n_e \exp^{(\beta\hbar\omega_e)} + \lambda\Sigma(n_e+1)}. \quad (8)$$

Thus unless $\chi = \lambda$ (requiring $\mu = 0$), ω_k represents a modified Bose distribution with chemical potential μ.

Now, for most more specific models, $\lambda \ll \chi$ holds ([16]). If this inequality holds to the extent that λ is negligible, then the above equations reduce to

$$\Sigma S_k = \phi\Sigma\left(n_k \exp^{(\beta\hbar\omega_k)} - (n_k+1)\right) \quad (9)$$

$$n_k = \left(1 + \frac{S_k}{\Sigma S_e}\frac{\phi}{\chi}\left(1 - e^{-\beta\mu}\right)\right)\frac{1}{\exp^{(\beta(\hbar\omega_k-\mu))}-1} \quad (10)$$

and μ satisfies

$$\hbar\omega_1 > \mu \geqslant 0. \quad (11)$$

The upper limit $\hbar\omega_1$ follows from the condition $n_k \geqslant 0$.Thus from (10) and (11)

$$\Sigma n_k \leqslant \left(1 + \frac{S_0}{\Sigma S_e}\frac{\phi}{\chi}\left(1 - \exp^{(-\beta\hbar\omega_1)}\right) \perp \Sigma \frac{1}{\exp^{(\beta(\hbar\omega_k-\mu))}-1}\right) \quad (12)$$

where S_0 is the largest of the S_k.

Now, from (9) it follows that Σn_k must increase proportionally to ΣS_k if this quantity is sufficiently large. This can be achieved only if μ comes very close to $\hbar\omega_1$ so that n_1 becomes much larger than the other n_k.

Thus the pumped system exhibits a phenomenon very well known for massive particles in thermal equilibrium: Einstein's condensation of a Bose gas; but, while in this case, the corresponding order arises when the temperature is decreased below a critical value, our case requires that the energy supply is raised above a critical value.

It should be emphasized that these results rest on a large magnitude of the nonlinear χ interaction. Other terms such as nonlinear direct interaction between the polarization waves could have been introduced. Such terms would tend to increase the temperature of the polarization waves above that of the heat bath and thus counteract Bose condensation.

Calculations of this type thus demonstrate the possibility of Bose condensation, i.e., of strong excitation of the lowest mode, provided certain material conditions are satisfied. This, one would conclude, has arisen through long evolutionary processes.

Even so, it seems difficult to expect excitations as narrow as those found experimentally and reported in Section III. Quite possibly, a second stabilizing agent will have to be found. If, for instance, the hypothesis of a limit cycle mentioned in Section III would hold, then the amplitude x would have to satisfy an equation of the type

$$\ddot{x} + \omega_1^2 x + \gamma\dot{x}(x^2 - a^2) = 0 \quad (13)$$

in the absence of an external field; γ and a^2 are constants. The missing agent would then replace ordinary friction terms $\alpha\dot{x}$ by the appropriate nonlinear terms which depending on the amplitude can extract or supply energy to the oscillator.

V. Coherent Vibrations and the Cancer Problem

While bacterial cells divide as long as nutrient and space are available, cell division in normal tissue is subjected to a control which is absent in cancer. It is required, therefore, to find the origin of this control.

We shall show that, in principle, this control could rest on the coherent electric vibrations discussed in the previous sections. In microorganisms, these vibrations have been found to exhibit quite extraordinary properties with regard to the sharpness of frequency resonances (Section III). It will be assumed then that they also exist in active normal tissue, though it will be for future experiments to verify this.

Suppose the coherent vibration in the assembly of cells forming a tissue to be excited as discussed in Section II. This requires each cell to oscillate with appropriate phase and with correct frequency. Changes in a cell that alter this frequency lead to the loss of most of its (negative) interaction energy with the coherent mode. Such changes can, therefore, occur only if sufficient energy is supplied. Now cell division may at certain stages lead to alteration of the relevant frequency. This step is, therefore, con-

trolled energetically by the interaction of the coherently excited mode with the particular cell. The magnitude of the required energy will depend on the strength of excitation of the mode. The availability of the required energy will depend on the available amount of nutrient though, to some extent this should also influence the strength of excitation.

Clearly, the oscillating system of cells exhibits a certain stability. Not only does it attract cells in the neighborhood if they have the correct frequency (Section II), but also an influence will be exerted on cells that for some reason have lost the correct frequency to reinstall it, for this gains free energy.

Now a cell that has lost the correct frequency will no longer contribute to the collective vibration and, hence, weaken it so that the potential barrier controlling cell division in other cells is reduced; but this will be a small effect. If a number of cells, however, will be so affected, then the strength of the collective vibrations will decrease more significantly, and a critical number of such cells should thus exist at which the control becomes ineffective. A phase transition into an uncontrolled state will thus take place.

Clearly, ideas of this type can give rise to many different specific situations in which the coherent vibration in conjunction with the available nutrient controls cell division. A more specific model [18] would, e.g., assume that the DNA protein complex of the cell nucleus of a differentiated cell is responsible for the vibration. Prior to cell division, this complex must unfold and would then loose the correct frequency which, as shown above, would require an appropriate supply of energy which may only rarely be available. Cancer would arise when, from external reasons, the frequency of a sufficient number of cells is changed. This might be caused through the invasion of the nucleus by foreign molecules. It might also arise through the transfer of a sufficient number of electrons to the conduction band of proteins, e.g., by sufficiently short-wave ultraviolet light. For the arising plasma oscillation would interact with our mode and alter its frequency [1].

VI. Proposed Experiments

The most important task should be experimental establishment of the conjectured vibrations in active (growing) tissues. Naturally, one would use the methods that have been successful in the cases of bacteria and other microorganisms, i.e., Raman effect and use of coherent millimeter waves to influence properties. In normal growth, one would expect sharp lines with some of the frequencies depending on the nature of differentiation. In cancer growth, some of these lines would either be absent or broadened.

If monolayers of cells are used, then the strength of the collective mode will not necessarily be the same as in bulk because of the contributions of other layers. The observed contact inhibition in normal tissue, i.e., the absence of growth in three dimensions, should then be understood in terms of the control by the collective mode which is absent in cancer tissues which do not exhibit contact inhibition. Another factor in such investigations must also be the amount of nutrient available. A certain amount of nutrient will be required to establish our mode and, hence, the energy barrier which a normal cell will have to overcome in cell division. The energy available to overcome this barrier might, however, also depend on the amount of available nutrient so that a fairly complex situation could be expected.

Spectroscopy with coherent millimeter waves might also be successful although it must be realized that individual cells will most likely oscillate with phase shifts such that the whole system will only be very weakly optically active. This also implies that the excited coherent vibration will emit only minute amounts of EM radiation.

In conclusion, it is hoped that coherent electric vibrations in the 5×10^{10}–3×10^{12} Hz region whose existence has been established in microorganisms also exist in growing tissues and play an important role in the control of growth. If the low frequency side, i.e., the range of millimeter waves is relevant, and if this relevance shows resonant effects similar to those discussed in Section III, then one should expect important nonthermal effects of millimeter waves of correct frequencies on cancer tissues.

Note Added in Proof

Recently S. J. Webb, R. Lee, and M. E. Stoneham (*J. Quantum Chem: Quantum Biology*, vol. 4, pp. 277–284, 1977) have demonstrated the existence of several (Stokes-) Raman lines in the region of 50–200 cm^{-1}. These were found to be broadened and split in the case of mammary carcinoma. If confirmed, and if strong anti-stokes lines also exist, then this finding is in accordance with the suggestion (1) that cancer cells contain unattached electrons such that their plasma frequency is close to the frequency of the coherent vibrations discussed in the present paper; interaction between the two vibrations will then lead to a splitting of lines.

References

[1] H. Fröhlich, *Int. J. Quantum Chem.*, vol. 2, p. 641, 1968.
[2] S. J. Webb and M. E. Stoneham, *Phys. Lett.*, vol. 60A, p. 267, 1977.
[3] S. J. Webb, M. E. Stoneham, and H. Fröhlich, *Phys. Lett.*, vol. 63A, p. 407, 1977.
[4] W. Grundler, F. Keilmann, and H. Fröhlich, *Phys. Lett.*, vol. 62a, p. 463, 1977.
[5] N. D. Devyatkov *et al.*, *Sov. Phys. Usp.*, vol. 16, pp. 568–579, 1974.
[6] H. Fröhlich, *Nature*, vol. 228, p. 1093, 1970.
[7] ——, *J. Collective Phen.*, vol. 1, p. 101, 1973.
[8] ——, *Proc. Nat. Acad. Sci. U.S.*, vol. 72, p. 4211, 1975.
[9] ——, *Bio Syst.*, vol. 8, p. 193, 1977.
[10] ——, *Phys. Lett.*, vol. 39A, p. 153, 1972.
[11] F. Fröhlich, in *Cooperative Phenomena*, H. Haken and M. Wagner, Eds. New York: Springer, 1973, p. 11.
[12] L. Genzel, F. Keimann, T. P. Martin, G. Winterling, Y. Yacobi, H. Fröhlich, and M. W. Makinen, *Biopolymers*, vol. 15, p. 219, 1976.
[13] S. J. Webb and A. D. Booth, *Nature*, vol. 222, p. 1199, 1969.
[14] J. Berteaud, M. Dardalhon, N. Rebeyrotte, and D. Averbeck, *C. R. Acad. Sci.*, vol. 281, p. 843, 1975.
[15] H. Fröhlich, *Phys. Lett.*, vol. 51A, p. 21, 1975.
[16] D. Bhaumik, K. Bhaumik, and B. Dutta-Roy, *Phys. Lett.*, vol. 56A, p. 145, 1976.
[17] ——, *Phys. Lett.*, vol. 59A, p. 77, 1976.
[18] H. Fröhlich, *Rivista del Nuovo Cim.*, vol. 7, p. 399, 1977.